Pigeonpea or red gram is an important crop in India next only to chickpea. Pigeonpea (*Arhar / Tuar*) is a major source of vegetable protein and it can be grown successfully by resource-poor farmers under rain fed dry lands. The present review provides the earlier published information on biochemical and induced mutational aspects of pigeonpea besides taxonomy and other related aspects.

**Center of origin:**

The exact origin of pigeonpea has remained controversial due to absence of archaeological evidence. According to de Candolle (1886) pigeonpea had originated in Africa and from there it was not only introduced to West Indies and Brazil but also to India.

There are two contrasting views on the center of origin of pigeonpea. One favors India, and the other Africa (Saxena, 2005). Considering the vast natural genetic variability in pigeonpea and presence of its wild relatives, Rheede (1686), Linnaeus (1737), and De (1974) supported the Indian origin for pigeonpea.

De (1974) and Vernon Royes (1976) published reviews that included discussion of pigeonpea’s origin. The latter considered the dispute settled in favour of Indian origin. The critical considerations have clarified this view a little further (van der Maesen, 1980).

Several authors considered eastern Africa as the “center of origin” since pigeonpea occurs wild in Africa (Zeven and Zhukovsky 1975). Although the reports of wild plants in India are scarce, the intensity of grazing animals in India easily explained this difference. The scarce but often cited archaeological evidence of seeds in an ancient Egyptian tomb, and the wild occurrence in Africa made many authors (Purseglove, 1968; Rachie and Roberts, 1974) believe an African origin. The range of diversity of the crop in India is much larger, and this made Vavilov (1951) list the pigeonpea as of Indian origin.
ARCHAEOLOGICAL RELICS:

Many references point to the presence of pigeonpea seeds (as *Cajanus indicus* = *C. cajan*) in an Egyptian tomb of the 12th Dynasty (2200-2400 BC) at Dra Abu Negga (Thebes) (Schweinfurth, 1884). But this concerns only a single seed in a grave offering of several agricultural seeds. The pigeonpea seed did not differ from those of plants with yellow flowers, then grown in Egypt. At present pigeonpea is still grown as a minor hedge crop by some farmers along the Upper Nile. Recently some archaeological remains of small-sized pigeonpea from Bhokardan in Maharashtra, India (Kajale, 1974) were dated from the 2nd century BC to the 3rd century AD, and hence do not support a very ancient use in India.

**Vernaculars of Pigeonpea:**

The name pigeonpea was first reported for plants used in Barbados where the seeds were once considered very useful as pigeon feed. The name has been translated into Dutch, French, German, Russian, and Spanish as one of the vernaculars in those languages. The vernacular names of pigeonpea, of which about 350 have been recorded, including slight orthographic variants (van der Maesen, 1986) do not allow to draw conclusions as to whether pigeon pea was first used in India or in Africa.

In India, many Sanskrit names have their modern equivalents: Adhaki or Adhuku became Arhar, the Dravidian Tuvanii or Tuvari, used in Sanskrit since 300-400 AD, became Tur (De, 1974). The names of pigeonpea in American hemisphere are derived from African and European tongues: an interesting subject for a linguist. The Portuguese "Guandu" and Spanish "Gandul" may have been derived from the Indian Telugu word "Kandulu" (van der Maesen, 1986), or may have the African roots, such as the Gabonese Fioffe "Oando". Alternative suggestions are that Guandu or Gandul could be a corruption of *Cajan* the name pigeonpea took from the Malay Kacang (Vernon Royes, 1976). The names Angola pea (pois d' Angole), Congo pea, Kachang Bali, Ads Sudani, Cajan des Indes, Puerto Rican pea, Indischer Bohnenstrauch, and Lentille du Soudan all point to the
purported origins. Most of the names in European languages, like the name pigeonpea itself, were not framed earlier than during the 16th century.

**Taxonomy:**

The taxonomy of *Cajanus* DC. has recently been revised (van der Maesen, 1986). The genus *Cajanus* is reported to include only one species *C. cajan* (L) Millsp. (syn.-*C. indicus* Spreng, Hooker 1879). According to Tutin (1958) the genus *Cajanus* was evolved from the Phaseoleae, one of the Papilionaceous tribes. Pigeonpea belongs to family Fabaceae. The genus 'Cajanus' belongs to the sub tribe 'Cajanae' under 'Phaseoleae' with sub-family 'Papilionaceae' (Aiyer, 1947). Hooker (1879) classified the genus *Cajanus* into a single species *Cajanus indicus*. Mehata and Dave (1931) attempted classification of pigeonpea. The systematic position of the pigeonpea according to the rules of ICBN is as follows:

- **Kingdom**: Planty
- **Division**: Spermatophytes
- **Order**: Rosales
- **Family**: Fabaceae
- **Subfamily**: Papilionaceae
- **Tribe**: Phaseoleae
- **Sub tribe**: Cajanae
- **Genus**: *Cajanus*
- **Species**: *cajan*

**Botanical description:**

**Habit:** Annual or biennial or perennial shrub (60 to 360 cm tall) with grooved silky branches.

**Root:** Pigeonpea has a taproot system. The root growth under ideal conditions begins on the 2nd day after sowing of the seed. The testa splits open near the micropyle. The primary structure of the root is tetrarch. Secondary thickening takes place as a result of cambial activity (Bisen and Sheldrake 1981). Tall, upright types produce longer and more deeply penetrating roots, whereas the
spreading types produce shallower and denser root systems. Large clusters of nodules are produced under the favourable conditions.

