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Induced Morphological and Quantitative Mutations in Mungbean

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ABSTRACT

Pulses occupy an important position in world agriculture because of their high protein content, several essential amino acids and their capacity for fixing atmospheric nitrogen. Mungbean (*Vigna radiata* (L.) Wilczek) is one of the most important pulse crops due to its nutritive value and property of maintaining and restoring soil fertility through biological nitrogen fixation. Genetic variability is one of the prerequisites for crop improvement. Lack of required amount of variability, limits the scope for the selection of better genotypes in mungbean. Artificially induced mutations are the best way to enlarge genetic variability considerably within a short time. Frequency of the natural mutation is very low and hence artificial mutations are induced and genetic variability is best enhanced with the application of mutagens. Based on above fact, the development of high yielding varieties in mungbean is possible by the exploitation of larger range of genetic variability. Mungbean have been traditionally grown in marginal land of lower productivity with the application of little inputs. The selection pressure in case of these crops has been concerned more with adaptation to stress conditions than for yield. Therefore the genetic improvement of such crops, for higher yield requires their genetic reconstitution to evolve different plant types. Induced mutations can help to regenerate and restore the variability, which has been lost in the process of adaptation to various stresses or adaptations during the course of evolution. Thus mutation breeding or induced mutation is having great potential for the improvement of traditional agricultural crops like mungbean.

Keywords: induced quantitative characters, mungbean, morphological mutations, mutagenesis
Abbreviations: Chl, chlorophyll; **EMS**, ethyl methane sulphonate; **Gy**, Gyran; **kR**, kilorad; **M**, molar; **SA**, sodium azide

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INTRODUCTION

Pulses being rich in quality protein, minerals and vitamins are inseparable ingredient of the diet of majority of Indian population (Siag *et al.* 2005). Pulses also occupy an important position in world agriculture because of their high protein content, several essential amino acids and their capacity for fixing atmospheric nitrogen.

Mungbean (*Vigna radiata* (L.) Wilczek), also known as green gram and mung, is one of the most important pulse crops of India. Mungbean seeds are an excellent source of easily digestible protein of low flatulence. Sprouted seeds of mungbean synthesize ascorbic acid (vitamin C), and show increased levels of riboflavin and thiamine during germination. In addition to its nutritive value, it also has a unique property of maintaining and restoring soil fertility through biological nitrogen fixation (Stevenson and Van Kessel 1996).

There are several reasons for the low productivity of mungbean (Singh 2009). Important among them are; lack of high yielding genotypes, seed replacement rate of improved / high yielding varieties, vagaries of monsoon, sowing on marginal land under rain fed situation, negligence of plant protection and imbalance use of plant nutrient. The poor yield of the existing local varieties of mungbean is also related to their evolutionary history. Most of these varieties

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have been selected for a low level of management and for cultivation under stress conditions. Under such conditions, natural selection has played a greater role and genotypes, which will respond to inputs like chemical fertilizers and irrigation, have been gradually lost. The genetic variability in most of the pulse including mungbean has been greatly reduced over the years, because of the role of natural selection under a low level of management. Mungbean being autonomous crop the naturally existing genetic variability may not be sufficient to achieve the desired improvement.

Genetic variability is one of the prerequisites for crop improvement. As a consequence, lack of required amount of variability, limits the scope for the selection of better genotypes. Artificially induced mutations are the best way to enlarge genetic variability, considerably within a short time (Patil *et al.* 2003; Singh and Singh 2003). Frequency of the natural mutation is very low and hence artificial mutations are induced and genetic variability is best enhanced with the application of mutagens. It is essential to regenerate or restore the lost genetic variability of different varieties from different part of the world through different techniques like induced mutagenesis.

WHY MUTATIONAL STUDIES IN MUNGBEAN?

Success of any breeding programme depends on the presence of significant genetic variability, which permits effective selection. In last few years induced mutations have been used as an important supplementary tool, to other conventional methods of plant breeding for improvement of crops by developing new plant types. In recent years mutation breeding has been gaining ground for inducing genetic resources (Datta *et al*. 1993). Micke *et al.* (1990) used induced mutations for obtaining desirable genetic changes like high yield, flower color, disease resistance, and early maturity in various crop, fruit and ornamental plants. Induced mutations contributed significantly to plant improvement programs, even though most of the induced mutations are recessive and deleterious from the breeding point of view (Maluszynski *et al*. 1995). Mungbean is an important pulse crop of semi arid and sub-tropics and information on mutagenesis induced population is scanty (Singh Awnindra 2009).

Several scientists have reported the use of mutagenesis for creating genetic variability in quantitative and qualitative characters and develop new desired correlation between the quantitative as well as qualitative traits. Clayton and Robertson (1964), Yamada and Kitagawa (1961), Kitagawa (1967), Kharakwal (2004), Khan *et al.* (2004) and Lal and Mishra (2006) have reported the use of induced genetic variability for the development of new plant types or artificial traits. The major goal of mungbean improvement in India is the development of widely adapted high yielding, disease resistant varieties responsive to improved cultural practices and possessing tolerance to adverse climatic conditions in locally adapted varieties.

In mungbean, mutation breeding is useful to recover the characters or defected traits, which are agronomically desirable (Kharakwal 2004). For example high yielding varieties or desirable varieties having some inherited undesirable characters such as high flower drop, instability in performance or undesirable green color or late maturity can be improved by using mutagenesis. Pulse crops including mungbean are very poor in partitioning the photosynthates from their vegetative parts to grains. A lot of dry matter goes for production of stalk, so the harvest index is very low. In such plants morphological frame of the plant must be reconstituted in such a way that the maximum dry matter produced by plant is more efficiently partitioned between grains and the vegetative parts. Employing the technique of induced mutations, it is possible to recover such type of plant framework or plant habit. Indeterminate growth habit in mungbean results in non-synchrony in maturity. Due to this quality, either picking of pods is required, which increases the cost of cultivation or certain percentage of pods remain immature at the time of harvesting. This is a serious problem in most of the *kharif* (crops cultivated in the monsoon season) pulse crops. Flower drop is another physiological problem in mungbean. This results in poor pod setting and consequently low yield. By using this technique, it is possible to develop new plant types with superior biochemical constitution and suitable physio-agronomic adaptation, which will help in controlling the above defects to some extent.

Mungbean or other pulses have been traditionally grown in marginal land of lower productivity with the application of little inputs. The selection pressure in case of these crops has been concerned more with adaptation to stress conditions than for yield. Therefore the genetic improvement of such crops, for higher yield requires their genetic reconstitution to evolve different plant types. Induced mutations can help to regenerate and restore the variability, which has been lost in the process of adaptation to various stresses or adaptations during the course of evolution. Thus mutation breeding or induced mutation is having great potential for the improvement of traditional agricultural crops like mungbean.

INDUCED MUTATIONS IN MUNGBEAN

The view is often expressed that genetic variability in mungbean is limited and that breeding efforts would be enhanced if the range of variability could be broadened. This view has led to mutation research directed towards the finding of mutagenic agents efficient on mungbean and producing variant mutant forms that may be used in breeding programs. In recent years, the field of mungbean research has proliferated particularly in India, Bangladesh, Pakistan, Burma, Thailand, Philippines, China, and Indonesia as well as in East and central Africa, West Indies, USA and Australia. During the past two decades, several attempts have been made to boost up the yield of mungbean. Comparison of mungbean mutant lines with the standard varieties (KPS 1 and CN36) was conducted at various locations in Thailand, during 1998 and 1999. In 1998, on the basis of good agronomic performance, 12 selected mutant lines were planted in 10 experimental plots at 7 locations (Wongpiyasatid *et al.* 2000). The use of chemical and physical mutagens for the induction of various types of mutations in mungbean has been reported by various scientists (**Table 1**).

