STUDIES ON RADIATION INDUCED VARIATION IN HORSEGRAM [*Macrotyloma uniflorum* (Lam.) Verdc.]

THESIS

BY

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Submitted to

HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA

PALAMPUR 176 062 (H. P.) INDIA

IN

Partial fulfilment of the requirements for the degree

OF

DOCTOR OF PHILOSOPHY

(PLANT BREEDING)

1992

CERTIFICATE - I

This is to certify that the thesis entitled, "Studies on radiation induced variation in horsegram (Macrotyloma uniflorum (Lam.) Verdc.)", submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Plant Breeding of Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is the bonafide research work carried out by Sh. Shiv Kumar son of Sh. Parkash Chand Sharma under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of this investigation have been fully acknowledged.

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CERTIFICATE - II

This is to certify that the thesis entitled, "Studies on radiation induced variation in horsegram (Macrotyloma uniflorum (Lam.) Verdc.)", submitted by Sh. Shiv Kumar Sharma (Admn. No.P-88-A-14-Ph.D.) in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Agriculture) in the subject of Plant Breeding has been approved by the Examining Committee after an oral examination of the same in collaboration with the External Examiner.

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ACKNOWLEDGEMENTS

It gives me an immense pleasure to express my d sense of gratitude and sincere thanks to **Dr V.P. Gup** **Professor,** Deptt. of Plant Breeding and Genetics and **Chairman** my Advisory Committee under whose guidance and inspiration tl research project was undertaken. I shall ever remain indebted him for his expert guidance, constructive criticism, painstak efforts and moral encouragement throughout the course investigation and preparation of this manuscript.

Grateful thanks are also due to Dr S.K.Sharn Professor (Genetics), Deptt. of Plant Breeding and Geneti Dr S.K. Sugha, Associate Professor of Plant Pathology Dr Harsh Nayyar, Asstt. Professor of Plant Physiology, membe of my Advisory Committee, for their deft advice and suggesti at all stages of this research project.

I owe my sincere thanks to Professor & Hea Department of Plant Breeding and Genetics and Dean, College Agriculture, Palampur, for providing me the necess facilities.

I am also highly thankful to Dr Prikshit Plat Asstt.Professor (Plant Breeding), Drs Pankaj Rathore and Rake Kapila for their timely help.

I take this opportunity to express my heartiest thank to the ex-Director of Agriculture, Dr Charanjit Singh fo sponsoring me to undertake the Doctoral Programme. Thanks ar also due to Dr J.C. Rana, Joint Director of Agriculture, Dr Vipin Awasthi, Distt.Agricultural Officer, Drs Rattan an Narinder Thakur for their kind co-operation.

I am grateful to the Govt. of Himachal Pradesh fo sanctioning my deputation for undergoing Ph.D. programme.

My vocabulary falls short of words to express m feelings for my wife Mrs. Rama, who strengthened my resolve t complete this project.

I am also indebted to my mother, who had to suffer lot to enable me to achieve this goal.

My in-laws and other relatives deserve appreciation fo inspiring me to undertake the Doctoral Programme.

I am thankful to Sh H.R.Saini, for typing thi manuscript.

Palampur — **Shiv Kumar Sharm**

26-9-1992

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INTRODUCTION

1. INTRODUCTION

Pulses being rich in proteins, are important ingredients in the Indian vegetarian diet. India is a major pulse growing country in the world, and shares 35-36% and 27-28% of the total area and production of pulses in the world, respectively. Among the pulses, horsegram (Macrotyloma uniflorum (Lam.) Verdc.) indigenously known as kulthi, is one of the most hardy and drought tolerant crops, which this country raises on large areas. The plants are self-fertilized and the chromosome number has been reported as 2n=24 by Rau (1929) and as 2n=20 by Sen and Vidyabhushan (1959). No historical or archaeological evidence is available regarding its origin. However, from the pattern of present day cultivation, it is considered to have originated in South-East Asia and probably the peninsular India. It is grown on small scale in some other parts of the old world including Burma, Africa, West-Indies and also Greensland province of Australia.

Horsegram is the poor man's protein rich (22%) pulse crop and is eaten both boiled and fried without splitting of pulses. In general, it is calorific food for cattle and particularly for horses. Nadkarni (1976) stated that it has several medicinal values in addition to its nutritional importance. It is recommended for removing kidney stones in human beings. The extracted juice of the fresh plant is given for diarrhoea, decoction of the pulse is useful in cases of haemorrhage from bowels, leucorrhoea and menstrual derangement in women. Its soup is a diet in sub-acute cases of enlarged liver and spleen. A powder of the seeds is applied to the skin to check cold sweats. Moreover, it enriches the soil considerably by fixing atmospheric nitrogen and by increasing the organic matter of the soil through shed leaves.

In India, it occupies an area of about 17 lakh hectares with average productivity of 3.57q/hactare, which is very low. The main horsegram growing states in the country are Karnataka, Maharashtra, Tamil Nadu, Madhya Pradesh, Andhra Pradesh,Bihar, Himachal Pradesh, Gujarat and Uttar Pradesh. In Northern India, its cultivation is mainly confined to North-Western Himalayas, specifically Himchal Pradesh, where horsegram is consumed as any other pulse crop. Inspite of such a large area under this crop, little concerted efforts have been made for the genetic amelioration of the crop. In India, from the available germplasm in Himachal Pradesh, Karnataka and Maharashtra, certain promising genotypes have been identified. From the varieties developed at the Himachal Pradesh Krishi Vishvavidyalaya, Palampur, HPK 2 has been identified as highly adapted across the seasons/regions at the All-India level, and HPK 4 (Baiju) has been released for general cultivation in Himachal Pradesh and HPK 6 (Deepali) has recently been notified for release in Maharashtra state.

The above mentioned high-yielding varieties are having indeterminate climbing growth habit, late maturity and lacks resistance to the prevailing diseases which are responsible for reduction in yield. Moreover, Jain (1973) has argued that pulses, including horsegram, had been raised under poor conditions of growth, with no fertilizers, irrigation, etc. Under such conditions, natural selection has played a greater role and genotypes which could have responded to inputs, like chemical fertilizers and irrigation have been lost gradually. For this reason, it has been difficult to develop high-yielding varieties using the limited germplasm available.

The classical work of Muller (1927) and Stadler (1928) have led to the realization that spontaneous variation occurring in nature can be speeded up by irradiation. Induction of mutation in crop plants offers the prospects of generating variability which may not be present in the natural gene pool or may not exist in the genotypes that can be combined with the desired variety (Gaul, 1965). It is now well established that in the genetic nature of increased variation, radiation is as efficient as hybridization in generating heritable variability for selection (Brock, 1965 and Gregory, 1968). At present, 1330 mutant cultivars are in cultivation throughout the world, most of which have been developed in ornamentals, rice, barley and wheat (Micke _et al_. 1990). In the crops like pulses where the available genetic variability is limited, the creation of new variability is the most urgent task. Inspite of several controversial opinions, induction of mutations is a well established procedure for improving crop plants. Based upon these considerations and keeping in view the potentialities of induced mutagenesis, the present study was undertaken in the M_3 generation of horsegram with the following objectives:

1. To understand the nature and magnitude of induced variation under different doses of gamma-rays for seed yield and other polygenic traits,

2. to understand the relationship of shift in mean and induced genetic variance in relation to different doses of gamma-rays, and

3. to identify superior mutants with high yield coupled with other desirable traits.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Natural selection coupled with spontaneous mutations and recombinations, has led to the evolution of present day domesticated plants from their wild ancestors. For a long time this process went on capitalizing the vast reservoirs of natural variability available. The classical discoveries of Muller (1927) and Stadler (1928), which offered the scope to create variation 'at will', opened new vistas for the improvement of crop plants. The mutation technique came as a potential alternative supplementary to the conventional breeding methods.

Mutations are the ultimate source of all variability in organisms. Variability caused by induced mutations is not essentially different from the one caused by spontaneous mutations during evolution. Variation generated following mutagenic treatment is often classified into macro- and micro-mutations, although this categorisation is only arbitrary (Gaul, 1965) because the genetic nature of the changes are of the same kind. In some cases, the classification of mutation into micro- and macro- depends on the power of observation method, as has been demonstrated by Seyffert (1962 and 1963) for colour differences in *Mathiola incana*. However, so long as we maintain this classification, the macro-mutations are those changes which give rise to discontinuous variation and are therefore, easily isolated in early generations, while micro-mutations are the mutational changes which can be isolated and fixed only through the adoption of biometrical procedures (Swaminathan, 1964). The variability caused by micro-mutations is polygenic in nature and are obviously of great interest to plant breeders. These are useful in plant breeding for two main reasons (Gaul, 1965), firstly, they might occur more frequently than macro-mutations, and secondly, they often do not affect vitality adversely as do macro-mutations because the minute changes having physiological behaviour are less drastic.

The polygenic theory, given by Mather (1941, 1943 and 1954) involved two different genetic units for the phenotypic determination of traits in any organisms, the oligogenes responsible for discontinuous variation and the polygenes responsible for characters with continuous variation. Synthesis and discussion on the theory about the inheritance of characters with continuous variation have been given by Lerner (1958), Scossiroli, (1960) and Gaul (1965). Any quantitative trait is the result of the joint action of many single genes whose individual substitution produces small phenotypic effects and of the environmental influences. Usually different genes co-operating to determine the same traits are kept together in blocks intermingled with genes co-operating to influence other traits. Such polygenic blocks are the result of a natural selection process but they may be broken by recombination. Therefore, one may say that in such blocks a genetic variation is stored which represents the potential to face ecological requirements at different locations and in different years to face evolutionary trends or provide variability for artificial selection.

Evidence for the spontaneous mutability of the genetic factors underlying quantitative characters has been provided by several workers in the past. According to Gaul (1967), the report of Johannson in 1913 might be considered first to prove the existence of spontaneous mutations for quantitative traits. Baur (1924) and Stubbe (1934) described spontaneous mutations for quantitative characters in Antirrhinum majus, East (1935) in tobacco and Schuler and Sprague (1956) in corn.

The possibilities offered by mutation breeding to induce new genetic variation, when the already existing gene pools have been exhausted or eroded due to management and preferential biases, are of extreme importance and of immediate interest. A mutation event is indeed very important even when it has a small effect for the specific morphological or physiological character, because it changes the balance established by natural selection in co-adapted blocks of genes and, therefore, offers new situations for natural or artificial selection.

Majority of the agronomically important plant characters are quantitatively inherited. Discrete classes can only be recognised rarely and the Mendelian methods for genetical analysis are impracticable, though not impossible.

The characters that display continuous variation are, in general, controlled by many genes showing Mendelian inheritance but subject to environmental modification. The creation of such variation artificially through induced mutagenesis is very important for crop improvement, which has been widely demonstrated to be the result of polygenic differences arising from micro-mutation (Oka et al., 1958; Sharma and Boyes, 1962; Brock, 1965 and Gregory, 1968). However, the approaches to partition the components of induced variation, which measures the different types of the gene effects, and in turn, to understand the genetic mechanism of yield traits have been comparatively fewer due to difficulty in identifying single mutational event in the genotype at the phenotypic level. This is only recently that improved biometrical procedures using statistical parameters such as means, variances and co-variances have reached a high level of sophistication for evaluating polygenic variation following mutagenesis.

The theoretical expectations of induced random micro-mutations in a self-fertilizing species with large number of genes, each having small individual positive or negative effect on a particular character (Brock, 1965), would depend on the total number of genes involved, relative proportion of genes with positive or negative effects and the degree to which the genes of the parental genome operate as a balanced set. In such cases random mutations would be expected to increase the variance and to shift the mean away from the direction of previous selection. In characters not subjected to previous selection, induced mutations do not follow a particular trend but would be random. The higher the selected or adapted trait, the greater will be the shift in mean and also greater asymmetry of distribution of variances. If the extreme limits are not reached in the parental genome, effective selection would be possible in either direction.

The first and extensive report involving the deliberate selection of mutations in quantatively inherited traits following irradiation with ionizing radiations came from Gregory's work in 1955, 1956, 1957 and 1961 in peanut. He concluded that mutations affecting quantitative characters in a crop plant can be induced by radiation and that phenotypic selection can accumulate positive mutations to produce better strains. Various other workers did a good work in this direction and induced polygenic variation successfully in many economic crop plants (Oka *et al.*, 1958 in rice; Moës, 1958 and Gaul, 1961 in barley; Rawlings *et al.*, 1958 in Soybean; Wittemer, 1960 in tobacco; Krull and Frey, 1961 in Oats; Scossiroli, 1962 in Maize; Bhatia and Swaminathan, 1962 in Wheat; Pate and Duncan, 1963 in Cotton; Palenzona, 1964 in wild tomato; and Gupta and Swaminathan, 1967 in *Brassica*). Many workers (Jinks, 1954; Hayman, 1954, 1958; Sprague, 1956; Scossiroli, 1962; Palenzona, 1965; Lawrence, 1965 and Scossiroli *et al.*, 1966), using different biometrical analysis, have clearly demonstrated that the increase of phenotypic variation in generations following irradiation particularly in self-pollinated plants is mainly due to an increase in genetic component and it may be accounted for by the effects of mutations on the genetic factors influencing quantitative characters. The genetic nature of increased variation, as well as the role and importance of radiation in plant breeding has been stressed by experiments of selection performed according to classical methods in different crop plants (Borojevic, 1965; Brock and Latter, 1961; Gaul, 1964 and 1965; Goud, 1967; Oka *et al*., 1958; Scossiroli, 1965 and 1966). In some instances improvement in yield obtained through radiation breeding were not obtained by the standard methods of plant breeding, that is selection following hybridization. It has been demonstrated and clearly stated by different workers that radiation is as efficient as hybridization in supplying genetic variability (Gregory, 1956, 1968; Frey, 1965 and Brock, 1965).

In grain legumes, specifically in horsegram, such information is limited, however, the available reports on the induction of polygenic variation for various economic traits in grain legumes is briefly reviewed hereunder:

Abo Hegazi (1973) used seeds of five legumes, *viz*., *Vicia faba*, *Lens culinaris*, *Trigonella fornum*, *Cicer arietinum* and *Lupinus tumis* to study the extent of variation generated in the M_1 generation of gamma-rays irradiation. It was observed that coefficient of variation increased for days to flowering, pods, branches, plant height and seed yield/plant.

Dahiya (1973) observed that radiation treatments with X-rays have been effective in two varieties of Mung in inducing variation for a number of character of economic value e.g. grain yield/plant, number of pods/plant, days to flowering and protein content. The study indicated that mutation breeding results in an increase in variation for all quantitative inherited characters, but there was a decrease, in general mean of the irradiated population with some exceptions and all early maturing mutations were less productive.

Mandal (1974) in gram showed that overall variance of the seeds/pod, pods/plant and single plant yield was higher in the treatments as compared to control.

Rao (1974) in pigeonpea was able to generate significant amount of variability for branches, raceme length, pods/raceme, seeds/pod, 1,000-seed weight and single plant yield. The variability was studied at various levels as overall, inter-family and intra-family variances. The pattern of induced variability showed that considerable scope existed for making selection between and within M_2 families.

Sarma (1975) in groundnut, observed significant increase in overall and inter-family variances for pods, 100-seed weight and seed yield/plant. The magnitude of heritable variation and estimate of genetic advance varied according to the mutagenic treatments, character in question and the genotypes. The character such as weight of pods, seed yield and secondary branches showed a higher response to mutagenic treatments.

Kulkarni and Shivashankar (1978) in horsegram observed that the frequency of chlorophyll mutations increased with increasing EMS concentration upto 1.2% and then decreased, whereas in the M_2 generation of seeds irradiated with gamma-rays showed increase in frequency as the dose increased from 5kR to 15kR and then decreased.

Kulkarni et al. (1978) in Dolichos biflorus L. indicated that LD 50 for dimethyl sulphate treatment was about 0.03%.

Hussain and Abdulla (1979) in field bean found that some of the mutants surpassed their control significantly in two successive generations, while other showed fluctuating results from M_4 to M_5 for seed yield.

Shamshi and Safaya (1980) studied the effects of low doses of gamma-radiation (100-5,000r) on the growth and yield of two cultivars of broad bean (French and Egyptian). Exposure to 100-1,000r caused a significant increase in the dry weight and leaf area of both cultivars. Most of the exposures caused increase in the weight of individual seeds, but not the number of pods. At higher exposures 3,000-5,000r survival and growth were severely curtailed. The French cultivar showed a higher degree of sensitivity to higher doses than Egyptian to gamma-radiation.

Tickoo and Jain (1979) in mung observed less variance in the M_3 than M_2 generation indicating that selection applied in M_2 was effective.

Al-Rubeai (1982) in Rajmash reported that the frequency of the Albina, Xantha and Viridis chlorophyll mutants in the M_2 generation was dependent on dose.

Manju and Merey (1981) observed greater injury by gamma-rays, whereas lethality and sterility were more due to EMS in horsegram.

Khan (1982) in mung bean found high mean values for plant height in M_2, M_3 and decreased mean values for characters like days to flowering and days to maturity.

Krishnaswamy and Rathinam (1982) in green gram observed increased heritability for yield and four other yield components, except plant height. There was no consistency in the superiority of one mutagen over the other, their behaviour varying with the cultivar and character studied.

Sood (1983) reported that sufficient polygenic variation was induced for most of the traits studied over generations and radiation doses. The variation induced was dose, variety and trait-specific. Variability induced persisted in later generations and segregation pattern revealed that within lines variance was more in M_3, whereas between lines variance was more in M_4.