**Stem:**

The pigeonpea has a strong woody stem. The primary vascular tissue of the stem is organized into strands connecting the nodes. Each strand is associated with a ridge on the stem. Collenchymatous bundle caps underlie epidermis of the ridges (Bisen and Sheldrake 1981). Branching begins from sixth to tenth node (i.e. from 15 to 25 cm above the ground). In spreading types, the basal branches arise at an angle of 60-70° and in erect types branching takes place at an angle of 30-40°.

**Branches:**

The branching pattern in pigeonpea depends on genotype and spacing between rows and plants. At a wide spacing, it may form a bush and at narrow spacing it may remain compact and upright. For agronomic purposes pigeonpea plants can be grouped as compact (erect), semi spreading (semi erect), and spreading types. Based on the flowering pattern it may be determinate or nondeterminate. The determinate type completes the vegetative phase and then enters into the reproductive phase. In this type, the apical bud of the main shoot develops into an inflorescence, and the sequence of inflorescence production is basipetal (developing in the direction of base). The nondeterminate type shows continuous vegetative and reproductive phases. In this type, the flowering starts at nodes behind the apex and proceeds both acropetally and basipetally.

**Leaf:**

Leaves are trifoliately compound; leaflets oblong or lanceolate, acute, entire; stipels filiform; lamina hairy with the under surface greyish due to dense hairs. Along with hairs there are yellow glands which are prominent.

**Inflorescence:** Terminal or axillary racemes carried on long peduncles.

**Flowers:**

Flowers are clustered at the top of the peduncle and are yellow or yellow with purple veins or diffuse red. Flowers are papilionaceous, bracteate and
bracteolate: calyx five, gamosepalous; corolla five, free; stamens, diadelphous; ovary unicarpellary, superior, subsessile with a few ovules; style long, filiform, much upcurved; stigma capitate.

**Pod:**

It is variable in shape, size, constriction, texture and pubescence. Pods with deep constrictions are known as beaded; while others are flattish.

**Seed:**

It may be round or lens shaped, colour ranging from silver white, fawn, brown or red to purple; blotched or speckled. There is much variation in the size of seeds.

**Germination:** Hypogeal.

**Cotyledons:** These are yellow coloured.

**Cytogenetics:** High degree of homology between chromosomes, among species which hybridize, has been reported (Deodikar and Thakar, 1956; Pundir, 1981 and Dundas et al., 1983). The cytological evidence supporting congenericity of *Cajanu*s and *Atylosia* has been considerable. There is no discrepancy between the chromosome number reports. All authors have found 2n=22 for *Cajanu*s (*sensu lato*) spp and some *Rhynchosia* spp (van der Maesen, 1986). The somatic chromosome number in pigeonpea is reported to be 2n = 22 with a basic number x=11 by several workers (Krishnaswami and Ayyangar, 1935; Naithani, 1941; Kumar et al. 1958; Akinola et al. 1972; Shrivastava et al 1973 and Sinha and Kumar, 1971; 1979).

Pigeonpea (2n=22) is mostly self-pollinating, but 3 - 5% out crossing has been on record for this plant. This is probably a function of environment and populations of pollinating insects (Sheldrake 1984). Karyotypes in different varieties of *Cajanu*s *cajan* have been studied by several workers (Deodikar and Thakar, 1956; Kumar et al., 1958; Shrivastava et al., 1973; Sidker and De, 1967; Sinha and Kumar, 1971, 1979). The study conducted by Shrivastava et al., (1973) on 15 varieties and by Sinha and Kumar (1979) on 13 varieties, revealed varietal
differences. Only one satellited chromosome was observed. In some varieties no
satellited chromosome could be noticed and in variety NP-69, heteromorphic pair
was observed in total chromatin length (mean 27.6 to 44.9, Shrivastava et al.,
1973; 35.4 to 51.2, Sinha and Kumar, 1979).

**Biochemical studies in pigeonpea:**

Pigeonpea is a rich source of protein, carbohydrates and certain minerals.
Its seed is made up of three anatomical structures; the seed coat, cotyledons and
the embryonic tissue. The cotyledons contain about 90% proteins, 95% fat, 86%
carbohydrates, 83% minerals and most of the phosphorus of the whole seed. The
seed coat contains most of the non-digestible carbohydrates and relatively higher
proportion of calcium and iron. The cotyledons are the major sources of nutrients
(Salunkhe et al., 1986).