Mutation breeding has been proved to be one of the important techniques to develop and release new genotypes and high yielding cultivars in mungbean. Mutation breeding is a type of conventional breeding technique useful for creation of desirable variability in crop and could be a driving force for evolution besides selection in mungbean (Priya Tah 2009) Acceleration of the frequency of mutation in mungbean has been accomplished by exposure of seeds of mutagenic agents such as ionizing radiations or chemical mutagens. Significant induced morphological, quantitative and genetic variability among various mungbean genotypes for various traits like leaf, flower, growth, height, pod number, seeds per pod and yield per plant have been reported by Sahu Patra (1997), Khan *et al.* (2004) and Lal and Mishra (2006) by following chemical and physical mutagenesis.

Khan and Goyal (2009) induced morphologically stable early mutants employing ethyl methane sulphonate (EMS), sodium azide (SA) and gamma rays and were evaluated up to M_5 generation and compared with parental lines. They also recorded high heritability coupled with high genetic advance for days to maturity indicated that genetic progress to be expected from the selection. Several researchers have induced viable mutations in mungbean employing physical and chemical mutagens in mungbean. Sangsiri *et al*. (2005) treated F_1 and F_2 generation seeds of mungbean varieties 'KPS2', 'VC 6468-11-1B', with gamma rays at the dose of 500 Gy. The mutants found were mainly of leaf chlorophyll (Chl) mutations, flower mutations and pod mutations. Chl mutations included *albina* coppery leaf, light-green leaf, variegated leaf, waxy leaf, white streak leaf, and *xantha* leaf.

Table 1 Use of chemical and physical mutagen for the induction of various types of mutations in mungbean.

Reference	Mutagen and doses used	Mutations
Chaturvedi and Singh 1980	EMS and NMU (0.1, 02, 0.3, 0.4%)	Synchronous mutant
Guhardja *et al*. 1980	Gamma radiation (45-72 kR)	Diseases resistance
Bhal and Gupta 1982	Gamma radiation and EMS (20, 30, 40, 50 kR; 0.2, 0.4% EMS; combined 0.2% EMS + 20, 30, 40, 50 kR)	Chlorophyll mutations
Singh and Chaturvedi 1982	EMS and HA (0.2, 0.3 and 0.4%)	Genetic variability in quantitatively characters
Bhal and Gupta 1983, 1984	Gamma radiation and EMS (20, 30, 40, 50 kR; 0.2 and 0.4%)	Early maturing and high yield mutants
Khan 1981, 1982, 1983, 1984	Gamma rays, EMS and hydrazine hydrate (15, 30, 40 kR; 0.3% EMS and 0.04% HZ)	Morphological mutations
Khalil *et al*. 1987	Gamma rays (10, 20, 30, 40, 50, 60, 70, 80 kR)	Late flowering mutant
Satayanarayana *et al*. 1989	Gamma radiation (40 kR)	Multifoliate mutant
Khan and Siddiqui 1993	EMS.MMS and SA (0.1, 0.2, 0.3, 0.4% EMS; 0.01, 0.02, 0.03, 0.04% MMS and SA)	Chlorophyll mutations
Khan *et al*. 1995	Diethyl sulphate (0.02, 0.04, 0.06%)	Plant type mutants
Kharkwal 1996	Gamma rays, EMS (10 kR, 0.1, 0.2%)	Disease resistant mutant (Pant Moog-2, BM-4, MUM-2, TARM-1, TARM-2, and TARM-18)
Sarkar *et al*. 1996	Gamma rays (10, 20, 30, 40 kR)	Plant type mutant
Wongpiyasatid *et al*. 1998	500 Gy gamma rays	Disease resistant mutant
Kharkwal 2000	Gamma rays, EMS and NMU (45, 50, 60 kR, 0.1-0.2% EMS 0.01, 0.02% NMU)	Plant type mutant
Srinives *et al*. 2000	Gamma rays (10, 20, 30, 40 kR)	Qualitative and quantitative traits
Wongpiyasatid *et al*. 2000	Gamma rays and EMS (500 Gy, 1% EMS)	Qualitative and quantitative traits
Yaqoob and Rashid 2001	Gamma radiation (10, 20, 30, 40 kR)	Early maturing mutants
Sarwar and Ahmed 2003	Gamma radiation (100-400 Gy)	High yielding mutant
Khan *et al*. 2004	0.01, 0.02% Sodium azide	Genetic variability in quantitative traits
Sangsiri ets al. 2005	Gamma rays (500 Gy)	Leaf, flower and pod mutants
Wani *et al*. 2005	EMS (0.1, 0.2, 0.3%)	Genetic variability in quantitative traits
Priya Tah 2006	Gamma rays (10, 20, 30, 40 kR)	Morphological mutants
Khan and Wani 2006	EMS (0.1, 0.2, 0.3%) and HZ (0.01, 0.2, 0.03%)	Genetic variability in quantitative traits
Auti *et al*. 2007	Gamma rays and EMS (0.01, 0.02, 0.03, 0.04 M; 30, 40, 50 kR)	Chlorophyll mutants
Singh Awnindra 2009	Gamma rays, EMS and combination (10-40 kR, 0.01-0.04 M)	Genetic variability in quantitative traits
Singh Awnindra and Kumar 2009	Gamma rays, EMS and combination (10-40 kR, 0.01-0.04 M)	Yield contributing characters
Kumar *et al*. 2009	Gamma radiation and EMS and in combination (10-60 kR and 0.1-0.4%)	Induced chlorophyll and morphological mutations, synchronous maturity mutants
Priya Tah 2009	Gamma rays (10, 20, 30, 40 Gy)	Synchrony in the maturity of mungbean
Khan and Goyal 2009	Gamma rays (20, 40 kR) and EMS (1.0, 2.0%)	Genetic variability in quantitative traits
Auti and Apparo 2009	Gamma rays (10, 20, 30, 40 kR) and EMS (0.1, 0.2, 0.3, 0.4 M)	Morphological and chlorophyll mutants
Ngampongsai *et al*. 2009	Gamma rays (500, 600 Gy) and EMS (1%)	Yield improvement and powdery mildew resistant
Reddy *et al*. 2009	Gamma rays (600 Gy)	Development of yellow mosaic resistant lines
Prakash and Ram2009	EMS (0.1, 0.2, 0.3, 0.4, 0.5%) and HA (1.0, 2.0, 0.3, 0.4 mM)	Genetic variability in quantitative traits
Dhole and Reddy 2010	Gamma rays (450 Gy)	Root mutant
Kozgar *et al*. 2011	EMS (0.1, 0.2, 0.3, 0.4%)	Yield and yield contributing characters
Lavanya *et al*. 2011	SA (0.01, 0.02, 0.03, 0.04, 0.05 M)	Genetic variability in quantitative traits

EMS, ethyl methane sulphonate; Gy, Gyran; HA, hydroxylamine; kR, kilorad; NMU, nitromethyl uethane; HZ, hydrazine

Leaf mutations were lanceolate leaflet, narrow leaflet, multiple leaflet, round-cuneate leaflet, unifoliate leaf and wrinkled leaf. Flower mutation gave looks like cock's comb with pollen sterility. Similar mutants were also reported by Santos (1969) and Lamseejan *et al.* (1983). A lobed pod mutation with fewer seeds per pod was also recorded. This trait may associate with partial sterility, causing constriction at the point where there was undeveloped seed. All mutants were purified for genetic study and possible uses of the traits.