Irfan and Khan (1984) in green gram reported high variance in the M_2 for plant height, days to maturity, productive branches, number and length of pods, seeds/pod, 100-seed weight and seed yield.

Khan (1984) in mung bean observed that the values of the genotypic coefficient of variation, heritability and genetic advance for the characters studied were high in the M_3 than in M_2 generation.

Verma and Singh (1984) in green gram observed high estimates of means for days to maturity, plant height, pods/cluster and 100-seed weight at doses 20,30,40 and 50kR gamma-rays, except days to maturity at 50kR. The M_3 populations showed higher variances for all traits than control.

Khan (1985) in mung bean reported that irradiation increased seeds/pod as compared to hydrazine treatment which resulted smaller number of seeds/pod. He further observed in 1987 that estimates of heritability and genetic advance were greater at 40kR than at 20kR for all selections.

Rudraswamy (1987) reported that gamma-rays induced a wider spectrum of chlorophyll mutations as compared to ethylmethane sulfonate. He induced large number of mutation with respect to leaf characters, testa colour, dwarfism and photoinsensitivity in horsegram.

Singh *et al.* (1987) in *Vigna mungo* observed that mutants had higher pods, branches, leaves and nodes/plant, seeds/pod, seed weight and seed yield/plant as compared to the control.

Ignacimuthu and Babu (1988) in *Vigna radiata, Vigna mungo* and *Vigna sublabata* found that seedling emergence, height, survival and pollen fertility were dependent on kind and rate of mutagen doses used.

Malik (1988) in mung bean reported two mutants which had an erect, determinate growth, short statured, early maturing and high yielding. Both of the mutants had high harvest index and were suitable for mechanical harvesting and intercropping and showed vide adaptability and stability when grown under different agronomic conditions.

Khan (1988) in *Vigna radiata* found that total phenotypic variability increased, as did the values of the phenotypic and genotypic coefficients of variability. Estimates of heritability and expected genetic advance for number of pods and 100-seed weight were the highest following gamma-irradiation and for plant yield following combined treatments.

Kumar and Sinha (1989) in *Cajanus cajan* reported that plant attributes like plant height, number of primary branches/tiller, total shoot length, flowers, pods and seed set/plant showed decreasing trend with increase in dose from 5kR to 40kR in M_1 generation. However, a slight increase in the number of primary branches was noted at lowest dose of 5kR due to stimulating effect of radiation at lower doses of radiation.

Kalia and Gupta (1989) observed that sufficient genetic variability was induced for most of the polygenic traits in both micro and macro types of lentils. High magnitude of increased induced variation within progeny with high heritability and genetic advance suggested that in mutation breeding programme, selection in M_3 generation would be more effective both between and within lines. Shift in population mean and induced genetic variance was dependent upon specific-genotype-trait-combination.

Ignacimuthu and Babu (1990) observed high levels of genetic advance and heritability for six yield components in the mutagenised population of Vigna sublobata, Vigna radiata and Vigna mungo.

Pulivarthi and Mary (1990) suggested that irradiated populations of Pusa 105 and Neelalu varieties of green gram be selected for pods/plant and 100-seed weight and pods/plant and pods/cluster, respectively.

Suresh et al. (1991) reported increased range of grain and dry matter yield along with positive shift in all irradiated populations of horsegram.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled, "Studies on radiation induced variation in horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.)" was carried out at the experimental farm of the Department of Plant Breeding & Genetics, Himachal Pradesh Krishi Vishvavidyalaya, Palampur, situated at 1,280 m above mean sea level and at $32^{o}6'$ North latitude and $76^{o}3'$ East longitude. This region is characterised as sub-temperate mid hill zone of Himachal Pradesh, having high rainfall.

3.1 Materials

The material consisted of M_3 population of two varieties of horsegram, namely, HPK 2 highly adapted variety across the seasons/regions at the All-India level and HPK 4 released for general cultivation in Himachal Pradesh. Three hundred dry seeds of these varieties were got irradiated with gamma-rays under different doses, *viz.*, 10,20,30,40 and 50kR from ^{60}Co source at IARI, New Delhi. The material irradiated under different doses in each variety was raised in M_1 generation during *kharif*, 1989. The surviving plants could only be obtained under 10,20 and 30kR doses which were raised during *kharif*, 1990 alongwith control as M_2 generation.

In the M_2 generation, promising plants which were looking normal visually for various morphological traits and free from sterility or any other abnormality, were harvested separately for raising the M_3 generation during *kharif*, 1991. The details of the irradiated material in M_2 and M_3 generation in different doses raised from the surviving M_1 population are given below:

Dose	HPK 2		HPK 4	
	Progenies raised in M_2 from M_1 surviving plants	Progenies advanced in M_3 generation	Progenies raised in M_2 from M_1 surviving plants	Progenies advanced in M_3 generation
10 kR	125	35	80	11
20 kR	70	31	84	9
30 kR	60	8	82	36

3.2 Layout and Design

The M_3 populations of different doses with respect to each variety were raised during *kharif*, 1991 in compact family block design with three replications. The checks used in the experiment were HPK 2 and HPK 4 varieties of horsegram.

Each plot consisted of single row of one meter length with row-to-row spacing of 40 cm. The recommended doses of fertilizers (20 kg N and 40 kg P_2O_5 per hectare) were applied at the time of sowing.

3.3 Data recording

Though various macro-mutations were observed in M_2 generation yet these were ignored in the present study and concentration was mainly focussed on polygenic variants for yield and morphological traits. The data were recorded on five random plants in each row for following polygenic traits:

1. **Seed yield/plant(g):** The weight of dried seed produce was recorded in grams.

2. **Biological yield/plant(g):** Plants were harvested at maturity at the ground level, dried and the weight of whole plant was recorded in grams.

3. **Harvest index %:** Harvest index was calculated as below:

$$\frac{\text{Seed yield (g)}}{\text{Biological yield (g)}} \times 100$$

4. **Pods/plant:** The number of pods were counted for each plant.

5. **Pod length (cm):** Length of five pods per plant randomly was recorded at the time of harvest in cm and averaged.

6. **Seeds/pod:** The five pods per plant were threshed and their seeds were counted for calculating the numbers of seeds/pod.

7. **100-seed weight (g):** A random sample of 100-seed was taken from the produce of each plant and weight recorded in grams.

8. **Primary branches/plant:** Primary branches in each plant were recorded.

9. **Internode length (cm):** Length between first and second fertile nodes from ground was recorded in cms.

10. **Plant height:** Height from the ground level to the tip of main shoot at the time of maturity was recorded in cm.

11. **Leaf area (cm^2):** Five leaves/plant taken randomly were used for recorded observations. The leaf area in cm^2 was worked out with the help of LICoR leaf-area meter.

12. **Specific leaf weight (mg/cm^2):** The leaves taken for recorded leaf area were dried at 80°C for 24 hours and then their weight was recorded in mg. Specific leaf weight (mg/cm^2) was calculated as the ratio of leaf weight (mg) to leaf area (cm^2).

13. **Days to flowering:** It was expressed as the number of days from the date of sowing to 50 per cent flowering.

14. **Days to maturity:** It was expressed as the number of days from the date of sowing to maturity.

15. **Reproductive phase (days);** Number of days from 50 per cent flowering to maturity was recorded.

3.4 Statistical Methods

Mean value in each replication for different progenies were calculated for all the fifteen characters studied. The following statistical analyses were performed:

1. **Analysis of variance for experimental design**

The analysis of variance for each trait was based on the following linear model of Panse and Sukhatme (1967).

$$y_{ij} = \mu + g_i + b_j + e_{ij}$$

where, Y_{ij} = Phenotypic effect of the ith genotype in the jth replication;

μ = General population mean,

g_i = Effect of ith genotype,

b_j = Effect of jth block/replication, and

e_{ij} = Random error associated with the ith genotype in the jth replication.

On the basis of this linear model the analysis of variance would be as follows:

Source of variation	df	Mean sum of squares	Expected mean sum of squares
Blocks	(b-1)	Mb	$\sigma_e^2 + g\sigma_b^2$
Genotypes	(g-1)	Mg	$\sigma_e^2 + b\sigma_g^2$
Error	(g-1)(b-1)	Me	σ^2_e

Genotypic variance $\sigma_g^2 = \frac{Mg - Me}{b}$

Phenotypic variance $\sigma_p^2 = \sigma^2_g + \sigma^2_e$

where, b = number of replication/blocks, g = number of genotypes

σ_b^2 = variance due to replications; σ_g^2 variance due to genotypes and σ_e^2 experimental error variance

(a) Critical difference C.D. : For calculating C.D. the following steps were followed:

Standard error of mean : $SE(m) = \pm\sqrt{\frac{Me}{b}}$

SE(d) of two means : $\pm\sqrt{\frac{2\ Me}{b}}$

CD at 5% = SE(d) x 't' 5% at error degree of freedom.

(b) Components of variations : Phenotypic and genotypic coefficients of variation were estimated as suggested by Burton and Devane (1953).

(i) Phenotypic coefficient of variation (PCV)% = $\frac{\sigma p \times 100}{\bar{x}}$

(ii) Genotypic coefficient of variation (GCV)% = $\frac{\sigma g \times 100}{\bar{x}}$

where σg and σp are the genotypic and phenotypic standard deviations and $\bar{x}$ represents grand mean.

(c) Genetic parameters: Heritability in broad sense (H) was calculated by the formula suggested by Burton and DeVane (1953) and Johanson et al. (1955).

$$\text{Heritability (\%)} = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2} \times 100$$

Heritability (bs) on mean was calculated as:

$$\sigma^2_E = \frac{EMS}{b.}$$

$$\sigma^2 p = \sigma^2_G + \sigma^2_E.$$

$$h^2(bs) = \frac{\sigma^2_G}{\sigma^2_P.}$$

The expected genetic advance resulting from selection of 5 per cent superior individuals was calculated as suggested by Burton and DeVane 1953 and Johanson et al. (1955).

Expected genetic advance (GA) = k x σp x h^2.

where, σp = Phenotypic standard deviation; k = selection differential at 5 per cent selection intensity (the value of k = 2.06), and h^2 = heritability.

For convenience following classification were used for describing various parameters of variability in the text:

PCV and GCV > 20% High
10-20% Moderate
<10% Low

Heritability (h^2) > 60% High
30-60% Moderate
<30% Low

Genetic advance > 30% High
20-30% Moderate
<20% Low

2. **Estimation of means and testing the significance of difference between two means**

(a) Mean: $\bar{x} = \dfrac{\sum_{i=1}^{n} x_i}{n}$, where $x_1, x_2, x_3 --- x_n$

are the n variable values.

(b) Testing significance of two means: The formula used was

$$t = \frac{m_1 - m_2}{s\sqrt{\frac{1}{n} + \frac{1}{n_2}}}$$

where, m_1 and m_2 are the means based on independent samples of size n_1 and n_2 and s is the pooled standard deviation given as :

$$S = \sqrt{\frac{(n_1-1)\ S_1^2 + (n_2-1)\ S_2^2}{n_1 + n_2 - 2}}$$

where, $S_1^{\ 2}$ and $S_2^{\ 2}$ are the variances with $(n_1\ -1)$ and (n_2-1) degree of freedom respectively.

The observed t - values were compared against t - values for (n_1+n_2-2) degree of freedom at $P = 0.05$.

3. **Combined analysis of variance for varieties, doses within varieties and progenies within doses within varieties for HPK 2 and HPK 4 varieties of horsegram was done as per ANOVA given below**

Source	df	M.S.
Replications	2	
Varieties	1	
Error (a) (Variety x Replication)	2	
Doses within varieties	6	
Error (b) (Doses x Replication)	12	
Progenies within doses within varieties	124	
Error (c)	260	

Varieties, doses within varieties and progenies within doses within varieties were tested with their respective errors.

EXPERIMENTAL RESULTS

4. EXPERIMENTAL RESULTS

Results obtained from the present investigation on the nature of induced polygenic variation in the M_3 generation with respect to HPK 2 and HPK 4 varieties of horsegram under different irradiation doses of gamma-rays, viz., 10,20 and 30kR for seed yield/plant(g) and 14 other polygenic traits, namely, biological yield/plant(g), harvest index (%), pods/plant, pod length(cm), seeds/pod, 100-seed weight(g), primary branches/plant, internode length(cm), plant height(cm), leaf area(cm^2), specific leaf weight(mg/cm^2), days to flowering, days to maturity and reproductive phase (days), are described hereunder different heads:

4.1 Analysis of variance

4.1.1 Results obtained with respect to HPK 2 variety in the M_3 generation under different doses are presented below:

4.1.1.1 Analysis of variance at 10kR irradiation dose

Analysis of variance in M_3 generation with respect to HPK 2 variety (Table 1) at 10kR dose along with control indicated significant differences among entries for all the traits studied except pod length. The variation due to entries was further partitioned into variation due to mutant progenies and due to comparison of mutant progenies with

Table 1. Analysis of variance for 10kR irradiation dose in HPK 2 variety of horsegram

	Source	Mean squares due to				
		Replications	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits	df	2	35	34	1	70
Seed yield/plant		63.44	25.18*	24.96*	32.53*	5.75
Biological yield/plant		363.09	134.06*	133.03*	168.64*	21.67
Harvest index		20.94	92.75*	95.00*	15.38	39.59
Pods/plant		1974.63	882.61*	886.27*	758.56*	64.95
Pod length		0.41	0.11	0.12*	0.001	0.08
Seeds/pod		0.35	0.30*	0.61*	0.10	0.13
100-seed weight		0.21	0.20*	0.20*	0.19	0.13
Primary branches/plant		0.43	4.53*	158.49*	0.08	2.05
Internode length		0.89	0.31*	0.32*	0.001	0.09
Plant height		123.24	148.66*	152.64*	13.29	14.51
Leaf area		5190.46	202.42*	204.16*	142.91	128.02
Specific leaf weight		4.06	3.13*	3.22*	0.23	1.87
Days to flowering		102.03	95.15*	97.77*	6.19	31.11
Days to maturity		663.10	82.78*	84.15*	35.79	19.71
Reproductive phase		373.12	155.86*	84.75*	12.11	69.25

*Significant at 5% level

control. Results indicated significant differences in mutant progenies with respect to all the traits studied. The mean square(ms) due to mutant progenies vs control was significant for seed yield/plant, biological yield/plant and pods/plant.

4.1.1.2 Analysis of variance at 20kR irradiation dose

Significant differences were observed among entries and mutant progenies with respect to induced polygenic variation for all the traits studied, except biological yield/plant and specific leaf weight (Table 2). Comparison of mutant progenies with control indicated that ms was significant only for 100-seed weight and days to flowering.

4.1.1.3 Analysis of variance at 30kR irradiation dose

Analysis of variance at 30kR dose with respect to induced polygenic variation in HPK 2 variety (Table 3) indicated significant differences among entries for seed yield/plant, harvest index, pods/plant, pod length, seeds/pod, 100-seed weight, primary branches/plant, plant height, leaf area, days to flowering, days to maturity and reproductive phase. Significant differences were observed among mutant progenies for all the traits studied, except biological yield/plant, internode length, leaf area and specific leaf weight. Comparison of mutant progenies with control indicated significant ms for biological yield/plant, pods/plant, internode length, plant height and leaf area.

Table 2. Analysis of variance for 20kR irradiation dose in HPK 2 variety of horsegram

		Mean squares due to				
	Source	Replications	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits	df	2	31	30	1	62
Seed yield/plant		58.89	6.13*	6.08*	1.47	3.57
Biological yield/plant		361.13	27.88	28.71	2.38	19.37
Harvest index		180.56	63.44*	65.06*	14.60	39.93
Pods/plant		535.17	266.49*	274.02*	40.77	38.73
Pod length		1.12	0.31*	0.32*	0.03	0.13
Seeds/pod		0.99	0.70*	0.69*	0.29	0.15
100-seed weight		0.08	0.16*	0.14*	0.18*	0.04
Primary branches/plant		5.77	2.41*	2.48*	0.29	0.44
Internode length		0.29	0.29*	0.28*	0.01	0.11
Plant height		269.18	496.61*	512.69*	14.44	59.77
Leaf area		226.78	1225.98*	203.02*	32.93	48.72
Specific leaf weight		2.38	1.51	1.55	0.24	1.32
Days to flowering		3.40	6.61*	5.65*	23.06*	3.10
Days to maturity		74.00	68.30*	70.55*	0.54	9.17
Reproductive phase		44.12	81.09*	83.73*	1.94	11.89

*Significant at 5% level

Table 3. Analysis of variance for 30kR irradiation dose in HPK 2 variety of horsegram

Source		Mean squares due to				
		Replications	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits	df	2	8	7	1	16
Seed yield/plant		0.86	10.14*	11.43*	1.07	1.38
Biological yield/plant		23.58	33.51	35.04	245.26*	17.39
Harvest index		19.12	112.46*	114.09*	101.09	34.10
Pods/plant		141.83	584.37*	590.47*	541.75*	31.01
Pod length		0.04	0.32*	0.36*	0.03	0.07
Seeds/pod		0.03	0.86*	0.90*	0.25	0.13
100-seed weight		0.11	0.22*	0.23*	0.12	0.06
Primary branches/plant		1.48	2.46*	2.77*	0.17	0.91
Internode length		0.03	0.11	0.08	0.29*	0.05
Plant height		212.45	419.26*	373.89*	736.90*	46.46
Leaf area		450.33	233.64*	197.05	489.79*	88.31
Specific leaf weight		0.61	0.24	0.26	0.19	0.19
Days to flowering		18.93	23.48*	25.88*	6.68	2.75
Days to maturity		14.92	33.75*	38.23*	2.45	4.96
Reproductive phase		12.27	37.87*	41.51*	12.37	6.09

*Significant at 5% level

4.1.1.4 Combined analysis of variance with respect to HPK 2 variety over doses

Combined analysis indicated significant ms for mutant progenies within doses for all the traits studied (Table 4) It was found that errors were homogeneous with respect to biological yield/plant, harvest index, pod length, and seeds/pod, and for rest of the traits these were heterogeneous. Results for these traits are to be viewed accordingly while comparing the mutant progenies across the dose.