A wide variability exists in chemical composition of pigeonpea seeds due
to genotype, growth conditions and duration/condition of storage (Salunkhe et al.,
1985; Amaefule and Onwudike, 2000). The protein content of commonly grown
pigeonpea cultivars ranges between 17.9 and 24.3 g/100 g for whole grain samples
(Salunkhe et al., 1986). Wild species have been found to be very promising
sources of high protein and several high protein genotypes have been developed
showing protein content as high as 32.5% (Singh et al., 1990).

These high-protein genotypes contain protein content 20% higher than the
normal genotypes (Reddy et al., 1979; Saxena et al., 1987). The high protein
genotypes also contain significantly higher (about 25%) sulphur-containing amino
acids, namely methionine and cystine (Singh et al., 1990). Pigeonpea seeds contain
about 57.3-58.7% carbohydrates, 1.2-8.1 crude fibre and 0.6-3.8% lipids (Sinha,
1977). Pigeonpea is a good source of dietary minerals like calcium, phosphorus,
magnesium, iron, sulphur and potassium. It is also a good source of water soluble
vitamins, especially thiamine, riboflavin, niacin and choline (Sinha, 1977). The
pigeonpea plant as a whole has been found to be useful. It is used for food, feed
and fuel. It is most widely eaten in the form of split seeds; it contains protein with
an amino acid profile similar to that of soybean (Singh et al., 1990).

The proximate analysis of pigeonpea seeds revealed the content like dry matter (95.89-96.34%), crude protein (21.03-21.07%), crude fat (4.43-5.96%), crude fibre (7.16-7.52%) and ash (3.76-4.02%), respectively for the raw and roasted seeds of pigeonpea. While values for nitrogen free extract ranged from 57.77-59.51% for the roasted and raw pigeonpea seeds, respectively (Akande et al., 2010). The same researchers further concluded in their study on the amino acid composition of pigeonpea, which revealed that some amino acids (arginine, aspartic acid, threonine, serine, glutamic acid, glycine, alanine, leucine and tyrosine) were generally heat-stable and their concentrations increased with the heat processing (roasting), whereas the concentration of other amino acids (lysine, histidine, proline, cystine, valine, methionine, isoleucine and phenylalanine) decreased with heat treatment. Glutamic acid was found to have the highest concentration in pigeonpea with the value of 14.21 g/16 gN for the roasted seed, which was closely followed by aspartic acid with the value of 11.56 g/16 gN for the raw seeds and 12.20 g/16 gN for the roasted seeds. Similar report was made by Apata and Ologhobo (1994).

Lysine showed a highest concentration among the indispensable amino acids (7.79 g/16 gN for the raw seeds and 7.55 g/16 gN for the roasted seeds). Pigeonpea seed was found to be deficient in sulphur-containing amino acids (cystine and methionine). The nutrient composition of immature seeds varies significantly depending on the degree of moisture content at the time of analysis. Generally the immature seeds contain more moisture and less protein, carbohydrates, fats, minerals and fibers than the mature seeds on fresh weight basis.

Pigeonpea is a rich source of carbohydrates, minerals and vitamins. The seeds contain a range of 51.4–58.8% carbohydrates (Faris and Singh, 1990), 1.2 - 8.1% crude fibre and 0.6–3.8% lipids (Sinha, 1977). It is a good source of dietary minerals such as calcium (Ca), magnesium (Mg), sulphur (S) potassium (K)
(Sinha, 1977) and water soluble vitamins, especially, thiamine, riboflavin and niacin (Salunkhe et al., 1986). Pigeonpea contains more minerals, ten times more fat, five times more vitamin A and three times more vitamin C than the ordinary peas (Foodnet, 2002).

Nwokolo (1987) has determined the pigeonpea seed content with protein as (19.34%), ash (4.05%), crude fibre (5.56%) and a low content of lipids (3.24%), similar to composition in cowpea, bean and other pulses. Mineral content of pigeonpea meal is at par with most pulses and oil seeds. The potassium and phosphorus content is quite high while the calcium and magnesium contents are moderate. Contents of iron, zinc, copper and manganese are low. Values for mineral content obtained in these studies were similar to figures reported by Deosthale and Rao (1981) for phosphorus, calcium, magnesium, iron, zinc, copper and manganese.

The seed proteins of wild species have a poor solubility than that of cultivated pigeonpea, and this indicates an increase in solubility under domestication, and perhaps improved nutritional quality in this grain legume (Ladizinsky and Hamel, 1980). Trypsin and chymotrypsin inhibitor activities of several wild species were considerably higher than in pigeonpea (Singh and Jambunathan, 1981). The in vitro digestibility of wild species was quite similar to the values found for pigeonpea except for Rhynchosia rothii which revealed much lower digestibility.