CHLOROPHYLL MUTATIONS

Chl mutations serve as an index for evaluating the efficiency and effectiveness of mutagens and its effective concentration so as to use them in mutation breeding. The frequency of Chl mutations is considered as a dependable index for evaluating the efficiency and effectiveness of the mutagens and their effective concentration, so as to use them in mutation breeding (Gustafsson 1951; Monti 1968). The Chl mutations are widely used as genetic markers in basic and applied research (Reddy *et al.* 1994). In physiological and biochemical research, these are used in studies involving the effect of specific gene products during differentiation (Robbelen 1968). Chl mutations are used as markers in genetic studies and in physiological and biochemical research (Stadler 1928a, 1930b).

A high proportion of Chl mutations were reported in mungbean by Khan and Siddiqui (1993) using EMS, MMS and SA (0.1, 0.2, 0.3 and 0.4%) obtained *albina*, *chlorina* and *viridis* type of chlorophyll mutations in 'PS-16' and 'Baisakhi' varieties of mungbean. EMS (0.3%) produced highest frequency of chlorophyll mutations followed by methyl methane sulphonate (MMS) and SA. Dahiya (1973) by employing a dose of 70 kR gamma radiation, Bhal and Gupta (1982) induced chlorophyll mutations by employing EMS (0.2, 0.4%) and gamma radiations (20, 30, 40, 50 kR) and in combination 0.2% EMS + 20, 30, 40, 50 kR. Auti *et al.* (2007) carried out comparative study of frequency and spectrum of chlorophyll mutations induced by EMS and SA (01, 0.02, 0.03, 0.04 Molar) and gamma radiation (30, 40, 50 kR). The result showed that SA and gamma radiation induced *striata*, *chlorine* and *xantha* while EMS induced *striata*, *chlorina*, *albina*, *variegated* and *xantha* type of Chl mutant. The presence of certain Chl mutants in some mutagenic treatments and absence in others indicate difference in the availability of mutagenic loci to the mutagen. EMS (0.2 M) was found to be most effective and among the mutant chlorine type appeared in maximum frequency. Singh *et al.* (1979) has been reported *chorina*, *albina* and *xantha* type of mutant by using EMS and gamma radiations. He found that *albina*, *xantha* and *chlorina* mutants were each controlled by two recessive genes segregating in the ratio1: mutant: 15 normal. Bhal and Gupta (1982) reported single gene inheritance for *albina*, *chlorina*, *xantha* and *virescens* mutants following gamma ray treatments. Reddy and Gupta (1989)

suggested that, EMS preferentially acts on genes responsible for Chl development. Natarajan and Upadhya (1964) have attributed the high incidence of Chl mutations, after EMS treatment, due to the specificity of the mutagen to certain regions of chromosomes. Kumar *et al.* (2009) using gamma radiation (10-60 kR) and EMS (0.1-0.4%) and in combination treatment obtained Chl mutations in mungbean cultivar 'PS-16' and 'Sona'. The spectrum of chlorophyll mutations consisted of *albina*, *chlorina*, *viridis* and *xantha*. Of these chlorophyll mutations, *xantha* type was predominant in both the mutagenic treatments. Results showed that 0.1 to 0.4% EMS produced the highest frequency of mutations (55.55%) followed by 10 to 60 kR gamma rays (48.66%) or their combinations (38.66%) in 'PS-16' while in 'Sona' gamma rays and EMS combination treatments showed highest frequency (67.33%) more than gamma radiation (39.33%) and EMS (44.44%) treatments. Radiation and chemicals cause Chl mutations in most plants and the severity increases with an increasing dose. According to Asencion *et al.* (1994) Chl mutation may relate to gene or chromosome changes or just relate to physiological mechanism of the plants. Frequency of Chl mutation in M_1 generation may be better used as an indicator to the effects of mutagens on gene mutation than plant growth or survival (Blixt *et al.* 1965).

Malik (1996) noticed genotypes controlling such Chl mutations to be usually heterozygous with the segregation of monogenic recessive. Treatment of mungbean by radiation or chemicals always resulted in Chl mutations, as reported by Bahl and Gupta (1983), Malik (1996) and Asencion *et al.* (1994). According to Shakvarnikov *et al.* (1976), the differences in the Chl mutation frequency and spectrum depends on the interaction of three factors such as mutagen, plant genotype and the physiological state of organism at the moment of treatment. This involves factors which determine whether a change in DNA will take place and even if it does, whether it will give rise to an observable mutations. Gustafsson (1951) considers involvement of about 120-150 loci in albino, 125 loci *in viridis* and 10-15 loci in others not commonly observed Chl deficient sector. *Viridis* is heterogenous group characterized by uniform yellowish-green or light-green colour, gradually changing to dark green and often viable (Gustafsson 1940). Ehrenberg *et al.* (1961) opined that the *viridis* sectors were more frequent as a result of chemical mutagen treatment. They concluded that different chemical mutagens affect individual genes differently. Ryan and Heslot (1963) stated that induction of Chl mutations is dependent on the randomized action of physical mutagens, whereas, the EMS has specificity to certain loci in barley. A number of scientists reported a significant difference between the relative proportions of different kinds of mutations induced by treatments with chemical mutagens and gamma radiation in Chl deficient mutations (Ehrenberg *et al.* 1961; Nilan and Konzak 1961; Siddiq and Swaminathan 1969).

There are many physical and chemical agents used now a day to increase yield of the crop or to develop high-yielding crop cultivars. Among the various agents radiomimetic agents are important one. These agents modify the bases or phosphates by alkylating them. These radiomimetic agents have bifunctional alkyl reactive groups that react with DNA, causes extensive cross linkage of DNA, chromosome breakage, chromosome mutations and gene mutation. Different such types of radiomimetic agents are tested by various workers time to time on various crops. The higher frequencies of Chl and other viable mutations are obtained in treatments with chemical mutagens than radiations (Blixt *et al.* 1958). Chopra and Swaminathan (1967) observed higher Chl and viable mutation frequency in M_2 under EMS treatment during the comparative study of EMS, hydroxylamine and their combination. Similarly, Jacob (1970) studied the comparative mutagenic effects of alkylating agents and gamma rays, and observed that EMS induced highest Chl mutation frequency as comparison to methyl methane sulphonate (MMS), *N*-methyl-*N*′-nitroguanidine (MNG), butyl methane sulphonate (BMS) and gamma rays. The following order of efficiency of various mutagens recorded was EMS > MNG > MMS > gamma rays > BMS in the case of *Arabidopsis thaliana*. Khan (1988) studied the effect of gamma rays and EMS in single and combination treatments on frequency and spectrum of Chl mutations in M_2.