4.1.2 Results obtained with respect to HPK 4 variety in M_3 generation under different irradiation doses are presented below dosewise:

4.1.2.1 Analysis of variance at 10kR irradiation dose

Analysis of variance in M_3 generation with respect to HPK 4 variety (Table 5) at 10kR dose along with control indicated significant differences among entries for seed yield/plant, biological yield/plant, pods/plant, seeds/pod, plant height, leaf area, days to flowering and days to maturity. The variation due to entries was further partitioned into variation due to mutant progenies and due to comparison of mutant progenies with control. Similar results were obtained for mutant progenies, i.e., these were significant with respect to the traits for which entries were significant.

Table 4. Combined analysis of variance over doses in HPK 2 variety of horsegram

Traits	Source / df	Replication (Mean square due to)	Mutant progenies within doses	Pooled error
	df	6	71	148
Seed yield/plant		11.63	15.64*	4.36
Biological yield/ plant		249.26	79.29*	20.24
Harvest index		73.54	84.23*	39.13
Pods/plant		833.87	598.41*	50.29
Pod length		0.52	0.22*	0.10
Seeds/pod		0.45	0.67*	0.13
100-seed weight		0.13	0.17	0.22
Primary branches/plant		2.56	77.21*	1.25
Internode length		0.40	0.27*	0.09
Plant height		201.62	326.58*	36.92
Leaf area		1955.85	202.97*	90.50
Specific leaf weight		2.35	2.22*	1.45
Days to flowering		41.45	51.85*	16.31
Days to maturity		250.67	73.87*	13.70
Reproductive phase		142.83	80.05*	38.39

*Significant at 5% level

Table 5. Analysis of variance for 10kR irradiation dose in HPK 4 variety of horsegram

Source	Mean squares due to				
	Replications	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits df	2	11	10	1	22
Seed yield/plant	2.91	20.67*	21.65*	10.94*	1.66
Biological yield/plant	49.90	136.05*	147.69*	19.68	26.85
Harvest index	11.96	38.12	27.12	148.18*	23.96
Pods/plant	95.65	1011.05*	1022.94*	892.23*	160.94
Pod length	0.22	0.33	0.36	0.04	0.17
Seeds/pod	0.25	0.73*	0.81*	0.05	0.22
100-seed weight	0.09	0.12	0.12	0.08	0.07
Primary branches/plant	1.62	0.93	0.87	34.68*	2.26
Internode length	0.22	0.38	0.39	0.30	0.46
Plant height	563.56	347.55*	376.34*	59.72	133.30
Leaf area	131.82	143.15*	144.79*	125.93	47.21
Specific leaf weight	1.20	0.77	0.83	0.21	0.52
Days to flowering	31.36	25.48*	27.42*	6.06	9.81
Days to maturity	14.25	14.57*	14.93*	11.00*	2.75
Reproductive phase	6.36	18.39	16.29	39.46	10.20

*Significant at 5% level

The ms due to mutant progenies vs control was significant for seed yield/plant, harvest index, pods/plant, primary branches/plant and days to maturity.

4.1.2.2 Analysis of variance at 20kR irradiation dose

Analysis of variance in M_3 generation with respect to HPK 4 variety (Table 6) at 20kR dose along with control indicated significant differences among entries for biological yield/plant, pods/plant, seeds/pod, 100-seed weight, primary branches/plant, internode length, plant height, leaf area, specific leaf weight, days to flowering, days to maturity and reproductive phase. After partitioning the variation due to entries into variation due to mutant progenies and comparison of mutant progenies with control, it was observed that ms due to mutant progenies was non-significant only for harvest index and pod length, whereas it was significant for rest of the traits studies. The ms due to mutant progenies vs control indicated significant differences with respect to seeds/pod, leaf area, specific leaf weight, days to flowering and reproductive phase.

4.1.2.3 Analysis of variance at 30kR irradiation dose

Analysis of variance revealed that ms due to entries and mutant progenies of HPK 4 (Table 7) were significantly different with respect to seed yield/plant, biological yield/plant, harvest index, pods/plant, primary branches/plant, internode length, plant height, leaf area, specific leaf weight, days to flowering, days to maturity and

Table 6. Analysis of variance for 20kR irradiation dose in HPK 4 variety of horsegram

Source	Mean squares due to				
	Replications	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits df	2	9	8	1	18
Seed yield/plant	0.39	8.11	8.33*	6.34	3.46
Biological yield/plant	1.95	61.77*	65.74*	29.99	14.46
Harvest index	5.77	48.20	50.27	32.44	25.26
Pods/plant	24.54	200.82*	221.63*	34.42	52.82
Pod length	0.07	0.08	0.07	0.18	0.08
Seeds/pod	0.03	0.27*	0.24*	0.54*	0.07
100-seed weight	0.01	0.45*	0.51*	0.01	0.05
Primary branches/plant	1.26	2.06*	1.95*	2.92	0.74
Internode length	0.19	0.58*	0.62*	0.36	0.11
Plant height	8.64	249.83*	271.41*	77.20	37.70
Leaf area	27.63	171.13*	147.00*	364.00*	13.76
Specific leaf weight	0.36	2.71*	2.46*	4.74*	0.37
Days to flowering	3.24	23.11*	21.36*	37.04*	5.01
Days to maturity	0.93	30.23*	33.48*	4.28	3.74
Reproductive phase	4.43	37.79*	34.20*	66.51*	4.13

*Significant at 5% level

Table 7. Analysis of variance for 30kR irradiation dose in HPK 4 variety of horsegram

Source	Mean squares due to				
	Repli-cations	Entries	Mutant progenies	Mutant progenies vs Control	Error
Traits df	2	36	35	1	72
Seed yield/plant	35.84	10.38*	10.46*	7.51	6.03
Biological yield/plant	173.12	63.01*	64.72*	2.92	38.81
Harvest index	131.00	95.59*	94.24*	143.08*	32.91
Pods/plant	1994.78	532.78*	537.14*	380.26	156.00
Pod length	0.14	0.08	0.05	1.13*	0.12
Seeds/pod	0.02	0.23	0.24	0.02	0.22
100-seed weight	0.44	0.16	0.17	0.02	0.12
Primary branches/plant	0.83	1.82*	1.87*	0.25	0.83
Internode length	0.04	0.45*	0.47*	0.07	0.13
Plant height	360.68	218.18*	222.43*	69.20	86.36
Leaf area	281.90	154.28*	155.68*	105.41	73.87
Specific leaf weight	16.09	4.93	4.89*	6.32	2.01
Days to flowering	181.00	25.95*	24.75*	67.92*	8.37
Days to maturity	37.15	16.87*	15.78*	39.08*	5.88
Reproductive phase	52.00	22.85*	23.46*	1.45	7.01

*Significant at 5% level

reproductive phase. The ms due to mutant progenies vs control was significant for harvest index, pod length, days to flowering and days to maturity.

4.1.2.4 Combined analysis of variance with respect to HPK 4 over doses

Combined analysis of variance (Table 8) indicated non-significant ms due to mutant progenies within doses for pod length, whereas it was significant for rest of the traits. It was found that errors were homogeneous with respect to harvest index and days to flowering, whereas for rest of the traits, these were heterogeneous. Results for these traits are to be viewed accordingly while comparing the mutant progenies across doses.

4.1.3 Combined analysis of variance for varieties, doses within varieties and progenies within doses within varieties for HPK 2 and HPK 4 varieties of horsegram

The mean squares due to varieties was tested with its respective error and results indicated significant differences with respect to seeds/plant, 100-seed weight and days to flowering, whereas it was non-significant for rest of the traits (Table 9).

The ms due to doses within varieties was tested with its error and significant differences were obtained with respect to seed yield/plant, biological yield/plant, harvest index,

Table 8. Combined analysis of variance over doses in HPK 4 variety of horsegram

Traits	Source / df	Mean square due to: Replication	Mutant progenies within doses	Pooled error
	df	6	53	112
Seed yield/plant		13.04	12.24*	4.75
Biological yield/ plant		74.99	80.52*	32.54
Harvest index		49.57	74.93*	29.92
Pods/plant		704.99	581.17*	140.38
Pod length		0.14	0.11	0.12
Seeds/pod		0.10	0.34*	0.19
100-seed weight		0.18	0.21*	0.09
Primary branches/plant		1.23	1.69*	1.09
Internode length		0.15	0.47*	0.19
Plant height		310.96	258.86*	87.76
Leaf area		147.11	152.44*	58.97
Specific leaf weight		5.88	3.75*	1.45
Days to flowering		71.86	24.74*	8.11
Days to maturity		17.72	18.59*	5.59
Reproductive phase		20.93	23.72	7.17

*Significant at 5% level

Table 9. Combined analysis of variance over varieties, doses within varieties and progenies within doses within varieties of horsegram

Source	Mean square due to						
	Replications	Varieties	Error(a)	Doses within varie-ties	Error (b)	Progenies within doses within varieties	Error (c)
Traits df	2	1	2	6	12	124	260
Seed yield/plant	16.05	258.85	109.58	83.72*	7.05	14.18*	4.52
Biological yield/ plant	163.92	853.99	698.94	391.34*	35.34	79.76*	25.53
Harvest index	6.35	1015.13	113.34	333.00*	64.07	80.25*	35.16
Pods/plant	37.69	82.87	3539.33	2037.29*	229.26	591.04*	89.09
Pod length	0.93	12.88	0.88	0.47	0.42	0.17*	0.10
Seeds/pod	0.34	22.65*	0.26	0.61*	0.11	0.52*	0.15
100-seed weight	0.69	36.70*	0.002	0.07	0.05	0.18*	0.16
Primary branches/plant	2.41	6.10	4.01	2.18	1.44	44.93*	1.18
Internode length	0.68	16.65	24.29	0.36	0.15	0.35*	0.13
Plant height	435.85	2874.77	854.67	119.91	68.54	297.63*	58.82
Leaf area	2816.04	4347.78	2387.71	289.49	1051.70	181.37*	76.91
Specific leaf weight	6.87	36.36	9.20	10.10*	1.86	2.87*	1.45
Days to flowering	12.37	9850.73*	294.71	538.23*	12.10	43.13*	12.77
Days to maturity	240.70	6146.44	444.64	302.69*	33.31	93.37*	10.20
Reproductive phase	303.11	494.43	60.38	365.72*	34.20	55.97*	24.96

*Significant at 5% level

pods/plant, seeds/pod, specific leaf weight, days to flowering, days to maturity and reproductive phase, whereas for other traits, it was non-significant.

The ms due to progenies within doses within varieties indicated significant differences for all the traits studied, indicating significant differences among all the mutant progenies evaluated. As errors were heterogeneous for all the traits studied the comparisons need to be viewed accordingly.

4.2 Estimates of mean performance of mutant progenies

The estimates of mean performance of the mutant progenies studied along with check under various doses for each variety are given in Annexure (i to V). It can be seen that there were a number of superior mutants for most of the traits under different doses specifically under 10kR dose in HPK 2. For seed yield, biological yield, harvest index, pods/plant, plant height and days to maturity several desirable mutants were obtained in both the varieties. The description of desirable mutants, range of superiority and range of per cent superiority over check under each dose for each variety has been deferred for a later stage while discussing the practical implication of the present results.

4.3 Estimates of parameters of variability in M_3 generation of HPK 2 and HPK 4 varieties of horsegram at 10, 20 and and 30kR irradiation doses

The estimates of mean, shift in mean, range, phenotypic coefficient of variability (PCV), genotypic coefficient of variability (GCV), heritability (%) in broad sense on plot and mean basis and genetic advance using heritability on mean basis expressed as percentage of mutant progenies as well as of check mean for various polygenic traits studied in M_3 generation of HPK 2 and HPK 4 varieties of horsegram under different irradiation doses are presented characterwise in Tables 10 to 24 and are described hereunder characterwise:

4.3.1 Seed yield/plant (g)

In both the varieties, i.e., HPK 2 and HPK 4, the mean of 10kR irradiation population deviated significantly in positive direction from the control, whereas for other two doses i.e., 20 and 30kR, it was comparable to the control. The estimates of range values were higher at 10kR as compared to other two doses, i.e., 20 and 30kR in both the varieties, namely, HPK 2 (3.56-13.87) and HPK 4 (2.35-12.33) as presented in Table 10.

In variety HPK 2, phenotypic coefficient of variability was high (>20%) at all the doses studied. Genotypic coefficient of variability was high (>20%) at 10 and 30kR, whereas it was moderate (10-20%) at 20kR. Heritability estimates on plot basis was high (>60%) at 30kR, moderate (30-60%) at 10kR and low (<30%) at 20kR, whereas on mean basis, it was high (>60%) for 10 and 30kR, and moderate for 20kR. Genetic advance was high (>30%) for 10 and 30kR with respect to both the conditions,

Table 10. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for seed yield/plant (g)

Parameters	Variety	HPK 2			HPK 4		
	Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		4.82 ±1.39	4.89 ±1.09	4.46 ±0.67	4.17 ±0.74	3.02 ±1.07	3.39 ±1.41
Irradiated		8.16 ±0.04	5.61 ±0.03	5.09 ±0.07	7.54 ±0.06	4.39 ±0.11	4.99 ±0.03
Shift in mean		+3.34*	+0.72	+0.63	+3.37*	+1.37	+1.60
Range		3.56-13.87	3.53-8.60	3.43-8.26	2.35-12.33	2.38-7.75	2.83-8.72
PCV(%)		42.71	37.43	42.73	34.22	49.53	54.88
GCV(%)		31.02	12.27	35.95	38.25	27.97	24.29
Heritability (h^2_{bs})							
Plot basis		52.67	18.22	70.82	80.04	31.88	19.60
Mean basis		76.92	41.61	87.92	92.32	58.41	42.24
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		56.00	21.84	69.45	67.74	44.00	32.52
Using check mean		94.82	25.06	79.26	122.48	66.35	47.88

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 20kR, genetic advance was moderate (20-30%).

In HPK 4, PCV (%) and GCV (%) was high at all the doses. Heritability estimates on mean basis were high at 10kR and moderate at 20 and 30kR, whereas on plot basis, it was high at 10kR, moderate at 20kR and low at 30kR. Genetic advance expressed as percentage of both the mutant progenies and the check mean was high at all the three irradiation doses, i.e., 10, 20 and 30kR.

4.3.2 Biological yield/plant (g)

In both the varieties, i.e., HPK 2 and HPK 4, the mean of the irradiated population was comparable to the control. Range values were high at 10kR as compared to 20 and 30kR in both the varieties (Table 11).

In variety HPK 2, PCV (%) was high at all the doses, whereas GCV (%) was high at 10kR and moderate at 20 and 30kR. Heritability estimates were low on plot basis at all the doses, whereas on mean basis, it was high at 10kR and moderate at 20 and 30kR. Genetic advance was high at 10 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies and the check mean. At 20kR, genetic advance was low.

Table 11. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for biological yield/plant (g)

Parameters	Variety	HPK 2			HPK 4		
	Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		18.68 ±2.69	14.56 ±2.54	11.06 ±2.40	13.73 ±2.99	11.65 ±2.19	13.72 ±3.60
Irradiated		21.28 ±0.07	15.46 ±0.08	14.45 ±0.30	16.40 ±0.27	14.98 ±0.24	14.32 ±0.10
Shift in mean		+2.60	+0.90	+3.39	+2.67	+3.33	+1.60
Range		6.76-35.68	10.45 22.04	10.80-20.40	6.57-32.89	7.79-23.17	6.37-24.33
PCV(%)		36.03	36.67	32.31	42.74	37.49	46.76
GCV(%)		28.63	11.41	14.54	38.69	27.59	19.94
Heritability (h^2_{bs})							
Plot basis		28.63	13.82	20.26	60.00	54.16	18.19
Mean basis		83.71	32.50	50.35	81.82	78.00	40.01
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		53.96	13.39	24.42	72.11	50.20	26.00
Using check mean		83.94	16.82	32.04	86.13	64.55	82.83

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

In variety HPK 4, PCV (%) was high at all the doses, whereas GCV (%) was high at 10 and 20kR and moderate at 30kR. Heritability estimates on plot basis was high at 10kR, moderate at 20kR and low at 30kR, whereas on mean basis, it was high at 10 and 20kR, and moderate at 30kR. Genetic advance was high at 10 and 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 30kR, genetic advance was moderate.

4.3.3 Harvest index (%)

In variety HPK 2, the mean of 30kR irradiated population deviated significantly in negative direction from the control, whereas for other two doses, i.e., 10 and 20kR, it was comparable to control. In variety HPK 4, the mean of 10 and 30kR irradiated population deviated significantly in positive direction from the control, whereas it was comparable to control at 20kR. Range values were high for 10kR as compared to 20 and 30kR in HPK 2, whereas it was highest at 30kR as compared to other two doses, i.e., 10 and 20kR in HPK 4 (Table 12).

In both the varieties, PCV (%) was high at 30kR, whereas it was moderate for other two doses, i.e., 10 and 20kR.