**Antinutritional factors (ANF) in legumes:**

Pulses are considered to be highly proteinaceous and nutritious food but they are known to contain toxic substances as well, called as antinutritional factors (ANF), which include trypsin and chymotrypsin inhibitors, phytohaemagglutinins (lectin), polyphenols, flatulence sugars, saponins and alkaloids. These factors impair nutrient absorption from gastrointestinal tract and can result in detrimental effects on animal health and growth (Christodoulou et al., 2006).
Anti-nutritional factors such as protease (trypsin and chymotrypsin) inhibitors, amylase inhibitors and polyphenols, which comprise a known problem in most legumes, are less problematical in pigeonpea than soybean, pea (*Pisum sativum*) and field bean (Singh and Eggum, 1984; Singh, 1988; Faris and Singh, 1990). Within pigeonpea cultivars, anti-nutritional factors are mainly found among dark seeded genotypes (Faris and Singh, 1990) that are typically grown in Asia. The native African pigeonpea types are largely cream or white seeded with relatively less antinutritional factors. Trypsin inhibitor was first reported by Read and Hass (1938). Later on Bowman (1946) purified it and Kunitz (1945) isolated it in crystalline form. In legumes in recent past trypsin and chymotrypsin inhibitors have been studied in different plants like soybean (George, 2006), urd bean (Sagade, 2008), moth bean (Khadke, 2005) and winged bean (Dadke, 1999).

The lectins play a role in the plant itself as a store of nitrogen and as a specific recognition factor. Mostly in legumes the lectins are localized in the seed cotyledons in protein bodies and subcellular organelles related to lysosomes. Besides seeds the lectins have been found in all kinds of vegetative tissues of plants (Lis and Sharon, 2003). Lectins are the carbohydrate-binding proteins (or glycoprotein) of non-immune nature, and bind reversibly to specific mono- or oligosaccharides (Goldstein *et al*., 1980, Van Damme *et al*., 1998). Lectins adhere to the glycol-proteins present on the inner linings of the small intestine and inhibit absorption of food particles.

**Importance of mutation breeding:**

Mutation breeding has been used for improving both oligogenic as well as polygenic characters. It has been employed to improve morphological and physiological characters, disease resistance and quantitative characters including yielding ability. It is a cheap and rapid method of developing new varieties. It is a best way to overcoming the problem of tight linkage between desirable and undesirable characters. The mutation breeders have visualized that the desirable mutants in different legumes and oil crops would be able to contribute effectively
towards yield and protein content besides providing induced variation for disease, insect and pest resistance. Our country has been a leading center as regards the mutation research on cultivated plants. The production of large number of mutant varieties has been achieved in different crops. The major advantage of the use of induced mutations has been the possibility to correct one or few negative characters or to get new gene combination, which is desirable without changing the major part of the systems total genetic makeup. Due to the advantages of mutation breeding many scientists are entering in this field, for the development of new cultivars in different crop plants.

**Mutation Breeding for Improvement of Food Legumes at IARI:**

Food legume crops in general have lost many of their alleles for high productivity in the process of natural selection for adaptation to stress environments. Mutation breeding offers greater possibilities of success to make it possible to regenerate some of the lost genetic variability. A massive programme on basic studies on induced mutagenesis and applied aspects of mutation breeding in several legume crops was launched in the Division of Genetics, IARI, New Delhi. As a result of sustained efforts through the use of physical and chemical mutagens, the institute has made important contributions in understanding of induced mutagenesis (Kharkwal, 1998b,1999, 2001, 2003, Kharkwal et al., 1988, 2004, 2005) and also achieved major success in developing eleven high yielding, disease resistant and agronomically suitable mutant varieties in several crops like chickpea (4), cow pea (4), field pea (1), pigeonpea (1) and soybean (1) (Kharkwal et al, 2004, Kharkwal et al., 2008).

**Genetic Improvement of Pigeonpea at Indian Agricultural Research Institute:**

Pigeonpea is the crop of Indian origin and India is both its largest producer and consumer. The traditional pigeonpea varieties were having very long crop duration covering *kharif* and *rabi*, seasons. In the initial phases, the emphasis on pigeonpea improvement was on late maturing varieties. The first wilt resistant variety of pigeonpea developed by IARI in this maturity group recommended for
cultivation in North West Plains Zone and Gujarat was NP (WR) 15. It was, however, experienced that the traditional plant type of pigeonpea does not match the requirements of the present day intensive agriculture. Wheat sowing is often delayed in pigeonpea-wheat rotation cropping system because varieties of pigeonpea released in the past matured in > 150 days. The IARI, therefore, initiated a programme on breeding early maturing varieties of pigeonpea that can be grown in one season either in *kharif* (in north west zone) or in *rabi* (in Bihar and other areas of the north-east) and as a result large number of early maturing varieties suitable for diverse agro-climatic conditions have been developed by IARI. This institute has also developed new extra early pigeonpea varieties which are ideally suitable for pigeonpea-wheat rotation. These newly developed extra-early varieties of pigeonpea for instance Pusa-991 and Pusa-992 mature 8-10 days earlier in comparison to early maturing varieties. Thus, these varieties are more advantageous to farmers for growing pigeonpea followed by winter crops like wheat, chickpea and lentil. These varieties have shown yield potential which is higher or at par to earlier released varieties. The data on the basis of weighted average showed that Pusa-992 and Pusa-991 had 17.44% and 17.58% superior performance for grain yield, respectively, than the control variety UPAS-120. Both these varieties also gave as high yield as 2500 kg/ha in pre-monsoon sowing in Delhi and National Capital Region (NCR). An average yield of 1643 kg/ha (Pusa-992) and 1645 kg/ha (Pusa-991) have been recorded based on inter-location trials over 3 seasons in North West Plains Zone (NWPZ). Both these varieties (Pusa-992 arid Pusa-991) have shown earliness in maturity by one week (maturing in 141 and 142 days, respectively) as compared to UPAS-120 (148 days), which will enable timely sowing of the following winter crops. Several potential donors for agronomic traits as well as resistance to biotic and abiotic stresses have also been identified.