LEAF MUTATIONS

A number of investigators have reported changes in the shape and size of leaves in leguminous members (Gelin 1954; Zacharias 1956; Jana 1962; Apparao and Jana 1976; Kothekar 1978; Deshpande 1980; Hakande 1992; Kothekar *et al.* 1994; Satpute 1994; Panchbhaye 1997). Singh and Chaturvedi (1982) and Apparao and Auti (2005) reported bifoliate, tetrafoliate and pentafoliate leaves in mungbean with EMS. Mahna *et al.* (1994) reported mature leaves with lobed lamina in mungbean as a result of treatment with hypoxanthine. Singh and Chaturvedi (1982) reported bi-, tetra- and pentafoliate leaves in mungbean employing EMS and NMU (0.1, 0.2, 0.3 and 0.4%). Mahna *et al.* (1994) reported mature leaf with lobed lamina in mungbean with hypoxanthine. Sharma and Singh (1992) reported long pod mutant in mungbean. Joshua *et al.* (1972) have correlated the development of leaf abnormalities to the pleotropic action of mutated genes. Prasad (1967) pointed that the splitting, rolling and constriction of organ in *Phalaris* are produced by irregularities in meristem after mutagenic treatment. Even though at this moment these leaf variations seems less important, they may be of immense value in understanding the genetic control of leaf formation and regulation of their size, shape and form. Cultivars with lanceolate leaflets and smaller leaf area have better light distribution through the canopy and higher photosynthetic rates than those with larger, oval leaves (Suh *et al.* 2000). They concluded that the predominance of additive effects for leaf shape and leaf area could be used in breeding programs for genetic gain and to enhance the photosynthetic rate of mungbean cultivars.

FLOWER MUTATIONS

Several workers have reported flower color mutations in mungbean and different plants employing different mutagens Mahna *et al.* (1994) isolated various types of morphological and chlorophyll mutants from M_2 and M_3 segregating families of mungbean after treatment with different concentrations of hypoxanthin (0.0003, 0.0005, 0.0010, 0.0050 and 0.0010%). Hypoxanthin is a naturally occurring purine derivative. It is formed from reduction of xanthin by xanthin oxidoreductase. Because of its resemblance to guanine the spontaneous deamination of adenine can lead to error in DNA transcription or replication. Among the different concentrations of hypoxanthin, only 0.005% concentration induces flower size and abnormal flower mutants (stamen) in mungbean. The distinguishing features of the flower mutant are long style, exposed stigma (stigma protruding out of the flower) and small sized stamens. Sangsiri *et al*. (2005) reported flower mutation which looks like comb with pollen sterility in mungbean. Flower mutation looks like cock's comb with pollen sterility. Similar mutants were also reported by Santos (1969) and Lamseejan *et al*. (1983). Four different types of flower mutations (small flower, large flower, abnormal flower and flower colour) were observed in the mutagen administered 'Vaibhav' variety plants in M_2 and M_3 generations of mungbean by Auti and Apparao (2009). Kumar *et al*. (2009) induced flower colour mutation in two mungbean varieties 'PS16' and 'Sona' by employing six doses (10 to 60 kR) of gamma rays and with four concentrations of EMS (0.1 to 0.4%) alone or in various combinations.

Datta *et al*. (1993) studied cytomorphological, anatomical and biochemical characters of mungbean mutant to understand the mechanism involved in the origin and evolution of somatic flower color mutation at molecular level.

According to Datta and Banerji (1995), chromosomal aberrations, changes in chromosome number, gene mutations, rearrangement of different histogenic layers and changes in biochemical pathways leading to pigment formation, may be prime cause for flower colour mutations. According to Datta (1994) flower color mutation appeared or produced due to qualitative and quantitative changes in pigments during pigment biosynthetic pathways due to gamma radiation. Different flower colours were used in germplasm characterization, evolution studies, and cultivar identification (Buzzell *et al.* 1977). Pigmentation in the flowers is controlled by a number of Mendelian loci in the anthocyanin pathway and many of these loci act pleiotropically (Fasoula *et al*. 1995).

Purple and white flower colors are controlled by a single gene with purple (*W1*) being dominant (Bernard and Weiss 1973). Atta *et al*. (2003), Barshile (2006) and Datta and Sengupta (2002) reported white flower mutant in *Cicer arietinum* L. with gamma irradiation. Flower colour mutation can be exploited as genetic markers in breeding experiment (Datta and Sengupta 2002; Atta *et al*. 2003). Flower colour mutant reported by Barshile (2006) in *C. arietinum* showed higher values for mean plant height, plant spread, leaf area and low value for number of pods per plant and yield per plant. Borkar and More (2010) has recorded different colour flower mutations in *Phaseolus vulgaris* var. 'Varun' by the treatment of EMS and irradiated with gamma radiation. In *Glycine max* the mutants flower with white or violet (Mullen 2003), off-colour flower (Ahire *et al*. 2005) and pink flower (Ahire *et al*. 2005; Manjaya and Nandanwar 2007) were obtained in the M_2 population. Some developmental flower mutants (double whorled mutant, double standard mutant and a mutant with white standard, wings and pink keel) were also reported by Ahire (2008) in M_2 generation of *G. max*. Chen and Nelson (2004) reported that insect pollinators discriminate against white phenotypes when white flowers are rare in populations. Since the plant is self-compatible, pollinator bias could result in an increase in self-fertilization in white maternal plants, which should lead to an increase in the frequency of alleles conditioning white flowers according to modifier gene theory. Petal color, size, and volatiles (floral scents) are important clues to attract pollinating insects (Palmer *et al*. 2001).

Homozygous recessive *wp* alleles produce pink flower color in presence of the non-allelic gene *W1*modifying the expression of purple pigmentation (Stephens and Nickell 1992). The pink flower phenotype is speculated to occur due to the presence of a defective *w*p-m transposable element located in the *Wp* allele responsible for purple pigment (Hegstad *et al*. 2000). A transposable element system has been proposed for *w4-m* (purple or white chimeric flowers) in soybean (Vodkin 1994).

POD MUTANTS

Singh and Chaturvedi (1982) reported pod size mutant with EMS in mungbean. Sharma and Singh (1992) reported a long pod mutant in mungbean. Singh and Agarwal (1986) reported long pod mutants in cluster bean by the treatment with EMS and gamma rays and their combined treatment. Sangsiri *et al.* (2005) recorded pod mutation in M_2 population of mungbean cv. 'KPS2' and 'VC 6468-11-1B'. The mutant showed lobed pod mutation with fewer seeds per pod and this trait associate with partial sterility, causing constriction at the point where there was undeveloped seed. Priya Tah (2006) reported cluster pod and synchronous pod maturity in 'K851' and 'Sona' mungbean cultivars by irradiating seeds with with 10, 20, 30 and 40 kR γ-radiation. Auti and Apparao (2009) irradiated seeds of 'Vaibhav' mungbean cultivar with 10, 20, 30 and 40 kR dose of gamma radiation to induced different morphological mutations. In their investigation pod colour, pod size, pod pubescence and pod shape mutants were obtained in the M_2 generation. Pods with dense and sparse pubescence were reported in the present study. Kumar *et al*. (2009) reported compact, dwarf, early, large pod size and synchronous maturity mutants in two mungbean varieties 'PS 16' and 'Sona' with the 10 to 60 kR gamma radiation and 0.1 to 0.4% EMS treatment.

Pod mutants were obtained from gamma ray treatments in *Cicer arietium* (Barshile 2006), *Vigna unguculata* (Kumar *et al*. 2007) and *Glycine max* (Ahire 2008). Ahire (2008) obtained pod colour, pod size, pod pubescence and pod shape mutants were obtained in the M_2 generation of soybean. Pubescence density can be an important factor in controlling infection because increased pubescence density can bring a delay in time of infection by acting as a mechanical barrier to aphid probing (Pfeiffer *et al*. 2003). Pundir and Reddy (1989) obtained a glabrous mutant from EMS treated chickpea seeds. The character is governed by a single recessive gene. This mutant can be useful in certain pathological studies. Glabrous plants are more damaged by insects; on the other hand, there is a cost for the plant to develop these structures (Karkkainen and Agren 2002). Production of trichomes is a variable character and the inheritance acts in a simple Mendelian fashion, where glabrousness is recessive to trichome production (Karkkainen *et al*. 2004).