In variety HPK 2, GCV (%) was moderate at 10 and 30kR, whereas it was low at 20kR irradiated population. Heritability estimates on plot basis was moderate at 10 and 30kR and low at

Table 12. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for harvest index (%)

Parameters	Variety / Dose	HPK 2 10kR	HPK 2 20kR	HPK 2 30kR	HPK 4 10kR	HPK 4 20kR	HPK 4 30kR
Mean ± SE							
Control		35.99 ±3.63	33.65 ±3.64	40.49 ±3.37	30.94 ±2.82	25.80 ±2.90	26.86 ±3.31
Irradiated		38.31 ±0.10	35.89 ±0.11	34.33 ±0.42	38.28 ±0.25	29.26 ±0.32	33.86 ±0.09
Shift in mean		+2.32	+2.24	-6.16*	+7.34*	+3.46	+7.00*
Range		27.85-52.27	26.43-44.13	26.92-44.48	30.94-43.80	23.96-34.79	23.64-46.24
PCV(%)		19.88	19.36	22.70	13.06	15.22	21.57
GCV(%)		11.24	8.06	15.03	2.67	9.86	13.35
Heritability (h^2_{bs})							
Plot basis		31.81	17.32	43.87	4.19	24.79	38.31
Mean basis		58.32	38.60	70.10	11.63	49.72	65.07
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		17.34	10.31	25.93	1.88	14.32	22.18
Using check mean		18.78	11.00	21.99	2.32	16.24	27.96

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

20kR, whereas on mean basis, it was high at 30kR and moderate at 10 and 20kR. Genetic advance was low at 10 and 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies and the check mean. At 30kR, genetic advance was moderate.

In variety HPK 4, GCV (%) was moderate at 30kR and low at 10 and 20kR. Heritability estimates on plot basis was moderate at 30kR and low at 10 and 20kR, whereas on mean basis, it was high at 30kR, moderate at 20kR and low at 10kR. Genetic advance was low at 10 and 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 30kR, genetic advance was moderate.

4.3.4 Pods/plant

In both the varieties, i.e., HPK 2 and HPK 4, the mean at 10 and 30kR irradiated population deviated significantly in positive direction from the control, whereas at 20kR, it was comparable to the control. In both varieties, range values were high at 10kR as compared to 20 and 30kR (Table 13). Phenotypic coefficient of variability was high at all the doses in both the varieties.

In variety HPK 2, GCV (%) was high at 10 and 30kR, whereas it was moderate at 20kR. Heritability estimates on plot basis were high at 10 and 30kR, moderate at 20kR, whereas on mean basis, it was high at all doses, i.e., 10, 20 and 30kR.

Table 13. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for pods/plant

Parameters	Variety	HPK 2			HPK 4		
	Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		28.08 ±4.65	28.08 ±3.59	24.33 ±3.21	25.26 ±7.32	27.00 ±4.19	26.26 ±7.21
Irradiated		44.21 ±0.13	31.82 ±0.11	38.58 ±0.40	43.27 ±0.66	30.57 ±0.46	37.68 ±0.20
Shift in mean		+16.13*	+3.74	+14.25*	+18.01*	+3.57	+11.42*
Range		20.25-91.08	14.00-51.11	23.31-64.00	18.89-83.41	18.50-43.37	19.00-73.36
PCV(%)		41.62	24.51	38.22	48.92	24.53	44.64
GCV(%)		37.42	14.77	35.39	39.16	34.16	29.91
Heritability (h^2_{bs})							
Plot basis		80.82	36.30	85.83	64.09	51.57	44.88
Mean basis		92.67	63.11	94.74	84.26	76.16	70.95
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		74.21	24.17	70.96	74.07	44.10	51.90
Using check mean		116.85	27.39	112.53	126.88	49.94	74.47

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

Genetic advance was high at 10 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 20kR, genetic advance was moderate.

In variety HPK 4, GCV (%) was high at all the doses, i.e., 10, 20 and 30kR. Heritability estimates on plot basis were high at 10kR, moderate at 20 and 30kR, whereas on mean basis, it was high at all the three doses, i.e., 10, 20 and 30kR. Genetic advance was high at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

4.3.5 Pod length (cm)

In both the varieties, i.e., HPK 2 and HPK 4, the mean of the irradiated population was comparable to the control. The estimates of range values were higher at 20kR as compared to other two doses, i.e., 10 and 30kR, in variety HPK 2, whereas it was higher at 10kR as compared to 20 and 30kR, in variety HPK 4 (Table 14).

In variety HPK 2, PCV (%) and GCV (%) were low at all doses, i.e., 10, 20 and 30kR. Heritability estimates on plot basis were moderate at 20 and 30kR and low at 10kR, whereas on mean basis, it was high at 30kR, moderate at 20 and low at 10kR. Genetic advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean bais and expressed as percentage of the mutant progenies mean and the check mean.

Table 14. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for pod length (cm)

Parameters (Variety / Dose)	HPK 2			HPK 4		
	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE						
Control	4.81 ±0.16	4.81 ±0.21	4.65 ±0.15	4.23 ±0.23	4.18 ±0.09	3.80 ±0.19
Irradiated	4.83 ±0.004	4.72 ±0.01	4.55 ±0.02	4.35 ±0.02	4.44 ±0.01	4.42 ±0.01
Shift in mean	+0.02	-0.09	-0.10	+0.12	+0.26	+0.62
Range	4.50-5.32	3.42-5.08	4.11-5.03	3.51-4.75	4.18-4.63	3.99-4.71
PCV(%)	6.31	9.44	8.79	9.12	4.60	-
GCV(%)	2.17	5.18	6.59	5.81	2.64	-
Heritability (h^2_{bs})						
Plot basis	11.82	30.16	56.25	27.35	32.95	-
Mean basis	28.69	30.72	78.48	53.04	59.65	-
Genetic advance (using h^2 on mean basis)						
Using mutant progenies mean	2.39	5.92	12.03	8.72	4.20	-
Using check mean	2.40	5.81	11.77	8.97	4.47	-

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

In HPK 4 variety, PCV (%) and GCV (%) were low at 10, 20 and 30kR doses. Heritability estimates on plot basis were low at 10kR and moderate at 20kR, whereas on mean basis, it was high at 10 and 20kR. Genetic advance was low for 10, 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

4.3.6 Seeds/pod

In both the varieties, i.e., HPK 2 and HPK 4, the mean of the irradiated population was comparable to the control. In variety HPK 2, range values were higher at 20kR as compared to 10 and 30kR, whereas it was high at 10kR as compared to 20 and 30kR in HPK 4 (Table 15).

In variety HPK 2, PCV (%) was moderate at 20 and 30kR and low at 10kR. GCV (%) was moderate at 30kR, whereas it was low at 10 and 20kR. Heritability estimates on plot basis was high at 30kR, and moderate at 10 and 20kR, whereas on mean basis, it was high at all the doses, i.e., 10, 20 and 30kR. Genetic advance was low for 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In variety HPK 4, PCV (%) was moderate at 10kR, whereas it was low for other two doses, i.e., 20 and 30kR. GCV (%) was low for all the doses studied. Heritability estimates on plot basis were moderate at 10 and 20kR and low at 30kR, whereas on mean basis, it was high at 10 and 20kR and low at 30kR. Genetic

Table 15. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for seeds/pod

Parameters	Variety / Dose	HPK 2			HPK 4		
		10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		5.60 ±0.20	5.54 ±0.22	5.41 ±0.20	4.94 ±0.38	4.40 ±0.15	4.93 ±0.29
Irradiated		5.42 ±0.01	5.22 ±0.70	5.10 ±0.02	4.80 ±0.02	4.84 ±0.02	4.85 ±0.01
Shift in mean		-0.18	-0.32	-0.31	-0.14	+0.44	-0.08
Range		4.53-6.10	4.08-5.75	4.20-5.66	3.66-5.78	4.40-5.32	4.12-5.25
PCV(%)		9.93	11.11	12.43	13.33	7.42	9.86
GCV(%)		7.38	8.27	10.18	9.08	4.88	1.68
Heritability (h^2_{bs})							
Plot basis		55.17	55.43	67.50	46.34	43.41	2.91
Mean basis		78.68	78.86	85.98	72.15	69.70	7.50
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		13.48	15.13	19.46	15.88	8.40	0.90
Using check mean		13.05	14.26	18.34	15.43	9.24	0.88

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

4.3.7 Hundred-seed weight (g)

In both the varieties, i.e., HPK 2 and HPK 4, the mean of irradiated population was comparable to the control. Range values were high at 20kR as compared to 10 and 30kR in both the varieties (Table 16).

In HPK 2, PCV (%) was moderate at 10kR, whereas it was low for other doses, i.e., 20 and 30kR. GCV (%) was low for all the doses, i.e., 10, 20 and 30kR. Heritability estimates on plot basis were moderate at 20 and 30kR and low at 10kR, whereas on mean basis, it was high at 20 and 30kR, and moderate at 10kR. Genetic advance was low for all the three irradiation doses with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In variety HPK 4, PCV (%) was moderate at 20 and 30kR, and low at 10kR. GCV (%) was moderate at 20kR and low at 10 and 30kR. Heritability estimates on plot basis were high at 20 and low at 10 and 30kR, whereas on mean basis, it was high at 20kR, moderate at 10kR and low at 30kR. Genetic advance was moderate at 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check, whereas low at 10 and 30kR.

Table 16. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for 100-seed weight (g)

Parameters	Variety / Dose	HPK 2 10kR	HPK 2 20kR	HPK 2 30kR	HPK 4 10kR	HPK 4 20kR	HPK 4 30kR
Mean ± SE							
Control		3.92 ±0.26	3.92 ±0.11	3.84 ±0.14	2.97 ±0.15	2.99 ±0.13	2.97 ±0.20
Irradiated		3.67 ±0.01	3.67 ±0.003	3.63 ±0.02	3.84 ±0.01	3.06 ±0.01	3.06 ±0.01
Shift in mean		-0.25	-0.25	-0.21	+0.87	+0.07	+0.09
Range		3.18-3.97	3.27-4.20	3.41-4.27	2.73-3.39	2.32-3.55	2.60-3.58
PCV(%)		10.62	7.19	9.51	7.63	14.97	12.12
GCV(%)		3.85	4.24	6.15	3.29	12.65	4.26
Heritability (h^2_{bs})							
Plot basis		13.33	42.85	41.91	18.60	71.42	12.35
Mean basis		31.57	69.23	71.42	40.67	89.64	29.10
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		4.47	8.08	10.72	4.32	24.64	4.79
Using check mean		1.05	7.57	10.13	5.59	25.26	4.93

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

4.3.8 **Primary branches/plant**

In both the varieties, i.e., HPK 2 and HPK 4, the mean of the irradiated material was comparable to control. Range values were higher at 10kR as compared to 20 and 30kR in HPK 2, whereas it was higher at 30kR as compared to 10 and 20kR doses in HPK 4 (Table 17).

In HPK 2, PCV (%) and GCV (%) was high for all the three doses. Heritability estimates on plot basis was high at 20kR and moderate at 10 and 30kR, whereas on mean basis, it was high for all the doses. Genetic advance was high at 10, 20 and 30kR with respect to both the conditions,i.e.,using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In HPK 4, PCV (%) was high at 10 and 30kR, whereas it was moderate at 20kR GCV (%) was high at 20kR, moderate at 30kR and low at 10kR. Heritability estimates on plot basis was moderate at 20kR and low at 10 and 30kR, whereas on mean basis, it was high at 20kR, moderate at 30kR and low at 10kR. Genetic advance was moderate at 30kR and low at 10kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 20kR, genetic advance using h^2 on mean basis and expressed as percentage of the check mean was high and was moderate for other situation, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean.

Table 17. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for primary branches/plant

Parameters	Variety: HPK 2			HPK 4		
Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE						
Control	4.30 ±0.82	4.30 ±0.38	3.93 ±0.55	3.40 ±0.86	2.87 ±0.49	3.40 ±0.52
Irradiated	4.14 ±0.02	3.98 ±0.01	3.71 ±0.06	4.15 ±0.07	3.91 ±0.05	3.69 ±0.01
Shift in mean	-0.16	-0.32	-0.22	+0.75	+1.04	+0.29
Range	2.08-8.78	1.50-6.00	2.50-5.50	2.66-5.16	2.32-5.03	2.39-5.58
PCV(%)	44.93	26.59	33.34	21.44	16.14	29.37
GCV(%)	28.68	20.71	21.22	4.16	27.25	15.80
Heritability (h^2_{bs})						
Plot basis	40.75	60.71	40.52	3.77	35.08	28.93
Mean basis	67.35	82.25	67.03	3.82	65.40	55.13
Genetic advance (using h^2 on mean basis)						
Using mutant progenies mean	48.48	38.70	35.79	1.67	27.70	24.16
Using check mean	46.68	35.82	33.79	2.04	37.74	26.23

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

4.3.9 Internode length (cm)

In both the varieties, i.e., HPK 2 and HPK 4, the means of irradiated populations were comparable to control. Range values were higher at 20kR as compare to 10 and 30kR in both the varieties, i.e., HPK 2 and HPK 4 (Table 18).

PCV (%) was moderate at 10 and 20kR, and low at 30kR. GCV (%) was moderate at 10kR and was low at other two doses. Heritability estimates on plot basis were moderate at 10 and 20kR, and was low at 30kR, whereas on mean basis these were high at all the three doses. Genetic advance was low at 10 and 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 30kR, genetic advance expressed as percentage of the mutant progenies mean was high and was low when expressed as percentage of the check mean.

In variety HPK 4, PCV (%) and GCV (%) was moderate 20 and 30kR and low at 10kR. Heritability estimates on plot basis were high at 20kR, moderate at 30kR and low at 10kR, whereas on mean basis, it was high at 20 and 30kR. Genetic advance was moderate at 20kR and low at 10 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

4.3.10 Plant height (cm)

In variety HPK 2, the mean at 30kR irradiated population deviated significantly in negative direction from the

Table 18. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for internode length (cm)

Parameters	Variety / Dose	HPK 2 10kR	HPK 2 20kR	HPK 2 30kR	HPK 4 10kR	HPK 4 20kR	HPK 4 30kR
Mean ± SE							
Control		2.68 ±0.17	2.66 ±0.18	2.83 ±0.12	3.29 ±0.39	3.39 ±0.19	3.11 ±0.29
Irradiated		2.66 ±0.004	2.73 ±0.01	2.50 ±0.01	2.96 ±0.03	3.02 ±0.02	3.28 ±0.01
Shift in mean		-0.02	+0.07	-0.33	-0.33	-0.37	+0.17
Range		1.78-3.40	2.23-4.00	2.26-2.75	2.64-3.72	2.45-3.78	2.33-3.95
PCV(%)		15.27	14.70	9.99	-	17.42	18.76
GCV(%)		10.31	9.01	4.35	-	13.54	11.01
Heritability (h^2_{bs})							
Plot basis		45.45	37.50	19.23	-	60.43	34.43
Mean basis		71.42	62.71	87.46	-	82.08	71.73
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		17.92	14.63	31.11	-	25.32	18.60
Using check mean		17.78	15.02	24.75	-	22.56	17.64

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

control and was comparable to control at 10 and 20kR, whereas in variety HPK 4, it deviated significantly in negative direction at all the doses. Range values were higher at 20kR as compared to 10 and 30kR, in variety HPK 2, whereas in HPK 4, it was high at 10kR as compared to 20 and 30kR (Table 19).

Phenotypic coefficient of variability was high at 20kR and moderate at 10 and 30kR. GCV (%) was moderate at all the three doses. Heritability estimates on both the plot and mean basis were high at all the doses, i.e., 10, 20 and 30kR. Genetic advance was high at 20kR and was low at 10kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 30kR, genetic advance was high when expressed as percentage of the mutant progenies mean and was low when expressed as percentage of the check mean.

In variety HPK 4, PCV (%) was high at 10kR and moderate at 20 and 30kR. GCV (%) was moderate at all the doses. Heritability estimates on plot basis were high at 20kR and moderate at 10 and 30kR, whereas on mean basis these were high at all the doses. Genetic advance was moderate at 10, 20kR and low at 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

Table 19. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for plant height (cm)

Parameters	Variety HPK 2			HPK 4		
Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE						
Control	69.17 ±2.19	69.17 ±4.46	81.26 ±3.95	66.03 ±6.66	67.33 ±3.55	66.02 ±5.36
Irradiated	67.04 ±0.06	66.94 ±0.14	64.64 ±0.49	61.36 ±0.60	61.98 ±0.39	61.15 ±0.14
Shift in mean	-2.13	-2.23	-16.62*	-4.67*	-5.35*	-4.87*
Range	51.00-79.65	34.41-93.76	48.53-77.11	48.15-81.16	48.33-75.75	44.78-73.47
PCV(%)	11.60	21.68	19.31	23.85	17.35	18.76
GCV(%)	10.12	18.35	16.15	14.66	14.24	11.01
Heritability (h^2_{bs})						
Plot basis	76.04	71.65	69.94	37.99	67.38	34.43
Mean basis	90.49	88.35	87.46	64.57	86.10	61.17
Genetic advance (using h^2 on mean basis)						
Using mutant progenies mean	19.83	35.53	31.11	24.27	27.21	17.74
Using check mean	19.22	34.39	24.75	22.56	25.05	16.43

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

4.3.11 Leaf area (cm^2)

In variety HPK 2, the mean of 10kR irradiated progenies deviated significantly in positive direction as compared to control, whereas it deviated significantly in negative direction at 20 and 30kR. In variety HPK 4, the mean of mutant progenies deviated significantly in negative direction as compared to control under all the doses. In variety HPK 2, range values were higher at 10kR as compared to 20 and 30kR, whereas it was high at 30kR in HPK 4 variety (Table 20).