*Helicoverpa armigera* or the legume pod borer is the most damaging pest that causes over 50% of pest induced losses. The losses due to this pest in
Pigeonpea have been estimated to be US$317 million in the Semi-Arid Tropics (SAT) and over US$ 2 billion on different crops annually (Sharma et al., 2005a).

Frequent and rapid changes in cropping pattern and agro-ecosystems, the polyphagous nature of the pest, and its cosmopolitan abundance, have multiplied the problem manifold globally.

In India, calendar sprays are recommended and followed, with the first application at 50% flowering and the second and third applications at fifteen-day intervals. Farmers in southern India now apply pesticides 3-6 times per season. The rapid increase in pesticide use on pigeonpea is alarming and emphasizes farmer’s concern with insect pests. The trend also highlights the need for safe and effective management strategies. Use of biopesticides viz., neem and nuclear polyhedrosis virus (NPV) to control H. armigera has received much attention, particularly in India, though reliable control on pigeonpea has not been obtained. Neem and NPV products suffer from poor and highly variable quality and a more limited distribution network than conventional insecticides.

Pigeonpea is a major pulse crop of India after chickpea and contributes significantly to nourishment of a sizeable population. It is a crop of marginal conditions and is reported to be non-responsive to production inputs (Whitman et al., 1985).

It is perennial crop with indeterminate growth habit, photo-thermal sensitivity of flowering, long duration and low harvest index of the crop. It has generally slow initial growth with late season vegetative vigour, extreme plasticity of branching, profuse flower bud production but poor pod setting, photo-thermo sensitivity and facing long duration environmental vagaries (Bhattacharya, 2005).

This clearly indicates that there is not much increase in yield and it is stagnated over a period of time with substantial fluctuations in spite of availability of number of disease resistant varieties. It seems that the yield of these varieties has not been fully realized and stabilized. It is possible to enhance the productivity
when grown as a sole or in a cropping system by adopting various efficient management practices.

In *kharif* season, because of favourable climatic conditions, weeds have become a major problem. Weeds cause great losses than either insect or plant diseases (Crafts and Robins, 1973). Tiwari (1989) reported that 68 percent yield losses caused in *Cajanus cajan* L. Millsp. in peninsular zone were due to weeds.

Generally following weed spp. (Monocot & Dicot) are observed in pigeonpea viz. Monocot - *Cynodon dactylon, Leucas aspera, Panicum ischami, Digitaria sanguinalis, Helandi latibrosa, Commelian benghalensis*, Dicot - *Argimone mexicana, Acalypha indie, Parthenium hysterophorus, Amaranthus polygamus, Xanthium strumarium, Phyllanthus niruri* and *Convolvulus arvensis*. Weed management plays significant role in enhancing the crop yield.

Pulses contribute close to 60 MMT in the global food grainary. Of this, India's contribution is approximately 12 to 14 MMT (Chaturvedi and Ali, 2002) making it the largest producer accounting for 27-28% of global production. India's per capita net availability of pulses has come down to 36g/day as compared to 70g/day in 1960 (Chaturvedi and Ali, 2002). Similarly, percent contribution of pulses vis-a-vis other food grains in total food grain production has also decreased (Chandra and Pental. 2003).

**Development of legume mutant varieties:**

Sustainable efforts for food legume crop improvement through induced mutations in a large number of countries and institutes have resulted in development and release of more than 408 mutant varieties of food legume crops in the world. The highest number of induced mutants (115) in a food legume crop was developed in soybean. Majority of food legume mutant varieties have been released during the last two decades. The cumulative number of officially released legume mutant varieties in six continents of the world indicates that Asia tops the regional list closely followed by Europe and North America as indicated in table 7.
Table - 7. Number of released mutant food legume cultivars in various regions and in the top six countries of the world.