Pubescence density can be an important factor in controlling *Soybean mosaic virus* (SMV) infection because increased pubescence density can bring a delay in time of infection by acting as a mechanical barrier to aphid probing (Pfeiffer *et al.* 2003). Pundir and Reddy (1989) obtained a glabrous mutant from EMS treated chickpea seeds. The character is governed by a single recessive gene. This mutant can be useful in certain pathological studies. Glabrous plants are more damaged by insects; on the other hand there is a cost for the plant to develop these structures (Karkkainen and Agren 2002). Production of trichomes is a variable character and the inheritance acts in a simple Mendelian fashion, where glabrousness is recessive to trichome production (Karkkainen *et al*. 2004). Hanna (2006) studied molecular and morphological analysis of genetic polymorphisms causing glabrousness in wild populations of *Arabidopsis lyrata*. Trichome mutants were first used as convenient genetic markers (Marks 1997). The glabrous1 (*gl1*) mutant, which lacks trichomes on most surfaces, was used in early gene mapping studies (McKelvie 1965). Trichome mutants were used to calculate mutation frequencies generated using several different mutagens (Koornneef *et al*. 1982). Hulskamp *et al*. (1994) used the Arabidopsis mutants to define steps in a pathway to trichome development. Trichome mutants were first used as convenient genetic markers (Mark 1997). Trichome mutants were used to calculate mutation frequencies generated using several different mutagens (Koornneef *et al*. 1982).

SEED TYPE MUTATION

Different types of seed mutations like seed size mutations and seed coat colour mutation have been reported by various workers in mungbean and other pulse crops by following mutagenesis with chemical and physical mutagens.

Variations in seed size have been reported by Singh and Chaturvedi (1982) in *Vigna radiata* with EMS and nitrozomethyl carbomide, or NMC. Auti and Apparao (2009) reported large number of seed coat colour (brown, dark green, yellowish green and black) seed size (small, bold) seed shape (round, wrinkled and elongated) with gamma radiation, EMS and SA treatment in 'Vaibhav' and 'Koppargaon' mungbean cultivars. Singh and Raghuvanshi (1991), Bhamburkar (1981) and Sudha Rani (1990) reported a bold-seeded mutant in *Phaseolus mungo* with gamma rays and EMS, Kharakwal (1999) and Barshile (2006) in *Cicer arietinum* with EMS and gamma rays, Nerkar (1970) in *Lathyrus sativum* by employing gamma rays, EMS and nitrosoethylurethane (NEU), Reddy and Reddy (1972) in *Oriza sativa* with hydrazine. Barshile (2006) recorded bold seeded mutant in chickpea cultivar 'Vijay' and 'Virat'. Bold seeded mutant recorded by Barshile (2006) showed vigorous growth, significant increase in leaf area, number of seeds

per pod and 100 seed weight over control. Bold seeded mutant earlier recorded by Auti (2009) in mungbean, Pawar (2011) in blackgram, Singh (1996) and Singh *et al.* (2000) in *Vigna* spp. and Wani and Anis (2001) in chickpea following mutagenesis with gamma rays and EMS. The bold seeded mutants may be utilized in various breeding programmes as donor parent for boldness character (Wani and Anis 2001). Pawar (2011) has successfully used bold seeded mutants with higher 100-seed weight in cross breeding programmes.

The various seed-coat colour mutants by using gamma rays have been reported by Auti (2006) in *Vigna radiata*, Kharkwal (2000) and Barshile (2006) in *Cicer arietinum*, Patil (2009) in *Phaseolus vulgaris* and Kumar *et al*. (2007) in *Vigna unguculata* and Kerketta and Haque (1986), Mehta *et al.* (1994), Ahire *et al.* (2005), Karthika and Subha Lakshmi (2006) in *Glycine max*. Bold and small seeded mutants in soybean were induced by gamma ray and EMS treatments individually (Karthika and Subha Lakshmi 2006). Increased seed size is generally attributed to increased cotyledonary cell volume, retaining similar cell number within unit area (Joshua and Bhatia 1983). Wrinkled seed mutants have been reported by Auti (2006) in mungbean, Kharakwal (2000), Barshile (2006) and Khan *et al*. (2004) in chickpea following mutagenesis with gamma rays, EMS and SA.

Seeds are sometimes big or small, long, round or oval, colour can also vary, some are yellow, green or even black, buff or with spots. Although some of these differences are determined by growing environments, others are genetic and stable and therefore can be used for cultivar identification (Liu 1997). According to Moh (1972) seed coat colour in beans is controlled by genetic factors especially modifying factors which do not produce colours, but influence the colour produced by other factors.

Hilum color is also a major factor in cultivar identification. Hilum color as well as other physical appearances have become important factors in determining the type of food application for a particular soybean cultivar (Liu 1997). However, yellow hilum cultivars are more susceptible to low temperatures, resulting in reduced seed yield and poor seed quality compared with brown hilum cultivars (Takahashi 1997).

Dwivedi and Singh (1986) suggested that the factors P and R are responsible for purplish black and brown color seeds respectively. The concurrent presence of both factors produces purplish black color. In the absence of both P and R, the seed coat is white. The seed coat color seems to be under the control of different genetic factors like pigmentation factors, pigment complementary factors and modifying factors, which depend upon the presence of the dominant pigment factor in order to express their colors. Once the dominant pigment factor is present, the complementary factors either produce a definite color by themselves or interact to produce a wide range of color.

PLANT TYPE

Micke *et al.* (1990) had reported about 336 cases of induced mutation for changed architecture of the plant among the registered mutant crop cultivars at that time dwarf, bushy and compact plant mutants have been induced in mungbean, chickpea, cowpea and other pulse crops by Kharkwal (2000). Mungbean mutant varieties 'NM-19' and 'NM121-25' have short stature, determinate growth habit (Malik 1988). Mutant with increased growth rate has been reported by Yadav (1987), Khan (1989), Subramanian (1980) and Sharma and Singh (1992) in mungbean. Tall mutants have been reported earlier in mungbean by Auti (2009), Yadav (1987), Khan and Tak (2000), Sharma and Haque (1983), Subramanian (1980), and Sharma and Singh (1992). Different scientists have attributed increase in plant height to different factors. According to Webber and Gottschalk (1973), the increase in plant height is due to the changes in the internode length. Blonstein and Gale (1984) opinioned that the increase in plant height is due to increase in cell number, cell length or both. From the foregoing discussion it is clear that the tallness of the tall mutants is basically due to an increase in cell number and cell length which in turn may increase the internode length or internode number.

Dwarf mutants have also been reported by several researchers (Kundu 1982; Auti *et al.* 2009). Different researchers have attributed reduction in plant height to different factors like destruction or inhibition of auxin synthesis (Smith and Kerstein 1942), genetic loss due to chromosomal aberration (Evans and Sparrow 1961), interference with the synthesis of new DNA (Pele and Howard 1955), damage and deficiency of physiological pre-requisites to cell divisions (Stein and Sparrow 1963), delay and loss of proliferation capacity and cell death (Evans 1965) and inhibition of phytohormone responsible for normal growth (Tarar and Dnyansagar 1974).