In variety HPK 2, PCV (%) was high at all the doses, i.e., 10, 20 and 30kR. GCV (%) was moderate at 20 and 30kR, and low at 10kR. Heritability estimates on plot basis were moderate at 20kR and low at 10 and 30kR, whereas on mean basis it was moderate at all the doses. Genetic advance was low at 10 and 20kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean. At 30kR, genetic advance was moderate and low when expressed as percentage of the mutant progenies mean and the check mean, respectively.

In variety HPK 4, PCV (%) was high at 10 and 30kR, and moderate at 20kR. GCV (%) was moderate at all the three doses. Heritability estimates on plot basis was high at 20kR, moderate at 10kR and low at 30kR, whereas on mean basis, it was high at 10 and 20kR and was moderate at 30kR. Genetic advance was moderate at 10kR and low at 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the

Table 20. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for leaf area (cm^2)

Parameters	Variety	HPK 2			HPK 4		
	Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		44.79 ±6.53	49.09 ±4.02	54.80 ±5.42	47.24 ±3.96	53.73 ±2.14	47.24 ±4.96
Irradiated		51.78 ±0.19	45.83 ±0.12	41.24 ±0.67	40.24 ±0.36	42.11 ±0.23	41.23 ±0.13
Shift in mean		6.99*	-3.26*	-13.56*	-7.00*	-11.62*	-6.01*
Range		36.43-70.14	26.74-59.39	32.13-55.35	29.62-52.19	33.40-55.64	25.35-63.53
PCV(%)		26.17	22.88	27.06	22.18	18.11	24.38
GCV(%)		9.72	17.03	14.59	14.17	15.82	12.66
Heritability (h^2_{bs})							
Plot basis		16.54	55.68	29.09	40.78	76.34	26.96
Mean basis		37.29	55.24	55.17	67.38	90.63	52.55
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		12.23	14.94	22.33	23.96	31.03	18.91
Using check mean		14.14	13.95	16.80	20.41	24.32	16.50

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

mutant progenies mean and the check mean. At 20kR, genetic advance was high and moderate when expressed as percentage of the mutant progenies mean and the check mean, respectively.

4.3.12 Specific leaf weight (mg/cm^2)

In both the varieties, the mean of the irradiated progenies was comparable to control for all the three doses. In variety HPK 2, range values were high at 10kR as compared to 20 and 30kR, whereas it was high at 30kR as compared to 10 and 20kR (Table 21) in variety HPK 4.

In variety HPK 2, PCV (%) was high at 10 and 20kR and low at 30kR. GCV (%) was moderate at 10kR, whereas it was low for other two doses, i.e., 20 and 30kR. Heritability estimates on plot basis were low at 10, 20 and 30kR, whereas on mean basis, it was moderate at 10kR and low at 20 and 30kR. Genetic advance was moderate at 10kR, low at 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In HPK 4, PCV (%) was high at 10, 20 and 30kR. GCV (%) was high at 20 and 30kR, and was low at 10kR. Heritability estimates on plot basis were high at 20kR, moderate at 30kR and low at 10kR, whereas on mean basis, it was high at 20kR&moderate at 10 and 30kR. Genetic advance was high at 20 and 30kR, low at 10kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

Table 21. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for specific leaf weight(mg/cm^2)

Parameters	Variety / Dose	HPK 2 10kR	HPK 2 20kR	HPK 2 30kR	HPK 4 10kR	HPK 4 20kR	HPK 4 30kR
Mean ± SE							
Control		3.36 ±0.78	3.36 ±0.66	2.80 ±0.25	3.16 ±0.41	2.56 ±0.35	3.06 ±1.16
Irradiated		3.63 ±0.02	3.64 ±0.02	2.99 ±0.03	3.43 ±0.03	3.88 ±0.03	4.54 ±0.03
Shift in mean		+0.27	+0.28	+0.19	+0.27	+1.32	+1.48
Range		2.50-7.36	2.63-5.71	2.61-3.49	2.77-4.64	2.56-5.65	2.72-8.31
PCV(%)		41.96	32.38	7.02	22.97	26.53	37.95
GCV(%)		18.47	7.26	4.72	9.37	21.40	21.60
Heritability (h^2_{bs})							
Plot basis		19.39	5.03	9.52	16.66	65.09	32.39
Mean basis		41.92	13.72	24.00	37.50	76.38	58.97
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		24.64	5.54	4.77	11.86	38.54	34.17
Using check mean		26.62	6.01	5.09	12.87	58.41	50.70

PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

4.3.13 Days to flowering

In both the varieties, the mean of irradiated population at 20kR deviated significantly in positive direction from control, whereas it was comparable to control at 10kR. At 30kR, mean of HPK 4 deviated significantly in positive direction as compared to control and was comparable to control in variety HPK 2. In both the varieties, range values were higher at 10kR as compared to 20 and 30kR (Table 22).

In variety HPK 2, PCV (%) was high at 10kR and was low at 20 and 30kR. GCV (%) was low at all the three doses. Heritability estimates on plot basis were higher at 30kR, moderate at 10kR and low at 20kR, whereas on mean basis it was high at 10 and 30kR and moderate at 20kR. Genetic advance was low for 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In variety HPK 4, PCV (%) and GCV (%) were low at all the three doses. Heritability estimates on plot basis were moderate at 10, 20 and 30kR, whereas on mean basis, it was high at all the doses. Genetic advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

Table 22. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for days to flowering

Parameters	Variety / Dose	HPK 2			HPK 4		
		10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE							
Control		58.00 ±3.22	60.33 ±1.16	61.66 ±0.95	64.66 ±1.81	67.33 ±1.12	66.33 ±1.67
Irradiated		56.54 ±0.09	63.15 ±0.03	63.66 ±0.11	66.15 ±0.16	71.03 ±0.12	71.15 ±0.04
Shift in mean		-1.46	+2.82*	+2.00	+1.49	+3.70*	+4.82*
Range		41.00-64.33	61.00-65.66	62.00-67.00	57.66-67.00	66.00-74.33	64.00-75.00
PCV(%)		12.91	3.39	5.08	5.98	4.55	5.22
GCV(%)		8.33	1.13	4.36	3.66	3.28	3.28
Heritability (h^2_{bs})							
Plot basis		41.66	11.23	73.70	37.43	52.10	39.47
Mean basis		68.18	53.10	89.37	64.22	76.54	66.18
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		14.18	2.57	8.49	6.04	5.92	5.50
Using check mean		13.82	2.69	8.76	6.18	6.24	5.90

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

4.3.14 Days to maturity

In variety HPK 2, the mean of irradiated population deviated significantly in negative direction at 10kR, whereas it was comparable to control at 20 and 30kR. Similarly, the mean of irradiated population at 30kR deviated significantly in negative direction and was comparable to control at 10 and 20kR with respect to HPK 4 variety. In variety HPK 2, range values were higher at 10kR, whereas it was high at 20kR in variety HPK 4 (Table 23). In variety HPK 2, PCV (%) and GCV (%) were low at 10, 20 and 30kR. Heritability on plot basis was high at 20 and 30kR, and was moderate at 10kR, whereas on mean basis, it was high at all the three doses. Genetic advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In HPK 4, PCV (%) and GCV (%) were low at 10, 20 and 30kR. Heritability estimates on plot basis were high at 20kR, moderate at 30kR and low at 10kR, whereas on mean basis, it was high at all the doses. Genetics advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

4.3.15 Reproductive phase (days)

In variety HPK 2, mean of irradiated population at 10, 20 and 30kR was comparable to control. In variety HPK 4,

Table 23. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for days to maturity

Parameters	Variety / Dose	HPK 2 10kR	HPK 2 20kR	HPK 2 30kR	HPK 4 10kR	HPK 4 20kR	HPK 4 30kR
Mean ± SE							
Control		125.67 ±2.56	116.66 ±1.74	119.00 ±1.28	128.33 ±1.32	128.66 ±1.29	131.00 ±1.40
Irradiated		122.16 ±0.07	116.23 ±0.05	118.04 ±0. 96	126.33 ±0.12	127.40 ±0.14	127.34 ±0.03
Shift in mean		-3.51*	-0.43	-0.96	-2.00	-1.26	-3.66*
Range		116.33-136.67	108.66-128.00	112.33-120.00	122.66-130.66	120.00-130.66	121.66-130.33
PCV(%)		5.25	4.68	3.39	2.65	2.89	2.37
GCV(%)		3.79	3.89	2.82	1.07	2.47	1.47
Heritability (h^2_{bs})							
Plot basis		52.12	69.05	69.09	16.38	72.60	35.94
Mean basis		76.57	87.00	87.02	64.28	88.82	62.73
Genetic advance (using h^2 on mean basis)							
Using mutant progenies mean		6.83	7.47	5.42	2.33	4.79	2.32
Using check mean		6.64	7.44	5.37	2.30	4.75	2.26

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

Table 24. Estimates of parameters of variability under different irradiation doses in HPK 2 and HPK 4 varieties for reproductive phase (days)

Parameters	Variety: HPK 2			HPK 4		
Dose	10kR	20kR	30kR	10kR	20kR	30kR
Mean ± SE						
Control	67.67 ±4.80	54.33 ±1.99	57.33 ±1.42	63.66 ±1.84	61.33 ±1.17	61.35 ±1.53
Irradiated	65.63 ±0.13	53.51 ±0.06	55.20 ±0.17	59.87 ±0.16	56.37 ±0.13	56.37 ±0.04
Shift in mean	-2.04	-0.82	-2.13	-3.79*	-4.96*	-4.98*
Range	51.00-79.65	34.41-66.66	48.53-60.11	56.33-64.33	51.33-62.66	51.66-60.66
PCV(%)	15.20	11.19	7.66	5.83	6.67	6.26
GCV(%)	8.38	9.14	6.22	2.37	5.61	4.15
Heritability (h^2_{bs})						
Plot basis	30.42	66.82	66.46	16.61	70.81	43.88
Mean basis	56.74	85.79	85.32	37.38	87.92	70.11
Genetic advance (using h^2 on mean basis)						
Using mutant progenies mean	13.00	17.44	11.84	2.99	10.84	7.17
Using check mean	12.61	17.18	11.40	2.81	9.96	6.58

*Significant at 5% level
PCV : Phenotypic coefficient of variability
GCV : Genotypic coefficient of variability
h^2_{bs} : Heritability in broad sense

mean shifted significantly in negative direction at 10, 20 and 30kR. Range values were higher at 20kR as compared to 10 and 30kR doses in both the varieties (Table 24).

In HPK 2, PCV (%) was moderate at 10 and 20kR and was low at 30kR. GCV (%) was low at 10, 20 and 30kR. Heritability estimates on plot basis were high at 20 and 30kR and was moderate at 10kR, whereas on mean basis, it was high at 20 and 30kR, and was moderate at 10kR. Genetic advance was moderate at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

In HPK 4, PCV (%) and GCV (%) were low at all the doses studied. Heritability estimates on plot basis were high at 20kR, moderate at 30kR and low at 10kR, whereas on mean basis, it was high at 20 and 30kR, and was moderate at 10kR. Genetic advance was low at 10, 20 and 30kR with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean.

DISCUSSION

5. DISCUSSION

The objectives of the present investigation in HPK 2 and HPK 4 varieties of horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.) were (i) to understand the nature and magnitude of induced variation under different doses of gamma-rays for various polygenic traits, specifically seed yield and phenological traits, (ii) to understand the relationship of shift in mean and induced genetic variance in relation to different doses of gamma-rays and, (iii) to identify superior desirable mutants with high yield coupled with early maturity in both the varieties. The results obtained on these aspects have been discussed for the genetic amelioration of horsegram in the following pages.

Mutation breeding is a valuable supplementary approach in plant breeding under the situation as is prevailing in food legumes, specifically in horsegram, where the variability existing in natural gene pool is not meeting the requirements of present genetic transformation. Under such situations, it is imperative to create the desired genetic variation through mutagenesis. Of various mutagens, ionizing radiations have been used most commonly for induction of mutations and resulted in the development of new varieties (Micke *et al*., 1990). These are preferred primarily because of their effectiveness, the ease of treating material and its handling immediately after treatment. Data on chemically induced polygenic variation are very limited (Ramel, 1983). Among ionizing radiations, gamma-rays are considered to be the most effective on account of their shorter wavelength, possessing more energy per photon and mono-energetic radiations, and hence the same have been used in present study for induction of polygenic mutations.

The importance of genotypes used for polygenic mutation as well as the intensity of radiation applied, are the factors of prime consideration specially in the initial stage of an effective mutation breeding programme. From a résumé of work on the induction of polygenic variation in various crops, it can be clearly seen that low doses of radiation are more effective for inducing polygenic mutations. Therefore, in the present study low doses, ranging from 10 to 30kR, have been used. It has been speculated that the best adapted and high-yielding lines should be favoured for the induction of polygenic mutants so that it is possible to accumulate in one genotype the most favourable alleles and, at the same time, eliminate the deleterious ones (Rawlings *et al.*, 1958). The material of the present study comprised HPK 2, a highly adapted variety across the seasons/regions at the All-India level, while HPK 4 (Baiju) has been released for general cultivation in Himachal Pradesh.

Micro-mutations are of importance for their adaptive evolution unlike macro-mutations with deleterious pleiotropic effects. Thus, polygenic variations are of paramount importance for achieving desirable and directed evolution. The high rate of micro-mutations coupled with their much greater probability of improving adaption explains why evolution in natural populations usually proceeds in the classical Darwinian mode, trekking its way through a series of small steps. Numerous studies of natural populations have demonstrated that phenotypic differences between individuals within populations, as well as differences between populations, races and species are generally influenced by multiple genetic factors with relatively small effects (Wright, 1968; Falconer, 1981; Lande, 1981; and Coyne, 1983). The optimum phenotype can be more nearly achieved by most individuals in the populations based on micromutations while avoiding the segregation load produced by polymorphism of macro-mutations. Thus, in the present study, emphasis has been on the polygenic mutations induced by different radiation doses and to carry out their genetic analysis in order to know the nature and magnitude of induced variability.

The results obtained from the combined analysis of variance with respect to HPK 2 and HPK 4 varieties over doses (Table 4 and 8) indicate that sufficient variation has been induced for most of the polygenic traits, viz., seed yield/plant, biological yield/plant, harvest index, pods/plant, seeds/pod, primary branches/plant, internode length, plant height, leaf area, specific leaf weight, days to flowering, days to maturity and reproductive phase. Dose-wise analysis (Tables 1 to 4) in HPK 2 has revealed the presence of sufficient induced variation under all the three doses namely, 10, 20 and 30kR gamma-rays for seed yield/plant and its major yield components. However, for biological yield/plant, it has been induced only in 10kR dose. The situation appears to be different in case of HPK 4, (Tables 5 to 8), where induction of variation for biological yield/plant is in all the three doses. In case of other yield traits, such as harvest index, induction of mutation has been under 10 and 30kR; for pods/plant and primary branches/plant, it has been observed in 20 and 30kR; and for 100-seed weight, it has been in 20kR. However, for seed yield/plant, 10, 20 and 30kR doses have generated sufficient variation in HPK 4 too. For internode length, 10 and 20kR doses have induced variation in HPK 2, whereas 20 and 30kR doses have induced variation for this trait in HPK 4. In case of plant height, induction of variation has been noticed under all the three doses in both the varieties.

For morpho-physiological traits, like leaf area, induction of variability has been evident in HPK 2 with 10 and 20kR, whereas it has been observed with all the doses in HPK 4. Induced variation for specific leaf weight is evident only under 10kR in HPK 2, while it has been observed under 20 and 30kR in HPK 4. As far as phenological traits are concerned, all the doses appear to be effective for the induction of variation for days to flowering and days to maturity in both the varieties. The induced variation for days to flowering is evident under all the doses of gamma-rays in HPK 2, while it is discernible under 20 and 30kR doses in HPK 4.

The results obtained from the comparison of control versus different doses in HPK 2 have further revealed that the variation has been induced in the population raised from seeds irradiated with 10kR dose for seed yield/plant, biological yield/plant, pods/plant; 20kR for days to flowering and 30kR for biological yield/plant, pods/plant, internode length, plant height and leaf area. In case of HPK 4, 10kR and 30kR doses appear to be inducing variation for harvest index, whereas 20 and 30kR doses have induced variation for days to flowering. Induced variation has also been generated for seed yield/plant, biological yield/plant, primary branches/plant, days to maturity under 10kR; for seeds/pod, leaf area, specific leaf weight and reproductive phase under 20kR; and for pod length and days to maturity under 30kR.

The results obtained from the combined analysis of induced variability over varieties, doses within varieties have revealed that sufficient variation has been generated due to irradiation for various polygenic traits, viz., seeds/pod, 100-seed weight and days to flowering for both the varieties (Table 9). The induced variation due to doses within varieties has been noticed for polygenic traits, like seed yield/plant, biological yield/plant, harvest index, pods/plant, seeds/pod, leaf area, specific leaf weight, days to maturity and reproductive phase. Significant variation induced due to progenies within doses within varieties further indicates significant differences among all the mutant progenies evaluated.