<table>
<thead>
<tr>
<th>Region</th>
<th>Region wise Number of released mutant cultivars</th>
<th>%of total</th>
<th>Country</th>
<th>Country wise Number of released mutant cultivars</th>
<th>%of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>257</td>
<td>63.0%</td>
<td>China</td>
<td>86</td>
<td>21.1</td>
</tr>
<tr>
<td>Europe</td>
<td>96</td>
<td>23.5%</td>
<td>India</td>
<td>85</td>
<td>20.8</td>
</tr>
<tr>
<td>N. America</td>
<td>39</td>
<td>9.6%</td>
<td>USSR/Russia</td>
<td>46</td>
<td>11.3</td>
</tr>
<tr>
<td>L. America</td>
<td>08</td>
<td>2.0%</td>
<td>USA</td>
<td>27</td>
<td>6.6</td>
</tr>
<tr>
<td>Africa</td>
<td>05</td>
<td>1.2%</td>
<td>Bangladesh</td>
<td>19</td>
<td>4.7</td>
</tr>
<tr>
<td>Australia</td>
<td>03</td>
<td>0.7%</td>
<td>Poland</td>
<td>22</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Japan</td>
<td>18</td>
<td>4.7</td>
</tr>
<tr>
<td>Total</td>
<td>408</td>
<td></td>
<td>Total</td>
<td>408</td>
<td></td>
</tr>
</tbody>
</table>

With more than 80 mutant varieties each, China (86 mutants) and India (85 mutants) are the leading countries engaged in the development and release of mutant varieties of food legume crops in the world. USSR/ Russia (46), USA (27), Pakistan (22), Poland (22), Bangladesh (19), Japan (18) Canada (12), Germany (10), Vietnam (10) and Italy (9) are among the other 31 countries, which have released mutant cultivars of legumes through mutation breeding.
Table 8. List of countries and number of mutant varieties of food legumes released by them through mutation breeding.

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Country</th>
<th>No. of Mutant Varieties</th>
<th>Sr. no</th>
<th>Country</th>
<th>No. of Mutant Varieties</th>
<th>Sr. no</th>
<th>Country</th>
<th>No. of Mutant Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Algeria</td>
<td>1</td>
<td>12</td>
<td>Germany</td>
<td>10</td>
<td>23</td>
<td>Poland</td>
<td>22</td>
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<td>Argentina</td>
<td>3</td>
<td>13</td>
<td>Hungary</td>
<td>1</td>
<td>24</td>
<td>Slovakia</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Australia</td>
<td>3</td>
<td>14</td>
<td>India</td>
<td>85</td>
<td>25</td>
<td>Sri Lanka</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
<td>15</td>
<td>Indonesia</td>
<td>4</td>
<td>26</td>
<td>Sweden</td>
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<td>5</td>
<td>Bangladesh</td>
<td>19</td>
<td>16</td>
<td>Iraq</td>
<td>2</td>
<td>27</td>
<td>Thailand</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Brazil</td>
<td>3</td>
<td>17</td>
<td>Italy</td>
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<td>28</td>
<td>Turkey</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Bulgaria</td>
<td>6</td>
<td>18</td>
<td>Japan</td>
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<td>29</td>
<td>USA</td>
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<td>8</td>
<td>Canada</td>
<td>12</td>
<td>19</td>
<td>Kenya</td>
<td>2</td>
<td>30</td>
<td>USSR/Russia</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>China</td>
<td>86</td>
<td>20</td>
<td>Korea</td>
<td>2</td>
<td>31</td>
<td>Vietnam</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Costa Rica</td>
<td>2</td>
<td>21</td>
<td>Myanmar</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Egypt</td>
<td>2</td>
<td>22</td>
<td>Pakistan</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: Kharkwal et. al., 2005a.)

Mutation breeding in some other crop plants:

Several scientists and plant breeders have contributed and developed high yielding varieties in different crop plants. Many attempts have been made to induce genetic variability for crop improvement through mutation breeding. Mutation breeding has made significant contribution in increasing the production of cereals, pulses and oil seeds. Kharkwal (2001) made survey of mutation.
breeding and related literature and suggested that the desirable results were obtained from the induced variability when it was fully integrated with conventional crop breeding programme.

The high yielding mutant in *Sesamum indicum* L. was developed through gamma radiation (Sarwar and Haq, 2005). The whorled capsule mutant in sesame has been achieved through the induction by gamma rays, ethyl methanesulphonate and sodium azide (Savant, 2008). Different types of mutant lines have been developed in pulses to increase their quantity and quality. Such lines have comprised dwarf, high yielding and early maturing mutants in cowpea (Pandey and Pawar, 1998), flower mutant and high yielding mutant in pigeonpea (Ratnam and Rao, 1998), high pod yield mutant in faba bean (Kalia et al., 2003), besides the compact bushy, dwarf and early maturing mutant lines in lentil (Solanki, 2005). Khatod *et al.*, (2002) studied the mutagenic effectiveness of gamma rays in inducing useful mutants in naturally coloured cotton.

Mishra *et al.*, (2005) stated that 15kR ·dose of Gamma rays was the most effective dose for creating polygenic variability for major economic traits in cowpea. Mutagenic effectiveness and efficiency of sodium azide (SA) on seed germination, early seedling growth and peroxidase isozyme composition has been evaluated in cowpea (*Vigna unguiculata* (L.) Walp) by Apparao (2005). Bharathi *et al.*, (2005) reported an increase in genotypic variability for the characters like number of pods per plant, pod yield per plant and seed yield per plant in *M₂* progeny of groundnut.