Compact and spreading type of mutants have been reported by Kharkwal (2000) in mungbean, Bhatia *et al.* (1999) obtained bushy and compact plant type mutants in several pulse crops. According to Malik (1988), mungbean mutant varieties 'NM19-19' and 'NM121-25' have a short stature, erect plants with a determinate growth habit. Kharkwal *et al.* (1988) and Anonymous (1987) obtained high yielding, dwarf, determinate or semi-determinate mutants of cowpea through gamma radiation. It seems that the genetic material of cell is quite sensitive to radiation damage and both the primary and secondary physiological effects of the mutagens might be responsible for the habit mutations (Auti 2005). Ignacimuthu and Babu (1988) employed gamma radiation and observed the following order of radio sensitivity for *Vigna* species. The order was *V. radiata* > *V. mungo* > *V. sablobata*. Ganguli and Bhaduri (1980) induced high proportion of morphological abnormalities by employing X-ray and thermal neutrons. The mutation rate was higher with neutrons than with X-rays. Until 2000, 19 mungbean varieties were developed through induced mutations. Malik *et al.* (1979) isolated mungbean mutants exhibiting desirable agronomic attributes and superiority in seed protein. Tickoo and Chandra (1999) reported two mutant lines with high protein content (30.4 and 30.8%) accompanied with high yield. Bhal and Gupta (1982) have reported a mutant mungbean variety 'MUM-2' with high yield potential. Kharkwal (1996) have reported six disease resistant varieties developed through induced mutations. These varieties are 'Pant Moog-2', 'BM-4', 'MUM-2', 'TARM-1', 'TARM-2', and 'TARM-18'. They were developed employing 10 kR gamma rays, EMS and crosses with mutants. All these varieties are resistant to MYMV and powdery Mildew. Ahmed *et al.* (1995) reported 'BINA Moog2' employing gamma rays, which was resistant to MYMV. **Table 2** provides the list of disease resistant varieties developed

Table 2 Disease resistant varieties of mungbean developed through induced mutations.

Variety	Mutagenic treatment and parent variety	Disease against which improved	Reference
BINA Moog-2 (MC-246)	γ-rays, MB-55, (Mutant MB-55 (4) x V-2273)	MYMV	Ahmed *et al*. 1995
Pant Moong-2	10 KR γ-rays,ML-26	MYMV	Kharkwal 1996
BM-4	EMS, T-44	Macrophomina blight, powdery mildew, MYMV	Kharkwal 1996
MUM-2	EMS, K851	MYMV	Kharkwal 1996
TARM-1, TARM-2, TARM-18	Crosses with mutants	powdery mildew	Kharkwal 1996
TM-96-2	Irradiation to TARM-2	powdery mildew; *Corymespora* leaf spot	IAEA 2011
TJT-501	-	Resistance to powdery mildew	IAEA 2011

EMS, ethyl methane sulphonate; kR, kilorad; MYMV, *Mungbean yellow mosaic virus*

Table 3 Mutant cultivars of mungbean released and approved for cultivation in India.

Mutant variety	Year of release	Institution	Mutagen and parent variety	Main characters induced / improved
TT9E	1979	OUA&T, Bhubaneshwar	-	High yield, early maturity and resistance to YMV
Pant Moong	1982	GBPUA&T, Pantnagar	100 Gy	Resistance to MYMV, high yield
Co-4	1981	TNAU, Coimbatore	40 kR γ-rays, Co-1	High yield
BM-4	1992	ARS, Badnapur	0.15% EMS, T-44	Resistance to Macrophomina, tolerant to MYMV
Dhauli (TT9E)	1979	OUA&T, Bhubaneshwar	Mutant of fixed line of cross T51 x local	High yield
LGG-407	1993	APAU, Lam	40 kR γ-rays, Pant Mung-2	High yield
LGG-450	1993	APAU, Lam	40 kR γ-rays, Pant Mung-2	High yield
ML-26-10-3	1983	PAU, Ludhiana	γ-rays	Yield and tolerance to MYMV
MUM-2	1992	CCSU, Meerut	0-2% EMS, K-851	Tolerance to MYMV and early maturity
PBM-1	-	PAU, Ludhiana	-	Yield and tolerance to MYMV
Pant Mung-2	1982	GBPUA&T, Pantnagar	10 kR γ-rays, ML-26	Yield and resistance to MYMV
TAP-7	1983	BARC, Mumbai	30 kR γ-rays, S-8	High yield, earliness, tolerance to PM and leaf spot
sTARM-1	1997	BARC, Mumbai & PKV, Akola	30 kR γ-rays, S-8	High yield, resistance to MYMV
TARM-2	1992	BARC, Mumbai & PKV, Akola	30 kR γ-rays, S-8	High yield, resistance to MYMV
TARM-18	1996	BARC, Mumbai & PKV, Akola	30 kR γ-rays, S-8 (PDM54 x TARM-2)	High yield, resistance to MYMV
TMB-37	2005	-	-	Early maturity, high yield and large seed size
TM-96-2	2007	Andhra Pradesh	Irradiation to TARM-2	Resistance to powdery mildew and Corymespora leaf spot
TJM-3	2007	Madhya Pradesh	Hybridization with a mutant variety of TARM-1	Early maturity, Large seeds and Resistance to powdery mildew, Rhizoctonia root-rot disease
TJT-501	2009	-	-	Resistance to powdery mildew

EMS, ethyl methane sulphonate; kR, kilorad; MYMV, *Mungbean yellow mosaic virus*
Source: http://nucleus.iaea.org/sso/NUCLEUS.html?exturl=http://www-mvd.iaea.org/MVD/default.htm

through induced mutations.

Sidique *et al.* (1999) developed a mungbean variety 'NIAB Mung 98', through hybridization between an induced mutant 'NM 20-21' and an exotic AVRDC accession 'VC 1482'. The Asian Vegetable Research and Development Center (AVRDC) working intensively on mungbean, has played an important role in mungbean improvement during the past decade. AVRDC was designated in 1983 by the International Board for Plant Genetic Resources (IBPGR) to hold the world mungbean base collection. According to Kharkwal *et al.* (2001) Co-4, Pant Mung-2, MUM-2 and TARM-1 are the important mungbean mutant varieties of economic importance released in India. In India, ten varieties of mungbean have been released for cultivation for different agro-climatic regions. The varieties 'Co-4', 'Pant Mung-2' and 'TAP-7' though released in early 1980s, are still grown widely in the country. The variety 'TARM-1' resistant to powdery mildew and YMV diseases, is the unique variety for *Rabi* cultivation. Details of the mungbean mutant varieties released and approved for cultivation in India has been shown in **Table 3**.

Some of the major research centers actively engaged in mungbean mutation work and contributed in the development and release of large number of mungbean varieties are IARI, New Delhi, BARC, Mumbai, TNAU Coimbatore, NBRI, Lucknow from India and AVRDC from Taiwan.

Thus mutation breeding has made significant contribution in increasing the production of mungbean in the Indian subcontinent. Lot of work has to be done to produce more high yielding varieties of mungbean to cope up with the ever growing future demand of this pulse.