Increase in variation in irradiated material of both HPK 2 and HPK 4 varieties may be the results of changes in the nature of genes or chromosomal re-arrangements or both at the post-irradiation stage. Earlier workers have also reported similar induction of polygenic variation through irradiation (Raja Ram, 1973; and Mandal, 1974 in gram; Rao, 1974 in pigeon-pea; Dahiya, 1973, Veeraswamy *et al*., 1973, Malik *et al*., 1979, Mohapatra *et al*., 1983, Sharma and Haque, 1983, Verma and Singh, 1984, Khan, Khan, 1983, 1987, 1988 in mungbean; Bhamburkar and Bhalla, 1983, Singh *et al*., 1987 in *Vigna mungo*; Sharma and Sharma (1978, 1979), Ravi *et al*. (1979), Sood (1983), Kalia and Gupta, 1989 in lentil; Suresh *et al*., 1991 in horsegram).

As varying doses of gamma-rays were used in the present study, it would be worthwhile to examine the relationship of different doses in relation to shift in mean and induced genotypic variance (Tables 10 to 24). Shift in mean in HPK 2 and HPK 4 varieties, in general, is of asymmetrical nature for biological yield/plant, seeds/pod, primary branches/plant and internode length. In case of HPK 2, for seed yield/plant, harvest index, 100-seed weight, plant height and leaf area, shift in mean is of symmetrical in nature, whereas for the remaining traits it is of asymmetrical nature. In case of HPK 4, shift in mean is asymmetrical for seed yield/plant, harvest index, pods/plant, 100-seed weight, plant height, leaf area and days to maturity, whereas it is symmetrical for specific leaf weight, days to flowering and reproductive phase. However, the shift in mean, specifically under 10kR, is towards positive side for seed yield/plant, biological yield/plant, harvest index and pods/plant, whereas for seeds/pod, 100-seed weight, primary branches/plant, internode length, plant height, specific leaf weight, days to flowering, days to maturity and reproductive phase, it is towards negative side. Negative shift in mean in irradiated material in comparison to control and its relationship with increasing dose has also been documented earlier (Scossiroli, 1965; Sinha and Goword, 1972; Sharma and Sharma, 1978; Tirdea, 1978; Khan, 1982 in mungbean). Positive shift in mean has been documented in mungbean by Verma and Singh (1983); and in horsegram by Suresh et al. (1991). It is of interest to discuss the behaviour of shift in mean in the two varieties studied in the light of hypothesis of Brock (1965). As per this, the theoretical expectation of inducing random micro-mutations, in self-fertilizing species, with large number of genes, each having small individual positive or negative effect, for a particular trait, would depend on the total number of genes involved or the relative proportion of genes with positive or negative effects and on the degree to which the genes of the parental genome operate in balanced set. In such cases, random mutation would be expected to increase the variance and to shift the mean away from the direction of previous selection history. Highly the selected or adapted traits, greater will be the shift in mean and also asymmetry of distribution of variances. In the present study, Brock's hypothesis fits well with respect to traits, like seed yield/plant, pods/plant, plant height, days to maturity and reproductie phase.

By contrast, the results obtained for other traits do not support the hypothesis. The differential behaviour of different traits may be due to the different varieties used, which have already been subjected to selection for high yield. As observed in the present study, other workers have also supported Brock's hypothesis (Swaminathan, 1965; Bansal, 1969; and Raja Ram, 1973). On the contrary, failure of hypothesis has also been reported by Gaul and Aastveit (1966) and Frey (1968). According to Frey (1968), shift in population mean induced by mutagens are generally un-predictable and are dependent upon specific genotype-trait combination. Interestingly, the present results are also, in fact, in favour of this view.

Before initiating a crop improvement programme, it is imperative to understand the nature and magnitude of variation either through hybridization or mutagenesis. Earlier, it has been clearly demonstrated (Gregory, 1956, 1968; Frey, 1968; and Brock, 1965) that radiation is as efficient as hybridization for generating variability for effective selection in order to achieve genetic gain. The results obtained on the genetic components of induced variability in the M_3 generation of HPK 2 and HPK 4 varieties under different radiation doses have revealed increased variation (Tables 10 to 24). As reported earlier (Scossiroli, 1965), genetic variability has been observed to increase with increase in the doses of gamma-rays.

In HPK 2, genotypic coefficient of variability (GCV) % is high (>20%) for seed yield/plant, pods/plant in 10 and 30kR doses, primary branches in all the doses, and biological yield/plant and specific leaf weight in 10kR. It is moderate (10-20%) for harvest index in 10 and 30kR, seeds/pod in 30kR, internode length in 10kR, plant height in all the doses, leaf area in 20 and 30kR. The low (<10%), GCV (%) is discernible for other traits at different doses of gamma-rays. In HPK 4, GCV (%) is high for seed yield/plant, pods/plant in all the three doses, biological yield/plant in 10 and 20kR, and primary branches in 20kR. The values are moderate for harvest index in 30kR, 100-seed weight in 20kR, internode length in 20 and 30kR, and plant height and leaf area in all doses, specific leaf weight in 20 and 30kR. Low values have been obtained for all other traits in the different doses.

Estimates of heritability (in broad sense) in HPK 2, on plot basis reveal that it is high (>60%) for seed yield/plant, seeds/pod, days to flowering in 30kR, pods/plant in 10 and 30kR, primary branches/plant in 20kR, and days to maturity and reproductive phase in 20 and 30kR. It is moderate (30-60%) for harvest index and pod length in 30kR; 100-seed weight in 20 and 30kR; and internode length and leaf area in 20kR in HPK 2. In case of HPK 4, high heritability appears to be for seed yield/plant, biological yield/plant, pods/plant in 10kR and 100-seed weight, internode length, plant height, leaf area, specific leaf weight, days to maturity and reproductive phase in 20kR. It is moderate for harvest index in 30kR; primary branches/plant in 20kR dose; seeds/pod in 10 and 20kR doses (Tables 10to 24).

Estimates of h^2 (bs) on mean basis with respect to HPK 2 variety, is high for seed yield/plant and days to flowering under 10kR and 30kR; biological yield/plant in 10kR; harvest index and pod length in 30kR dose; rest of the other traits at all the doses, except moderate estimates for leaf area under all the doses and specific leaf weight under 10kR. As far as HPK 4 is concerned, high heritability (bs) on mean basis appear to be for seed yield/plant in 10kR; biological yield/plant and leaf area in 10 and 20kR doses; harvest index in 30kR; 100-seed weight, primary branches/plant and specific leaf weight in 20kR; internode length and reproductive phase in 20 and 30kR doses, and rest of other traits in all the doses, except for pod length in 10 and 20kR doses, which possessed moderate heritability.

In HPK 2, estimates of genetic advance with respect to both the conditions, i.e., using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the control mean reveal that it is high (>30%) for biological yield/plant in 10kR dose; plant height in 20kR dose; seed yield/plant, 100-seed weight and internode length in 30kR dose and primary branches/plant in all the doses. It is moderate (20-30%) for specific leaf weight in 10kR dose, and harvest index in 30kR dose. In HPK 4, the estimates of genetic advance is high for seed yield/plant, biological yield/plant in 10kR dose; pods/plant in 10 and 30kR doses; primary branches/plant and specific leaf weight in 20 and 30kR doses. It is moderate for harvest index in 30kR dose; 100-seed weight and internode length in 20kR dose, and plant height and leaf area in 10 and 20kR doses. In HPK 2, high heritability coupled with high genetic advance as per cent of mutant progenies mean and the check mean is discernible for seed yield/plant, biological yield/plant in 10kR dose and primary branches/plant in all the three doses. It is, whereas moderate for specific leaf weight in 10kR, which indicates that induced genetic variability may be due to additive gene effects. However, for rest of the traits and doses, there appears to be no apparent relationship between high heritability and high genetic advance. In HPK 4, high heritability coupled with high genetic advance as per cent of mean is evident for seed yield/plant, biological yield/plant in 10kR dose which reveals that induced variability may be due to additive gene effects (Tables 10 to 24). Several workers have observed increase in genetic parameters in mutagenised population(Papa et al., 1961 and William and Hanway, 1961 in Soybean; Rao, 1974, Shrivastava, 1974, Jain, 1976 and Sharma, 1979 in pigeonpea; Bandopadhaya and Bose, 1982, Mohapatra et al.,1983, Khan, 1982 and 1984, Malik, 1988 in mungbean; Hussain and Abdulla, 1979 in field beans; Krishnaswamy and Rathinam, 1982, Sood, 1983, Kalia and Gupta, 1989 in lentil and Bhamburkar and Bhalla, 1983 in blackgram).

Another important aspect is to look at the induced polygenic variation in order to identify potential mutants for desirable traits. The number of superior mutants, range of superiority and range of per cent superiority with respect to different traits in HPK 2 and HPK 4 are given in Tables 25 and 26, respectively. It can be seen that in HPK 2, such desirable mutants are available for seed yield/plant, biological yield/plant, pods/plant, primary branches/plant, plant height and days to maturity under different doses. Superior mutants have also been observed for harvest index in 10 and 20kR, 100-seed weight in 30kR, leaf area in 10kR, days to flowering in 10 and 30kR, reproductive phase in 10 and 20kR. In HPK 2, desirable mutants for all the traits, except pod length, seeds/pod, 100-seed weight, specific leaf weight and reproductive phase are higher under 10kR, which appears to be the effective dose for isolating desirable mutants. However, for bold seed size, which is unique speciality of HPK 2, 30kR dose appears to be the most efficient for inducing still bolder seed size in one of the mutants, namely HPKM 141.

As in HPK 2, earliness is the most desired trait in order to widen its adaptability, 10kR dose happens to be one, which has induced five mutants which show significant earliness in maturity and high yield over the check. The range of per cent superiority varies from 5.84-7.83% over the control for five mutants, namely, HPKM 10, HPKM 26, HPKM 33, HPKM 36 and

Table 25. Superior mutant progenies under different doses in HPK 2 variety of hoursegram for different traits

Dose	Seed yield/ plant (g)	Biological yield/ plant (g)	Harvest index (%)	Pods/ plant	100-seed weight (g)	Primary branches/ plant	Inter-node length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf weight (mg/cm^2)	Days to flowering	Days to maturity	Reproductive phase (days)
10kR													
Number of superior mutants	14 (1,3,10,22,24 26,28,33,36, 37,39,46,64, 76)	14 (1,3,10,16 22,24,26, 28,33,36, 37,39,46,64)	3 (13,28,38)	16 (1,3,10,13, 22,24,26 31,33,34, 36,37,39, 41,49,64)	-	2 (33,43)	2 (10,53)	11 (11,13,22, 23,26,28, 34,48,49, 53,64)	3 (22,51, 76)	1 (48)	4 (14,22,36 37)	10 (10,14,16 23,26,33, 36,37,51,53)	2 (22,26)
Range of superiority	8.81-13.87	21.34-35.38	47.93-52.27	41.46-91.08	-	6.75-8.75	2.18-1.78	64.58-51.00	64.62-70.14	-	45.00-41.00	118.33-116.00	82.67-83.00
Range of per cent superiority	82.78-187.75	55.99-160.82	33.17-45.23	47.64-224.35	-	56.97-104.18	18.65-33.58	6.63-26.26	44.27-56.59	-	22.41 29.31	5.84 - 7.69	22.16-22.65
20kR													
Number of superior mutants	2 (103,118)	1 (103)	1 (118)	7 (86,103,104, 108,118,121,122)	-	2 (121, 122)	2 (97, 135)	5 (89,105, 112,116, 130)	-	2 (102, 120)	-	7 (97,103, 105,106, 121,129,135)	3 (86,116, 118)
Range of superiority	8.09 - 8.60	-	-	40.70-51.11	-	5.85-6.00	2.32-2.23	55.87-34.41	-	5.27-5.71	-	111.66-108.66	60.66-65.66
Range of per cent superiority	65.43 - 75.86	-	-	44.94-82.02	-	36.04-39.53	12.53-16.04	19.22-50.25	-	56.84-69.94	-	4.28-6.85	11.65-22.69
30kR													
Number of superior mutants	2 (138,141)	1 (141)	-	3 (138,141, 143)	1 (141)	-	-	4 (140, 143,151,153)	-	-	1 (138)	2 (135,138)	-
Range of superiority	8.13-8.26	-	-	45.28-64.00	-	-	-	58.66 - 48.53	-	-	-	114.00-112.33	-
Range of per cent superiority	82.28 - 85.20	-	-	86.10 - 163.04		-	-	27.81 - 40.27	-	-	-	4.20-5.60	-

Table 26. Superior mutant progenies under different doses in HPK 4 variety of horsegram for different traits

Dose	Seed yield/ plant (g)	Biological yield/ plant (g)	Harvest index (g)	Pods/ plant	Pod length (cm)	Seeds/ pod	100-seed weight (g)	Primary branches/ plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf weight (mg/cm^2)	Days to maturity
10kR													
Number of superior mutants	4 (159,165 171,173)	3 (165,171 173)	4 (161,165, 166,171)	5 (157,159 165,171, 173)	-	1 (173)	-	-	-	-	-	1 (168)	2 (157,159)
Range of superiority	6.68- 12.33	20.21- 32.89	39.20- 43.80	47.46- 83.41	-	-	-	-	-	-	-	-	126.66- 122.66
Range of per cent superiority	60.19 - 195.68	47.19- 139.55	26.69- 41.56	87.88- 230.20	-	-	-	-	-	-	-	-	1.30- 4.41
20kR													
Number of superior mutants	1 (186)	2 (186,189)	1 (187)	2 (184,186)	4 (181, 184,185 186)	4 (181, 184,186, 188)	2 (185, 189)	2 (183, 186)	4 (182, 184,186, 189)	3 (182, 183, 189)	-	4 (183, 185,187) 188)	2 (184,189)
Range of superiority	-	18.49- 23.17	-	39.50- 43.37	4.52- 4.63	4.87- 5.05	3.50- 3.55	4.62- 5.03	2.73- 2.45	53.45- 48.33		3.77- 5.65	124.66- 120.00
Range of per cent superiority	-	58.71- 98.88	-	46.29- 60.62	8.13- 10.76	10.68- 14.77	17.05- 18.72	60.97- 75.26	19.46- 27.72	20.61- 28.22		47.26- 120.70	3.10- 6.73
30kR													
Number of superior mutants	8 (201, 204 215,218, 227,231, 233,244)	2 (204,227)	10 (209,215, 217,219, 226,231, 233,245, 249,253)	6 (201,204, 215,218, 227,244)	27 (192, 195,200, 208,211, 215-220, 226-27, 231-235, 241,245, 249,256)	-	1 (196)	3 (192, 118,227)	6 (202, 207,215, 216,217, 220)	6 (195, 196,200, 202,241)	1 (197)	11 (198, 202,212, 215,216, 219.220. 226,227, 231,233)	14 (197,204, 208,209,211, 212,216,217, 219.226.233 235,247,249)
Range of superiority	7.56- 8.72	23.70- 24.33	37.02- 46.24	47.00- 73.36	4.34- 4.71	-	-	5.15- 5.58	2.61- 2.33	50.36- 44.78	-	5.09- 8.31	127.66- 121.66
Range of per cent superiority	123.00- 157.22	72.74- 77.11	37.82 - 72.15	78.97- 179.36	14.21- 23.94	-	-	51.47- 64.12	20.42- 40.77	23.72- 32.17	-	66.33- 171.56	2.54- 7.12

HPKM 37. In both the varieties, 20kR dose appears to be less potent with regards to isolation of desirable mutants. In HPK 2, the maximum number of desirable mutants for seed yield have been induced in 10kR dose which are HPKM 1, HPKM 3, HPKM 10, HPKM 22, HPKM 24, HPKM 26, HPKM 28, HPKM 33, HPKM 36, HPKM 37, HPKM 39, HPKM 46, HPKM 64 and HPKM 76. Range of per cent superiority over check for these mutants varies from 82.78-187.50%. In HPK 2, high yielding mutants under 20kR dose are HPKM 103, HPKM 118, whereas in 30kR, these are HPKM 138 and HPKM 145. In case of 30kR, HPKM 141 has the highest 100-seed weight of 4.27 gm. Mutants HPKM 11, 13, 22, 23, 26, 28, 34, 48, 49, 53 and 64 happen to be short statured. HPKM 26 happens to be the most desirable mutant with short statured, early maturing and high yield.

It can be seen that in HPK 4, such desirable mutants are available for seed yield/plant, biological yield/plant, harvest index, pods/plant and days to maturity under different doses. For seed yield, the frequency of desired mutants is higher under 30kR dose, whereas for 100-seed weight, it is higher in 20kR. Most promising mutants for seed yield are HPKM 159, HPKM 165, HPKM 171, HPKM 173 and range of per cent superiority over control varies from 60.19-195.68%. In 30kR, superior mutants for seed yield/plant are HPKM 201, 204, 215, 218, 227, 231, 233 and 244 with range of superiority as 123.00-157.22%. Early maturing mutants are HPKM 157 and HPKM 159 in

10kR; and HPKM 184, HPKM 189 in 20kR. Under 30kR, HPKM 197, 204, 208-209, 211-212, 216-217, 219-226, 233, 235, 247 and 249 are early maturing mutants with range of superiority as 2.54-7.12%. For pod length, primary branches/plant, internode length, plant height and specific leaf weight, superior mutants are available at 20 and 30kR. Two mutants namely HPKM 204 and HPKM 235 were high yielding and early in maturity. Superior mutants has also been isolated in other pulse crops [illegible] Shrivastava, 1974, Sharma, 1979 in pigeonpea; [illegible] 1972, Prasad, 1976, Tickoo and Jain, 1979, Bandopadhyay and Bose, 1982 in mungbeans; Sood 1983, Kalia and Gupta, 1989 in lentil; Kulshrestha and Singh, 1983 in blackgram).