Kumar *et al.*, (2007) described a wide range of chlorophyll and viable morphological mutations affecting almost all the parts of the plant and seed characteristics isolated in *M₂* generation of black gram. Sagade (2008) reported drastic results in quantitative traits in urdbean by employing gamma rays, EMS and MMS. Auti and Apparao (2009) induced viable mutants in mung bean and Bhosle (2009) in cluster bean in *M₂* population by using SA, EMS and Gamma rays.
Kulthe (2009) and Barshile et al., (2009) successfully isolated different mutants in different cultivars of chickpea by employing different concentration/doses of SA, EMS and gamma rays, such as chlorophyll mutations, leaf mutations, pod mutations, seed mutations, flower mutations and morphological mutations.

**Mutation breeding in pigeonpea:**

Both physical and chemical mutagenesis have been reported in the improvement of pigeonpea.

**Physical mutagenesis:**

Abrams and Velez-Fortuno (1961) reported induced variability in the M$_2$ generation due to gamma irradiation for plant height and days to flowering. It was possible to fix some genetic characteristics in the M$_3$ and M$_4$ generations by single-plant selection (Abrams and Velez-Fortuno 1962).

The mutant under review was a bushy plant taller than the parental type, acquired habit of a xerophyte carrying reduced and thick leaves, reduced internodes and four types of branches borne on the same plant.

Konzak et al., (1965) put forward the concept of mutagenic effectiveness and efficiency. They have proposed the term 'effectiveness' as a measure of gene mutations in relation to dose and the “efficiency” as an estimate of mutation rate in relation to other biological effects induced, such as lethality, injury and sterility.

The very dwarf mutant and mutant with terminal clusters seemed to resemble the mutants Parbhani dwarf and Parbhani top reported earlier by Chopde (1969). Singh (1973) recorded an increase in number of branches, 1000-grain mass, and grain yield per plant in pigeonpea when treated with 10 kR gamma rays. Khan et al., (1973) have found a considerable amount of variability in x-ray and ethyl methanesulphonate (EMS) treated populations of CO-I. The maximum frequency of viable mutants was noted with 16 kR of x-rays and 60 nm of EMS.

Rao (1974) induced variability in pigeonpea for raceme length, pod number per raceme, seeds per pod, seed yield, and earliness when gamma rays were used in presoaked seeds at 2.5 kR, 5 kR, and 7.5 kR doses. Sharma and
Shrivastava (1974) reported irradiation induced mutant from variety T-21 and designated it as No. 9. This genotype had more primary branches, more pods and larger flowers, pod size, and seed number per pod. Another high yielding pigeonpea variety (CO 2) suitable for both rainfed as well as irrigated conditions was also developed through mutation breeding (Veeraswamy et al. 1975).

Jain (1976) reported induced mutations for pod number, pod size, seed size, and number of fruiting branches in pigeonpea due to ionizing radiations. Das and Tickoo (1977) studied the effect of EMS (0.05 to 0.2%) on germination and seedling injury in different varieties of pigeonpea (AS-3, AS-5, NP-69 and NP (WR) 15). They have reported that with the increase in concentration, there was decrease in germination.

Pawar et al., (1978) studied relative biological effectiveness (RBE) and mutagenic efficiency (ME) of gamma-rays (10-40kR) and Fast Neutrons (1-3kR) in Cajanus cajan var. T-21. Pawar et al., (1979) reported two early maturing bold seeded mutants TT -4 (Trombay Tur) and TT -6 from M3 generation of pigeonpea cultivar Type21.

Chaudhary and Singh (1980) recorded decreased germination with an increase in gamma ray dose, while the seedling lethality value increased in variety H-7020. The varietal and species specific differences as regards the radio-sensitivity could be recorded. Results obtained from pigeonpea were more uniform over cowpea, suggesting higher stability of pigeonpea crop.

Irradiating pigeonpea with gamma rays beyond 30 kR resulted in more than 50% reduction in germination and survival percentage (Mehetre et al., 1983). Natarajan et al., (1983) reported induced mutation in M2 generation with gamma irradiation and diethyl sulfate (DES). The maximum variability could be recorded for number of pods per plant followed by plant height. Rao et al., (1984) treated seeds of variety T-21, ICP-7409, and ICP2836 with various doses of gamma rays, DES, HZ, and EMS. Gamma rays proved to be the most potent in their study. It was reported that T -21 is most sensitive followed by ICP-2836 and ICP-7409.
varieties. Several mutants with profuse branching, prolific pod clusters and bold seeded pods appeared promising for increasing yield.

Pawar et al., (1984) irradiated seeds of T-21 with gamma rays at Bhabha Atomic Research Center, Trombay, Mumbai, India, and selected a new induced mutant, T-6. Natarajan et al. (1985) reported the effect of gamma rays and DES on germination, survival of seedlings, plant height, pollen fertility, and seed number in the M1 generation. The germination of seeds and survival of seedlings gradually reduced with an increase in dose of mutagens, but the reduction was more with gamma rays than DES.

Rao and Reddy (1983 and 1986) reported induced polygenic variability due to gamma rays, diethyl sulphate, ethyl methanesulphonate, and hydrazide hydrate in two varieties of pigeonpea (ICP 7439 and ICP 2836). The genotype, TAT 5, was developed in India by fast neutron irradiation of variety T 21. TAT 5 had larger seeds and early maturity feature (Anonymous 1986).