Along with simple viable mutations, multiple mutagenic effects on two or more characters were also found in all the mutagenic treatments. However their frequencies differed with mutagen and variety. According to Patil (1966) multiple mutations are either due to mutation of pleotropic gene, mutation of the gene clusters or due to loss of chromosomal segments. Gaul (1961) interpreted the occurrence of such mutants as due to chromosomal rearrangement or deletion. Occurrence of multiple mutations has also been reported in groundnut by Ashri and Golden (1965) and Patil (1966). Auti (2005) has reported multiple mutations in mungbean. By employing 50 kR dose of gamma radiation, he induced a novel mutant that showed multiple morphological mutations like large flowers with dark yellow petals, dense thick hairy pods and black coloured seeds. It is named as *lhb* mutant (large flower, hairy pod and black seed mutant). Such a mutant has not been reported earlier in mungbean. *lhb* mutants also showed multiple mutagenic effects on various other traits. Important among them are semi-dwarf habit, late flowering, large-sized flowers, dark-yellow petals, late maturing, broad and short pods, thick dense hairs on pods. Gamma radiation and EMS is utilized for widening the frequency and spectrum for getting extra genetic variability (Singh and Singh 2007).

The second important conclusion in addition to the mutagen and its nature is the genetic makeup of the variety. The genetic makeup of the material has a significant role in determining its mutability. According to Gregory (1961), the genetic material or makeup of the experimental material is the prime factor that influences the induction and recovery of mutations and not the mutagen used. According to Gustaffson (1944), Konzak *et al.* (1961) and Brojevic (1966) even the small genetic difference of a single gene could bring about significant changes in the frequency and spectrum of recoverable mutations. Our experimental results fully support the view that the frequency and spectrum of induced mutations are affected by the genetic makeup of the variety. Priya Tah (2006) studied the effect of chemical and physical mutagens for the induction of macro mutant. Obtained macro mutants were analyzed by using various molecular markers. Paper also explains the importance of high-density mapping and its application in map-based cloning for isolation of useful genes liked with morphological attributes. Auti (2005) have been induced morphological mutants like early maturing, high yielding and early flowering mutants, these are agronomically valuable and they may be utilized in future breeding programs.

Early and late-flowering mutants

Early flowering mutants have been reported earlier by several authors (Dahiya 1973; Singh and Chaturvedi 1981; Khalil *et al.* 1987) in mungbean. According to Jana (1962), the early maturing mutants are produced as a result of physiological changes and increased production of flowering hormones, which are usually associated with mutagenesis. The earliness gets attained mainly due to early transition of vegetative meristem to a reproductive one. The transition from vegetative to reproductive growth is largely under genetic control. Flowering depends on a number of physiological changes that take place in the meristem during its

transition from vegetative to reproductive phase.

Early and late maturing mutants

The early maturing mutants require less number of days and the late maturing mutants require more number of days for attaining maturity. Awan (1991) reported mungbean mutant varieties 'NIAB Mung 19-19' and 'NIAB Mung 121-25' maturing in 65-70 days. Early maturing mutants produced as a result of mutagenic action have been reported in *Vigna mungo* (Ramaswami and Rangaswmy 1974). Yaqoob and Rashid (2001), Prasad (1967, 1976), Dahiya (1973) and Bahl and Gupta (1983) reported late maturing mutants in *Vigna radiata*. Yaqoob and Rashid (2001) reported late maturing mutants in mungbean employing gamma radiation. According to Sparrow (1966) the change in phytohormones and reduction in photoperiodic cycle are the main causes for early as well as late maturity in the mutants.

Treatment with SA seems to be more effective in reducing days in maturity in M_2 generation but no relationship was observed with concentration (Lavanya *et al.* 2011).

Khan and Goyal (2009) reported high heritability coupled with high genetic advance recorded for days to maturity indicated that genetic progress to be expected from the selection. Priya Tah (2009) has induced novel mungbean mutants with synchronous maturity in two mungbean genotypes K851 and Sona by employing 10, 20, 30 and 40 Gy. She also studied the correlation in days to flowering and pod maturity in two diverse mungbean genotypes through induced mutagenesis.

INDUCED QUANTITATIVE MUTATIONS IN MUNGBEAN

According to the theory of quantitative genetics, the polygenic traits are controlled by a multiplicity of minor genes with small but cumulative effect and these "minor" genes can mutate with equal probability in both directions i.e. from the dominate state to the nonfunctional or recessive state and back. Thus the possibility of shifting population means for a particular character in both directions through mutations in character specific genes with equal probability is ruled out. Mutations with very small phenotypic effect would occur with high frequency and will have an equal probability of being positive or negative in their phenotypic effects (Gregory 1961). Khan and Wani (2006) has made an attempt to evaluate quantitative characters viz., fertile branches per plant, pods per plant and total plant yield in M_2 and M_3 generations following mutagenesis with EMS and SA in mungbean var. 'Pusa Baisakhi'. They have recorded significantly increased in number of fertile branches per plant and pods per plant after mutagenic treatments.

Several researchers induced genetic variability in quantitatively inherited characters in mungbean. Verma and Singh (1983), (Dahiya (1973, 1978), Singh and Chaturvedi (1981), Kundu and Singh (1982), Khan (1982, 1983, 1984a, 1985), Yaqoob and Rashid (2001), Singh and Yadav (1991) studied quantitative characters like plant height, number of primary branches, number of leaves per plant, pod number, pod length, seeds per pod, hundred seed weight, yield per plant, fresh weight, dry weight and number of nodules in M_2 and M_3 generations. All these researchers have noted that the mean values for the quantitative characters reduced, enhanced or equal to that of control in all the mutagen treated populations. Singh Awnindra (2009). Significant genetic variability was induced through use of mutagen gamma rays and EMS for quantitative traits in two varieties 'T 44' and 'PDM 54' of mungbean. Khan *et al.* (2004) has made an attempt to evaluate quantitative characters viz., fertile branches per plant, pods per plant and total plant yield in M_2 and M_3 generations in mungbean employing EMS and SA. They also recorded increase in number of fertile branches per plant, pods per plant and yield increased significantly after mutagenic treatments. Sharma and Haque (1983), Khan and Tak (2000), Yaqoob and Rashid (2001) in mungbean have reported significant positive shift in the mean values of quantitative characters at low concentrations of the chemical mutagens. Wongpiyasatid *et al.* (1998) used Gamma rays of 500 Gy and 1% EMS to induce mutation in mungbean 'KPS1' and 'CN36' varieties for improvement of disease resistance to cercospora leaf spot and powdery mildew as well as producing high yields. According to Lavanya *et al.* (2011), SA treatment significantly increased cluster/pod, pod/plant and seed yield/plant at low concentrations.

Yield per plant is an important trait as it measures the economic productivity in mungbean. But its inheritance is extremely complex. Its expression is inherited by many genes including those controlling production, transport and storage of assimilates, genes determining the plant growth and development and genes contributing to adaptation in stress environments. Studies for combining ability and types of gene action indicate that both additive and non-additive gene effects contribute to seed yield. According to Singh and Jain (1971), Singh and Singh (1971), Luthra *et al.* (1979), Reddy and Ramulu (1982) and others, additive gene effects were predominant in the inheritance of seed yield, pods per plant, seeds per pod, seed weight, branches per plant, pod length, days to flowering and days to maturity. Yaqoob and Rashid (2001) studied the effect of gamma radiation on some agronomic traits of five mungbean cultivars. Obtained results showed existence of wide range of variability in all the characters except plant height. The genotype × dose interaction was highly significant for days to 50% flowering, maturity, number of branches and clusters and non-significant for plant height and number of pods. Wani and Khan (2006) in mungbean found early ripening mutants are competitive with or even superior to their mother varieties with regard to seed production.