It can be concluded from the above discussion that sufficient genetic variability with respect to different traits has been induced in both HPK 2 and HPK 4 varieties of horsegram which may contribute to yield and maturity. Some of the mutants isolated are early in maturity with good yield. Both HPK 2 and HPK 4 are probably having differential mutability for polygenic traits. It is suggested that for inducing variation for seed yield and related traits low dose (10kR) should be used, whereas for inducing earliness, moderate dose would be more rewarding.

SUMMARY

6. SUMMARY

The present investigation in horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.) was undertaken (i) to understand the nature and magnitude of induced polygenic variation (ii) to understand the relationship of shift in mean and induced genetic variance in relation to diferent doses of gamma-rays and (iii) to isolate mutants with desirable traits.

The material comprised M_3 generation of HPK 2 and HPK 4 varieties of horsegram mutagenised with 10, 20 and 30kR doses of gamma-rays. The M_3 populations of each dose along with checks were raised in a compact family block design with three replications. Each plot consisted of single row of one metre length with row-to-row-spacing of 40cm. The polygenic traits studied were seed yield/plant(g), biological yield/plant(g), harvest index (%), pods/plant, pod length(cm), seeds/pod, 100-seed weight(g), primary branches/plant, internode length(cm), plant height(cm), leaf area(cm^2), specific leaf weight(mg/cm^2), days to flowering, days to maturity and reproductive phase.

Analysis of variance revealed the presence of sufficient polygenic variation among the mutant progenies of HPK 2 for all the traits studied in 10kR dose. However, in 20kR dose, significant differences were observed among the mutant progenies for all the above mentioned traits, except biological yield/plant and specific leaf weight. Mutant progenies were also significant for the traits other than biological

yield/plant, internode length, plant height, leaf area and specific leaf weight in 30kR. Comparison of mutant progenies versus control was significant for seed yield/plant, biological yield/plant and pods/plant in 10kR dose; 100-seed weight and days to flowering in 20kR dose; and biological yield/plant, pods/plant, internode length, plant height and leaf area in 30kR dose.

Analysis of variance revealed the presence of sufficient polygenic variation among the mutant progenies of HPK 4 for seed yield/plant, biological yield/plant, pods/plant, seeds/pod, plant height, leaf area, days to flowering and days to maturity in 10kR dose. In 20kR dose, significant differences were observed for all the traits, except harvest index and pod length. Mutant progenies were also significant for all the traits studied, except pod length, seeds/pod and 100-seed weight. Comparison of mutant progenies versus control was significant for seed yield/plant, harvest index, pods/plant, primary branches/plant and days to maturity in 10kR dose; seeds/pod, leaf area, specific leaf weight, days to flowering and reproductive phase in 20kR dose; and harvest index, pod length, days to flowering and days to maturity in 30kR dose.

Combined analysis of variance for varieties, doses within varieties and progenies within doses within varieties for HPK 2 and HPK 4 revealed significant differences between varieties with respect to seed yield/plant, 100-seed weight and days to flowering. Doses within varieties were significant for all the traits, except for pod length, 100-seed weight, primary branches/plant, internode length, plant height, and days to flowering. The significant differences were observed for progenies within doses within varieties for all the traits studied.

Shift in mean was variety dose-trait specific. Asymmetrical shift in the means in both the varieties was observed for biological yield/plant, seeds/pod, primary branches/plant and internode length. Shift in mean 10kR dose was towards positive side for yield/plant, biological yield/plant, harvest index and pods/plant. In 10kR dose, significant shift in mean for seed yield/plant was mainly due to shift in mean for pods/plant in both the varieties.

In HPK 2, genotypic coefficient of variability (GCV) was high (>20%) for seed yield/plant, pods/plant in 10 and 30kR doses, primary branches in all the doses, and biological yield/plant and specific leaf weight in 10kR dose, moderate (10-20%) for harvest index in 10 and 30kR doses, seeds/pod in 30kR dose, internode length in 10kR dose, plant height in all the doses, and leaf area in 20 and 30kR doses and low (<10%) for other traits in all the doses. In HPK 4, GCV (%) was high for yield/plant, pods/plant in all the three doses, biological yield/plant in 10 and 20kR doses and, primary branches in 20kR dose; moderate for harvest index in 30kR dose, 100-seed weight in 20kR dose, internode length in 20 and 30kR doses, plant height and leaf area in all the doses, specific leaf weight in 20 and 30kR doses, whereas low values were observed for all other traits in all the doses.

In HPK 2, the estimates of heritability (broad sense) on the basis of check mean were high (>60%) for seed yield/plant, days to flowering in 10 and 30kR doses; for biological yield in 10kR dose; for harvest index and pod length in 30kR dose; and for rest of the other traits in all the three doses, except moderate (30-60%) for leaf area in all the doses and for specific leaf weight in 10kR dose. In HPK 4, high heritability was observed for seed yield/plant in 10kR dose, biological yield/plant, seeds/pod, and leaf area in 10 and 20kR doses, harvest index in 30kR dose, 100-seed weight, primary branches/plant and specific leaf weight in 20kR dose, internode length and reproductive phase in 20 and 30kR doses and for other traits in all the doses, except for pod length in 10 and 20kR doses, which had moderate heritability.

In HPK 2, the estimates of genetic advance (GA), using h^2 on mean basis and expressed as percentage of the mutant progenies mean and the check mean was high (>30%) for biological yield/plant in 10kR dose, plant height in 20kR dose, seed yield/plant, 100-seed weight and internode length in 30kR dose and primary branches/plant in all the three doses. However, it was moderate (20-30%) for specific leaf weight in 10kR dose, and for harvest index in 30kR dose. In HPK 4, it was high for seed yield/plant, biological yield/plant in 10kR dose, pods/plant in 10 and 30kR doses, primary branches/plant, specific leaf weight in 20 and 30kR doses, whereas it was moderate for harvest index in 30kR dose, 100-seed weight and internode length in 20kR and plant height and leaf area in 10 and 20kR doses. In HPK 2, high heritability coupled with high genetic advance as per cent of mutant progenies mean and the check mean was observed for seed yield/plant, biological yield/plant in 10kR dose, primary branches/plant in all the three doses, whereas it was moderate for specific leaf weight in 10kR dose. In HPK 4, high heritability coupled with high genetic advance as per cent of mean was observed for seed yield/plant, biological yield/plant in 10kR dose.

Some high yielding and early maturing mutant were induced with gamma-rays in both the varieties. Such desirable mutants were available in HPK 2 for seed yield/plant, biological yield/plant, pods/plant, primary branches/plant, plant height and days to maturity. Superior mutants were also observed for harvest index in 10 and 30kR doses, 100-seed weight in 30kR dose, leaf area in 10kR dose, days to flowering in 10 and 30kR doses and reproductive phase in 10 and 20kR doses. Five mutants, namely HPKM 10, HPKM 26, HPKM 33, HPKM 36 and HPKM 37 were high yielding and early maturing with 5.84-7.60% superiority for earliness over the control. HPKM 1, HPKM 3, HPKM 10, HPKM 22, HPKM 24, HPKM 26, HPKM 28, HPKM 33, HPKM 36, HPKM 37, HPKM 39, HPKM 46, HPKM 64 and HPKM 76 were high yielding mutants.

Percentage range of superiority of these mutants varied from 82.78-189.75% over the control. High yielding mutants in 20kR dose were HPKM 103 and HPKM 118, whereas HPKM 138 and HPKM 141 were induced in 30kR dose gamma-rays. HPKM 11, HPKM 13, HPKM 22-23, HPKM 26, HPKM 28, HPKM 34, HPKM 48-49, HPKM 53 and HPKM 64 were the dwarf mutants with 12.63-26.26% range of per cent superiority over check. HPKM 26 mutant was high yielding, short statured and early maturing.

In case of HPK 4, such desirable mutants were induced for seed yield/plant, biological yield/plant, harvest index, pods/plant and days to maturity under different doses. Most promising mutants for seed yield were HPKM 159, HPKM 165, HPKM 171 and HPKM 173 with 60.19-195.69% range of superiority over control. HPKM 201, HPKM 204, HPKM 215, HPKM 218, HPKM 227, HPKM 231, HPKM 233 and HPKM 244 were the induced mutants for seed yield with 123.00-157.22% range of superiority over the control. Early maturing mutants HPKM 157 and HPKM 159 were isolated in 10kR dose, while HPKM 184 and HPKM 189 were observed in 20kR dose. As far as 30kR dose is concerned, HPKM 197, HPKM 204, HPKM 208-209, HPKM 211-212, HPKM 216-217, HPKM 219, HPKM 226, HPKM 233, HPKM 235, HPKM 247 and HPKM 249 were early maturing mutants with 2.51-7.12% range of superiority. Of these, HPKM 204 and HPKM 233 were high yielding and early maturing mutants.

Sufficient genetic variability was induced in HPK 2 and HPK 4 varieties of horsegram which can be used to improve yield and other desirable traits. Some of the generated mutants possessed desirable traits such as high yield, reduced plant height and early maturing. HPK 2 and HPK 4 exhibited differential mutability for polygenic traits. The results appear to suggest that for inducing variation for seed yield and related traits low dose should be used, whereas for inducing earliness, moderate dose would be more rewarding.

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Annexure

Estimates of means of HPK 2 and HPK 4, and their mutant progenies under different doses for the traits studied

Dose/progeny	Seed yield /plant (g)	Biological yield (g)	Harvest index (%)	Pods/ plant	Pod length (cm)	Seeds/ /pod	100-seed weight (g)	Primary branches /plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf area (mg/cm^2)	Days to flowe-ring	Days to matu-rity	Reprodu-ctive phase
10kR															
HPK 2C	4.82	13.68	35.99	28.08	4.81	5.60	3.92	4.30	2.68	69.17	44.79	3.36	58.00	125.76	67.67
HPKM 1	11.18*	27.93*	39.38	56.27*	4.71	5.27	3.74	5.61	2.61	68.82	47.61	2.84	56.67	119.67	63.00
HPKM 3	12.47*	31.41*	40.14	63.16*	5.03	5.97	3.90	5.52	2.38	75.28	63.11	2.58	58.00	122.00	64.00
HPKM 10	10.20*	26.62*	38.05	72.00*	5.15	5.75	3.80	4.73	1.78*	69.13	52.92	2.56	61.67	118.33*	56.33
HPKM 11	8.19	20.47	40.84	38.81	4.66	5.25	3.45	4.07	2.73	58.41*	36.43	2.85	58.00	131.00	73.00
HPKM 12	5.57	17.74	31.25	33.22	4.84	5.60	3.78	3.50	2.33	69.88	46.83	4.32	57.33	128.00	70.67
HPKM 13	3.56	6.76	52.27*	43.33*	4.50	4.53	3.81	2.70	2.50	51.00*	47.54	5.10	54.33	119.67	65.33
HPKM 14	7.21	20.60	34.41	37.00	5.17	6.10	3.97	4.16	2.43	65.00	44.74	5.17	44.00*	118.33*	74.33
HPKM 16	8.16	22.67*	35.84	40.60	4.95	5.90	3.36	5.00	2.50	70.80	60.60	2.80	52.00	116.67	64.67
HPKM 22	12.28*	28.24*	43.28	59.91*	4.71	5.33	3.18	4.50	2.40	64.58*	70.14*	3.40	43.00*	126.0 0	83.00*
HPKM 23	3.67	12.58	29.07	20.25	4.51	4.93	3.67	2.08	2.75	57.87*	44.94	3.23	57.67	116.33*	58.67
HPKM 24	11.25*	28.84*	39.57	55.05*	4.72	5.13	3.84	3.27	3.08	71.52	49.14	3.84	54.33	124.00	69.67
HPKM 26	11.87*	28.29*	39.80	77.50*	4.84	5.34	3.40	4.26	2.83	60.43*	50.57	3.03	58.00	118.33*	60.66
HPKM 28	8.85	21.34*	48.23*	36.37	4.77	5.70	3.89	3.50	2.71	63.87 *	52.29	2.50	52.00	136.67	82.67*
HPKM 29	5.91	14.56	36.31	30.73	4.58	5.33	3.51	4.80	2.99	74.83	48.94	2.93	57.33	126.33	69.00
HPKM 31	8.34	20.73	42.98	43.51*	5.02	5.72	3.61	4.40	2.59	73.89	61.44	4.34	59.00	119.33	58.66
HPKM 32	4.53	11.58	40.61	21.91	4.68	5.59	3.97	3.13	3.57	72.79	48.62	5.12	62.00	119.67	57.67
HPKM 33	12.97*	28.05*	43.08	91.08*	5.17	5.58	3.97	6.75*	2.50	79.29	52.62	3.35	63.00	116.33*	53.00
HPKM 34	8.17	21.12	38.50	47.33*	4.83	5.91	3.96	4.66	2.86	57.30*	46.51	3.67	62.00	129.67	67.67
HPKM 36	10.65*	27.21*	39.35	53.38*	5.07	5.68	3.86	4.00	2.78	72.62	53.30	3.25	45.00*	118.33*	73.33
HPKM 37	9.16*	30.90*	29.87	48.58*	4.85	5.38	3.18	3.83	2.75	69.00	44.75	3.82	41.00*	116.67*	75.67
HPKM 38	5.69	12.49	47.93*	23.73	4.67	5.17	3.54	2.81	2.51	66.91	54.97	3.13	57.33	124.00	66.67
HPKM 39	13.87*	35.68*	38.90	64.89*	4.80	5.29	3.83	4.94	2.56	68.19	41.27	5.80	55.00	122.00	67.00
HPKM 41	6.39	15.11	37.81	41.46*	4.90	5.44	3.72	3.66	2.76	68.43	49.23	3.23	58.33	118.67	60.30
HPKM 43	6.39	17.55	36.68	34.63	5.32	5.26	3.87	8.78*	2.43	67.61	41.35	2.71	60.67	116.33*	59.00
HPKM 45	6.33	19.43	31.66	35.62	4.95	5.61	3.90	3.64	2.58	77.72	62.50	4.30	57.33	128.33	71.00
HPKM 46	9.12*	22.65*	40.12	37.18	4.89	5.32	3.72	3.80	2.71	67.85	61.89	3.54	56.67	118.67	62.00
HPKM 48	7.81	17.59	44.83	82.73	4.75	5.40	3.56	3.60	2.52	54.13*	52.17	7.36*	61.33	127.67	66.33
HPKM 49	7.97	20.72	38.69	44.50*	4.77	5.27	3.66	3.33	3.00	63.75*	52.11	2.91	64.33	123.33	59.00
HPKM 51	5.29	16.76	31.81	24.89	4.75	5.16	3.76	3.15	3.40	67.17	65.02*	2.88	64.33	115.33	51.00

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Dose/progeny		Seed yield /plant (g)	Biological yield (g)	Harvest index (%)	Pods/ plant	Pod length (cm)	Seeds/ /pod	100-seed weight (g)	Primary branches /plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf area (mg/cm^2)	Days to flower-ing	Days to matu-rity	Reproductive phase (days)
HPKM	53	4.76	13.64	35.29	33.08	4.76	5.43	3.65	4.03	2.18*	53.82*	40.86	3.82	55.00	116.33	61.33
HPKM	55	5.86	18.34	31.37	39.00	4.67	5.58	3.52	4.82	2.50	69.79	42.48	3.16	56.67	119.67	63.00
HPKM	64	12.74*	30.53*	41.68	75.89*	4.91	5.06	3.05	4.33	2.46	58.90*	60.45	3.64	55.67	118.67	63.00
HPKM	76	8.81*	21.39	40.83	36.51	4.88	5.48	3.42	2.53	2.94	79.65	64.62*	3.28	60.67	135.00	74.33
HPKM	81	5.04	15.83	32.06	35.80	4.69	5.40	3.50	3.33	2.66	69.83	49.80	3.43	63.00	123.00	59.00
HPKM	82	5.48	19.70	27.85	27.03	4.50	4.96	3.46	3.53	2.81	66.25	51.20	3.38	59.67	126.00	66.33
CD at P= P=0.05		3.92	7.60	10.18	13.09	0.46	0.58	0.58	2.34	0.48	4.38	18.46	2.22	9.10	7.64	13.58
20kR																
HPK 2C		4.89	14.56	33.65	28.08	4.81	5.54	3.92	4.30	2.66	69.17	49.09	3.36	60.33	116.66	54.33
HPKM	83	6.73	18.17	36.40	30.47	4.89	4.90	4.20	4.40	2.72	66.07	56.80	3.40	61.33	117.66	56.33
HPKM	85	4.84	12.31	40.21	34.38	4.92	5.20	3.75	3.86	2.84	58.21	46.14	2.63	62.66	121.00	58.33
HPKM	86	6.68	19.02	36.01	42.13*	4.90	5.74	3.65	4.00	2.63	76.50	57.40	3.40	62.33	121.33	65.00*
HPKM	88	7.41	17.65	40.35	35.12	5.06	5.24	3.66	5.21	3.17	63.47	47.52	3.33	62.00	118.66	56.66
HPKM	89	4.31	12.52	34.16	25.00	4.17	4.65	3.67	3.45	2.78	54.16*	52.96	3.51	61.33	117.33	56.00
HPKM	91	6.87	19.27	35.25	34.03	4.77	5.38	3.48	4.58	2.73	64.93	46.85	3.92	62.66	116.00	53.33
HPKM	93	3.85	13.84	26.43	27.00	4.98	5.63	3.53	3.83	2.58*	63.58	31.61	3.01	65.66	120.66	55.00
HPKM	97	6.35	16.58	39.88	47.20	5.08	5.37	3.56	3.78	2.23	78.84	52.84	3.80	63.00	110.33*	47.33
HPKM	99	4.72	13.45	35.40	26.24	4.83	5.24	3.27	3.40	2.72	65.62	56.42	3.84	63.66	116.00	52.33
HPKM	102	4.82	12.90	36.69	28.03	4.75	4.85	3.52	4.44	2.63	59.83	33.66	5.71*	61.00	119.00	58.00
HPKM	103	8.09*	22.04*	36.34	46.06*	5.03	5.74	3.99	4.40	2.65	85.93	43.07	3.15	63.33	109.66*	46.33
HPKM	104	7.64	18.61	41.35	40.70*	4.77	5.24	3.82	4.61	2.66	93.76	49.94	3.77	63.66	115.66	52.00
HPKM	105	3.88	10.69	36.14	26.37	5.08	5.03	3.37	3.49	2.36	55.87*	42.03	3.93	64.66	108.66	34.41
HPKM	106	5.81	13.76	41.82	26.53	4.58	5.53	3.76	3.26	2.80	75.86	51.63	4.21	64.00	110.00*	46.00
HPKM	107	6.00	16.25	36.85	29.13	4.56	5.41	3.54	3.00	3.06	74.53	46.85	3.49	64.00	119.00	55.00
HPKM	108	6.83	19.34	34.75	41.25	4.39	5.20	3.74	4.23	2.64	67.43	59.39	4.06	62.00	116.66	54.66
HPKM	109	4.26	13.27	31.93	26.29	4.65	5.27	3.62	3.55	2.59	67.72	47.45	2.78	65.00	123.00	58.00
HPKM	112	4.64	14.15	32.78	15.75	4.59	5.33	3.82	3.96	2.64	46.01*	44.36	2.84	63.66	114.66	51.00
HPKM	116	3.87	10.45	31.16	31.53	3.42	4.08	3.50	4.46	3.30	34.41*	32.05	3.80	63.00	128.00	65.00*
HPKM	118	8.60*	19.59	44.13*	50.24*	5.05	5.73	4.19	5.17	2.72	92.00	31.43	3.10	60.66	125.00	66.66*
HPKM	119	3.53	13.44	26.93	24.33	4.89	4.86	3.75	4.34	2.73	71.00	43.96	4.12*	63.66	115.00	51.33
HPKM	120	6.86	18.83	35.17	32.66	4.77	5.57	4.18	3.61	2.66	64.20	40.03	5.27	63.66	113.33	49.66

Contd...

Dose/progeny		Seed yield /plant (g)	Biological yield (g)	Harvest index (%)	Pods/ plant	Pod length (cm)	Seeds/ /pod	100-seed weight (g)	Primary branches /plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf area (mg/cm^2)	Days to flower-ing	Days to matu-rity	Reprodu-ctive phase (days)
HPKM	121	5.59	15.78	42.10	43.05*	4.63	5.33	3.49	6.00*	2.58	59.91	48.35	3.88	62.66	111.66*	49.00
HPKM	122	6.75	19.27	34.31	51.11*	4.72	5.25	3.63	5.85*	4.00	74.08	40.39	3.51	61.66	113.66	52.00
HPKM	123	6.89	18.38	38.28	35.50	4.46	4.97	3.67	4.81	2.70	69.46	50.54	3.90	61.66	115.33	53.33
HPKM	124	3.78	13.06	27.64	23.31	4.75	5.08	3.74	3.45	2.64	72.49	50.93	4.33	61.33	114.00	52.66
HPKM	125	4.85	13.83	35.33	22.53	4.52	5.24	3.30	2.86	2.66	67.73	49.81	3.66	64.00	118.00	54.00
HPKM	126	6.34	14.66	43.65	23.73	4.73	5.17	3.66	3.26	2.66	66.63	48.35	4.52	65.00	112.66	47.66
HPKM	129	3.91	13.23	28.74	14.00	4.80	5.75	3.75	1.50	2.50	65.50	26.74	2.61	64.33	111.66*	50.33
HPKM	130	4.34	11.29	38.60	22.83	4.62	4.93	3.53	3.20	2.50	39.16*	40.23	2.65	62.33	122.00	59.66
HPKM	135	4.71	13.88	33.96	30.10	4.78	5.22	3.60	3.36	2.32*	80.15	51.94	2.87	64.00	110.66*	46.33
CD at P=0.05		3.08	7.18	10.32	10.16	0.60	0.62	0.32	1.08	0.32	12.12	11.39	1.86	2.87	4.94	5.62
30kR																
HPK 2C		4.46	11.06	40.49	24.33	4.65	5.41	3.84	3.93	2.83	81.26	54.80	2.80	61.66	119.00	57.33
HPKM	135	4.24	13.17	32.34	29.43	4.91	5.42	3.54	3.60	2.26	76.73	52.01	2.92	62.66	114.00*	51.33
HPKM	138	8.13*	18.92	44.48	45.28*	5.03	5.30	3.41	3.90	2.62	73.37	55.35	2.84	57.64	112.33*	54.33*
HPKM	140	4.29	14.78	28.67	32.33	4.56	5.10	3.53	4.16	2.75	57.02*	39.98	2.99	63.66	118.66	55.00
HPKM	141	8.26*	20.40*	39.17	52.83*	4.85	5.63	4.27*	5.50	2.50	70.99	38.36	2.83	64.66	118.33	53.66
HPKM	143	3.43	12.60	26.92	64.00*	4.28	4.30	3.60	2.50	2.40*	54.66*	32.13	3.49	67.00	116.66	48.33
HPKM	144	4.66	12.42	38.36	29.16	4.46	5.66	3.41	4.20	2.61	77.11	36.17	2.87	62.00	120.33	60.11
HPKM	151	4.03	10.80	35.89	23.31	4.21	5.21	3.79	3.14	2.46	58.66*	39.56	3.38	66.33	120.00	55.67
HPKM	153	3.70	12.53	28.81	32.33	4.11	4.20	3.50	2.70	2.33*	48.53*	36.40	2.61	62.00	120.00	58.00
CD at P=0.05		2.03	8.02	10.09	9.63	0.46	0.61	0.44	1.65	0.38	11.82	16.26	0.74	2.86	3.76	4.17
						HPK 4										
10kR																
HPK 4C		4.17	13.73	30.94	25.26	4.23	4.94	2.97	3.40	3.29	66.03	47.24	3.16	64.66	128.33	63.67
HPKM	157	5.83	17.52	35.64	47.46*	4.42	4.83	3.22	4.18	2.99	69.46	48.02	2.92	66.33	122.66*	56.33
HPKM	158	3.38	10.39	34.91	24.50	4.25	4.45	3.04	3.16	2.64	66.75	31.94	3.44	67.33	126.66	59.33
HPKM	159	6.68*	17.20	38.66	50.64*	4.32	4.97	3.05	4.29	2.88	49.99	36.15	3.18	57.66*	124.00	66.34

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Dose/progeny		Seed yield /plant (g)	Biological yield (g)	Harvest index (%)	Pods/ plant	Pod length (cm)	Seeds/ /pod	100-seed weight (g)	Primary branches /plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf area (mg/cm^2)	Days to flower-	Days to matu- rity	Reproductive phase (days)
HPKM	161	5.51	13.23	41.84*	34.00	3.51	3.66	3.10	4.00	2.75	57.79	39.10	3.38	65.33	125.00	59.66
HPKM	165	12.33*	32.89*	39.2[illegible]*	83.41*	4.51	5.21	3.28	5.16	3.04	81.16	45.35	3.82	66.00	126.66	60.66
HPKM	166	5.06	12.70	40.44*	23.66	4.36	4.86	3.21	4.00	2.50	52.58	29.62	3.58	66.33	126.00	59.67
HPKM	168	2.35	6.57	36.05	18.89	4.03	4.49	2.90	2.66	2.66	52.57	40.35	4.64*	57.66	125.00	57.34
HPKM	171	8.64*	20.21*	43.80*	56.93*	4.49	4.84	3.39	4.43	2.64	70.33	39.26	2.89	68.00	126.33	58.33
HPKM	173	7.56*	22.10*	34.04	53.94*	4.75	5.78*	3.22	4.83	3.72	73.29	52.19	2.77	66.33	130.66	64.33
HPKM	174	5.56	14.65	37.85	40.66	4.46	4.91	3.39	5.00	2.86	48,15	45.33	3.70	67.33	128.66	61.33
HPKM	176	4.96	12.95	38.69	41.94	4.43	4.85	2.73	4.00	3.02	53.92	35.36	3.51	69.33	128.00	56.66
HPKM																
CD at P=0.05		2.17	6.45	8.25	21.44	0.68	0.78	0.43	2.54	1.13	19.49	11.68	1.20	5.28	3.87	5.39
20kR																
HPK 4C		3.02	11.65	25.80	27.00	4.18	4.40	2.99	2.87	3.39	67.33	53.73	2.56	67.33	128.66	61.33
HPKM	181	4.30	17.39	23.96	35.50	4.52*	5.05*	3.22	3.87	3.47	62.37	36.17	3.45	72.00	130.66	58.66
HPKM	182	2.41	7.79	26.75	18.50	4.26	4.76	3.17	2.32	2.66*	48.33*	33.40	3.33	69.00	128.00	59.00
HPKM	183	2.38	9.82	24.31	20.50	4.25	4.70	2.56	5.03*	3.05	53.45*	37.66	5.65*	71.33	126.66	55.33
HPKM	184	5.15	15.67	32.87	39.50*	4.62*	5.03*	3.05	4.32	2.64*	66.17	55.64	3.59*	68.66	120.00*	51.33
HPKM	185	3.47	11.68	29.74	29.75	4.58*	4.52	3.50*	3.25	3.00	58.81	49.87	4.42*	66.00	128.66	62.66
HPKM	186	7.75*	23.17*	31.42	43.37*	4.63*	4.93*	2.87	4.06	3.43	67.50	40.79	2.70	74.33	130.00	55.66
HPKM	187	5.38	15.34	34.79*	36.16	4.36	4.52	3.26	3.50	2.73*	75.75	39.00	3.77*	72.66	128.00	55.33
HPKM	188	5.13	15.48	33.35	26.47	4.36	4.87*	2.32	4.62*	3.78	73.12	44.64	4.75*	73.66	130.00	56.33
HPKM	189	4.94	18.49*	26.29	25.36	4.35	4.40	3.55*	4.25	2.45*	52.35*	41.88	3.27	71.66	124.66*	53.00
CD at P=0.05		3.17	6.51	8.61	12.45	0.27	0.46	0.39	1.47	0.57	10.52	6.36	1.03	3.82	3.30	3.49
30kR																
HPK 4C		3.39	13.72	26.86	26.26	3.80	4.93	2.97	3.40	3.28	66.02	47.24	3.06	66.33	131.00	64.67
HPKM	192	4.05	17.05	23.64	28.83	4.40*	4.85	2.96	5.58*	3.95	56.00	43.27	3.97	70.00	129.33	59.33
HPKM	195	3.52	12.06	29.37	33.10	4.43*	4.80	2.84	3.25	3.29	49.32*	36.62	4.74	73.33	129.66	56.33
HPKM	196	3.29	10.46	32.22	27.91	4.44*	4.52	3.58*	3.50	3.79	44.78*	39.97	4.48	73.66	128.00	54.33
HPKM	197	3.92	11.93	32.55	29.55	4.32	4.80	3.18	3.76	3.33	70.38	63.53*	4.51	72.00	127.66	55.66
HPKM	198	4.98	14.72	33.88	43.00	4.33	4.95	2.96	4.16	3.16	57.50	37.43	6.81*	70.33	129.00	58.66

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Dose/progeny	Seed yield /plant (g)	Biological yield (g)	Harvest index (%)	Pods/ plant	Pod length (cm)	Seeds/ /pod	100-seed weight (g)	Primary branches /plant	Internode length (cm)	Plant height (cm)	Leaf area (cm^2)	Specific leaf area (mg/cm^2)	Days to flower-ring	Days to matu-rity	Reproductive phase (days)
HPKM 200	3.04	8.79	35.75	21.61	4.55*	5.25	2.69	2.39	3.44	45.73*	34.46	3.08	67.33	128.33	60.00
HPKM 201	7.56*	21.15	34.24	55.38*	4.54 *	5.19	3.12	4.55	2.79	72.11	45.58	4.75	73.66	130.00	56.33
HPKM 202	2.83	9.01	[illegible]9.66	36.46	4.23	4.83	3.44	4.50	2.33*	50.36*	48.23	8.31*	72.00	128.33	56.33
HPKM 203	5.02	17.12	31.25	36.66	4.53*	5.22	2.81	3.21	2.76	61.18	39.70	3.30	73.33	128.00	54.66
HFKM 204	8.72 *	24.33*	34.95	62.66*	4.58*	5.03	3.10	4.83	3.45	65.91	25.35	3.65	67.33	125.66*	58.33
HPKM 207	4.06	16.16	25.18	42.16	4.58*	4.25	2.82	3.50	2.61*	56.75	33.46	3.87	71.33	128.66	57.33
HPKM 208	4.11	13.82	29.21	34.25	4.40	4.75	3.00	3.81	3.03	54.00*	40.85	4.73	74.00	126.66*	52.66
HPKM 209	4.82	13.34	37.52*	44.00	4.02	4.56	2.93	3.60	2.73	68.01	38.10	4.35	64.00	124.66*	60.66
HPKM 211	4.49	13.35	33.96	29.16	4.61*	4.82	3.31	4.06	3.06	70.17	44.44	3.53	73.00	125.00*	52.00
HPKM 212	4.96	14.46	25.53	36.16	4.52*	5.13	3.07	4.23	3.42	61.05	43.73	5.79*	75.00	126.66*	51.66
HPK 213	3.16	11.18	28.29	20.90	4.28	4.88	3.49	3.16	3.10	62.70	45.82	3.38	74.33	127.33	56.33
HPKM 215	8.01*	20.77	39.73*	47.00*	4.58*	5.22	3.10	3.80	2.56*	71.86	36.22	7.88*	74.00	127.33*	53.33
HPKM 216	3.17	11.65	28.17	40.51	4.42*	4.92	3.07	3.71	2.46*	64.70	50.67	5.70*	68.00	122.00*	54.00
HPKM 217	4.79	12.38	42.36*	39.16	4.54*	5.21	2.94	2.83	2.60	68.71	43.81	4.19	71.66	124.66*	53.00
HPKM 218	8.22*	20.94	36.12	60.05*	4.60*	5.03	3.22	5.47*	3.17	73.47	42.96	4.83	72.33	128.66	56.33
HPKM 219	3.98	10.41	38.66*	19.66	4.35*	4.63	3.48	2.83	3.31	54.65*	31.75	5.93*	67.33	126.33*	59.00
HPKM 220	4.79	14.97	32.81	17.66	4.40*	4.63	3.17	3.00	2.33*	55.86	36.00	5.17	68.00	127.66	59.66
HPKM 226	7.39	18.65	40.62*	41.96	4.56*	4.93	3.19	3.04	3.21	62.25	48.07	5.47*	68.00	123.66*	55.66
HPKM 227	8.43*	23.70*	33.80	73.36*	4.45*	5.06	2.74	5.15*	3.16	72.68	50.17	5.09	69.33	129.00	59.66
HPKM 231	8.18*	21.38	37.02*	40.21*	4.55*	5.19	3.43	4.28	3.75	70.52	47.96	5.15	73.00	130.00	57.00
HPKM 232	4.36	13.55	32.24	23.46	4.47*	4.83	3.15	3.33	3.00	69.54	45.36	2.87	74.66	127.66	53.00
HPKM 233	7.58*	16.95	43.24*	43.50	4.38*	5.04	3.19	3.81	2.87	64.74	41.80	5.26	74.66	126.66*	52.00
HPKM 235	4.34	13.77	30.29	34.86	4.71*	5.00	2.60	3.80	3.15	58.13	29.95	4.07	66.00	126.00*	60.00
HPKM 241	4.05	14.51	32.04	43.61	4.36*	4.44	2.92	3.33	3.44	45.11*	42.91	4.14	74.00	130.33	59.66
HPKM 244	7.65*	23.27	32.11	56.33*	4.20	4.73	3.06	4.06	3.21	69.23	44.69	3.70	73.00	129.66	56.66
HPKM 245	[illegible]	11.96	41.28*	40.51	4.46*	4.32	2.92	2.66	3.62	63.83	38.58	3.48	70.00	130.00	60.00
HPKM 247	[illegible]	13.01	35.00	43.55	4.26	4.65	3.00	3.73	2.97	64.61	41.17	2.72	72.33	123.00*	54.00*
HPKM 249	[illegible]	6.37	45.13*	19.00	4.50*	5.08	3.09	2.63	3.26	53.64	32.35	3.82	67.00	121.66*	54.66
HPKM 253	[illegible]	6.73	46.24*	19.66	3.99	4.12	2.76	3.72	3.40	47.33*	30.66	3.58	74.00	127.33	53.33
HPKM 256	[illegible]	10.54	30.23	22.33	4.34*	4.93	2.90	2.83	3.05	57.25	42.11	3.93	70.00	129.66	59.66
HPKM 257	[illegible]	15.73	25.83	38.21	4.40	4.80	2.84	2.63	3.12	67.50	46.63	3.44	73.00	130.00	57.00
CD at P=0.05	[illegible]	10.16	9.36	20.38	0.56	0.76	0.56	1.48	0.58	15.16	14.04	2.32	4.72	3.95	4.32

*Significantly superior over the control