Comparative studies on macromutation data revealed that the chemical mutagens particularly alkylating agents are more effective than ionizing radiation. The above fact is reported by several researchers (Brock 1976; Sharma and Sharma 1979; Sharma 1986; Sarkar and Sharma 1988; Singh and Sharma 1989; Solanki and Sharma 1999; Kharkwal 2001; Auti *et al.* 2005). Induced variability was by Khan (1984) studied in the quantitative characters of mung bean (*Phaseolus aureus* Roxb.) after treatment with gamma rays, EMS, and hydrazine hydrate (HZ) in M_1, M_2, and M_3 generations. Coefficient of variation values, heritability, and genetic advance increased more in M_3 as compared with M_2, indicating that the significant gain could possibly be achieved through selection in M_3 generation.

Patil and Wakode (2011) estimated various genetic variability parameters using physical (gamma rays) and chemical (EMS) mutagens using two cultivars i.e. 'PKV-1' and 'JS-335'. Results indicated that genotypic coefficient of variation and phenotypic coefficient of variation, heritability were significantly high for different characters studied i.e. Plant height, number of branches per plant, number of clusters per plant, number of pods per plant, yield per plant, 100-grain weight.

High-yielding mutants

The yield character in crop plants is genetically controlled. The genes concerned with yield follow quantitative inheritance and show additive interaction. They are influenced by various environmental factors.

High-yielding mutants were reported in mungbean earlier by Dahiya (1973) and Shakoor *et al.* (1978) employing gamma radiation. Tikoo and Jain (1979) obtained high-yielding and disease resistant mutants in mungbean. Pawar *et al.* (1986) developed a mungbean genotype with high yield potential and improved efficiency of nitrogen fixation. Pawar and Wanjari (1994) induced high yielding varieties of mungbean, blackgram and pigeonpea. Sharma and Singh (1992) and Kwon and Oh (1983) reported similar mutants in mungbean. Mungbean lines with high yield and early maturity were obtained by Prasad (1976) and Bhal and

Gupta (1983).

Singh *et al.* (2000) isolated a bold seeded mutant in urdbean following mutagenesis with gamma rays and EMS. This mutant showed vigorous growth and produced more leaves and pods per plant. Khan and Tak (2000) reported morphological and high yielding mutants in black gram. Mechanism of action of mutagens in induction of high yielding mutants is still unknown. The mutagens, through some unknown mechanism, must be inducing the expression of other yield controlling genes, which are otherwise remaining silent in the plant.

Shakoor *et al.* (1978) observed mutants resistant to *Mungbean yellow mosaic virus* (MYMV) in the M_2 generation. Some of these mutants were shorter in stature than the parents. The induced mutations are generally recessive and resistant to MYMV. Therefore, it is expected that induced mutations may be rather more useful for this character. More number of progenies with resistance to MYMV were obtained at 10 and 20 kR doses of gamma rays. Singh (1981, 1982) reported that some of these plants or progenies were superior for yield traits and gave significantly higher yield in replicated yield traits, compared to the parental variety of mungbean 'ML 26'. One of these progenies 'ML 26/10/3' out yielded the 'ML5' check in multiplication trials and is released as 'pant Moong-2' in the year 1982 for cultivation.

Several authors previous reported the positive effect of synchronous pod maturity in seed yield (Afzal *et al.* 2003; Brar *et al.* 2004; Hamid *et al.* 2004; Chen *et al.* 2008). Induction of flowering and synchronous transformation from vegetative phase to the floral initiation is important stages of synchronous pod maturity (Corbesier *et al.* 2003). The time of pod maturation also plays an important factor in the synchronous pod maturation and could be due to variation in the degree of indetermination of growth duration (Brar *et al.* 2004).

Uneven pod maturity and maturation leads to low yield potential and low harvesting index (HI) in mungbean (Bushby and Lawn 1992; Egli and Bruening 2002). A high HI could be achieved with high proportion of total biomass production. Thus in order to increase the seed yield, selection of higher HI could be achieved through synchronous maturity. This has been previously identified by (Bisht *et al.* 1998) who indicated the inverse effects of seed yield due to high leafiness and asynchronous flowering. Tickoo and Jain (1979) reported that EMS was more effective in inducing variations for pod number, and gamma rays for seed weight. Rajput (1974) reported positive and negative shift mean values for all the polygenic traits, except mean pod length. Prasad (1976) stated that variation in pod number, early maturity, yield and tolerance to drought could be brought about by 0.2 to 0.3% EMS.

CONLUSIONS AND FUTURE PERSPECTIVES

Available literature suggests that lot of efforts have been made for the improvement of mungbean by using different techniques of mutation breeding. The narrow genetic base is a serious impediment to breeding progress in mungbean. The selection pressure in case of these crops has been concerned more with adaptation to stress conditions than for yield. In last few years induced mutations have been used as an important supplementary tool, to other conventional methods of plant breeding for improvement of crops by developing new plant types. Induced mutations can help to regenerate and restore the variability, which has been lost in the process of adaptation to various stresses or adaptations during the course of evolution.

Various scientists have tried to improve genetic improvement in mungbean by developing various morphological mutants like plant type mutations, leaf mutations, flower mutations and seed type mutations. Due to increase genetic variability all these mutants are able to resist with different biotic or abiotic stresses. Prime achievement is the development of high yielding mutants, synchronous pod maturity mutants, disease resistance mutants and early maturing mutants. Several researchers have reported the use of mutagenesis for creating genetic variability in quantitative and qualitative characters and develop new desired correlation between the quantitative as well as qualitative traits. In addition to applications of these mutants in the breeding programme they are valuable for genetic analysis of traits, genome mapping, and molecular analysis for gene function. In mungbean, mutation breeding is useful to recover the characters or defected traits, which are agronomically desirable. For example high yielding varieties or desirable varieties having some inherited undesirable characters such as high flower drop, instability in performance or undesirable green color or late maturity can be improved by using mutagenesis. Thus induced mutation is having great potential for the improvement of traditional agricultural crops like mungbean and can contribute to further increase global food production.

FUTURE SCOPE

The narrow genetic base is a serious impediment to breeding progress in mungbean. As wild relatives are rich reservoir of genes for resistance to biotic and abiotic stresses, introgression of these genes is option to genetically mitigate the effect of these stresses. Further, the exploitation of genomic tools in conjunction with conventional breeding programmes can also be helpful. In the past few years, a large number of genomic tools has been developed in mungbean for resistance to various stresses. Further, intensive efforts through *in vitro* techniques are underway towards identifying complex abiotic stress traits, alien gene introgression aided by embryo rescue and rapid fixation of stress tolerant recombination through doubled haploid breeding. The selected lines can be further exploited for large-scale cultivation or breeding to combine the desirable traits in to high yielding mungbean lines. Some mutants would be useful to understand physiological pathways, inheritance studies and dissection of traits. The mutant with new traits can be used as new source. In addition stable mutants can be used as source material for tagging of specific loci with DNA markers and for molecular analysis for gene function.

Meanwhile, induced mutations have become more and more useful and important in modern genetics studies, such as gene discovery and function elucidation. By integrating molecular techniques, such as high throughput mutation screening techniques, induced mutations are now widely expected to play an even greater role in plant improvement than even before.

With population growth, the demand for food and feed is growing as well, while natural resources are limited. Erratic rain falls, sudden and severe drought conditions etc. often related to climatic change even deteriorate crop production conditions. During the last decade, induced mutations have also been gaining increasing importance in plant molecular biology as a tool to identify and isolate the genes and to study their structure and function. Knowledge of genes controlling important agronomic and quality traits are critical for plant breeders to develop proper strategies and efficiency implement breeding programmes.

These techniques in combination with more efficient screening methods deserve special attention in the days ahead to make mungbean cultivation a promising, remunerative and viable option for pulse growing farmers of the world.

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