Rangaswamy (1986) studied pigeonpea variety CO-5 derived from CO-1 by gamma irradiation. It was characterized by early maturity, day-length insensitivity, and drought tolerance.

Rao et al., (1988) reported 20kR gamma ray induced mutants in pigeonpea cv. T-21 and found an increase in range, mean, genetic advance, GCV and heritability features. Selection for earliness in M2 and for plant height, pod bearing branches and seed yield per plant in M3 was found useful. Chary and Bhalla (1988) isolated a male-sterile mutant from pigeonpea ICP-7295 in M2 after treatment with 0.2 per cent EMS. The leaves of the mutant were long and narrow.

Shanmugasundaram et al., (1989) recorded an early mutant in red gram variety Co-5 for Tamil Nadu, having drought tolerance, lodging resistance and photosensitive feature, semi-spreading habit and giving good seed yield.

At ICRISAT, wilt resistant mutants have been isolated from the irradiated population of a highly wilt susceptible cultivar, LRG 30 (Saxena 1989).
Micke et al., (1990) recorded that the induced mutation in plant breeding can supplement the existing germplasm and can be used to improve specific characters. The various varieties obtained through mutagenesis considered mutation breeding in context of conventional plant breeding and new biotechnologies.

Toprope et al., (1999) detected a mutant in pigeonpea genotype BDN-1 with obcordate leaves and zygomorphic papilionaceous corolla. In the floral mutant, pollen grains were fertile, but the pod set was poor and occurred only on monocarpellate flowers. Seeds can be obtained by crossing mutant with any other variety.

Pandey and Pawar (2000) recognized a mutant with multifoliate leaves in the breeding material of TT 44-1, derived from an inter-specific cross of TT-5 (a radiation induced mutant of cv. T -21 of Cajanus cajan) and C. scarabaeoides.

Ravikesavan et al., (2001) isolated the extra early mutant from 100Gy dose treated 'Prabhat DT' variety of pigeonpea. The mutant gives the same yield in 90 days as that of the parent variety in 107 days, which made it an economic mutant.

**Chemical mutagenesis:**

The chemical mutagens have been found more effective as compared to irradiation. Khan et al. (1973) induced mutation in pigeonpea using presoaked seeds for 6 hours and by employing 60, 70, and 80 nm concentrations of EMS for 4 hours. Chaturvedi and Sharma (1978) isolated six male-sterile mutants of tall and dwarf habit in M₂ progenies of Pusa Ageti following treatment of presoaked seeds with 0.1-0.3% ethyl methanesulphonate for 6 hours. These mutants were late in flowering, had reduced inflorescence length, poor fruiting and high pollen sterility.

Genotype QMS1 treated with 0.03% sodium azide for 48 hours or 500 mg streptomycin sulfate per kg for 24 hours appeared to undergo mutational change from gametophytic to sporophytic sterility maintenance. Sterility was maternally
inherited and resembled genetic CMS. The maintainer was the heterozygous sib. Arinayagam et al.,(1995).

Srivastava and Singh (1996) reported that pigeonpea cv. Pusa-85 treated with 0.3 percent EMS and 0.03 percent NMU and of Pusa-601 treated with 450 Gy gamma rays, 0.2 per cent EMS and 0.3 per cent EMS had significant increase in total grain yield due to increased number of pods per plant. The highest rate of high yielding mutants was obtained from the 0.3 per cent EMS treatment in Pusa-85 and from 450Gy gamma ray treatment in Pusa-601.

Biradar (2004) studied gamma ray and ethyl methanesulphonate induced mutation in pigeonpea. In M₁ and M₂ generations there was general reduction in percent germination irrespective of doses. A wide range of variation was found in all the quantitative characters due to various mutagenic treatments. The study also revealed that combination treatment of gamma rays and 0.2% EMS were most effective in inducing qualitative mutants.

Shinde (2007) studied gamma ray and EMS induced mutation in pigeonpea. In M₃ generation there was general reduction in percent germination. A wide range of variation was found in all the quantitative characters due to various mutagenic treatments. The study revealed that the combination treatment (20 kR + 0.2% EMS) was most effective in inducing qualitative mutants.

The recent review of published literature indicates that physical as well as chemical mutagenesis was useful in improvement of pigeonpea. Mutation breeding offers an opportunity to improve the yield contributing characters in pigeonpea as a supplement to conventional breeding procedures. Some of the varieties developed by mutation breeding in India are listed in following Table 9.
Table 9. Pigeonpea varieties developed from induced mutations in India.

<table>
<thead>
<tr>
<th>Sr no.</th>
<th>Name of variety</th>
<th>Year of release</th>
<th>Mutagen</th>
<th>Main Characters improved</th>
<th>Reference MBNL (Issue: page)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Co 3</td>
<td>1977</td>
<td>EMS (0.6%)</td>
<td>High yield, bold seeded higher degree of shelling, field dormancy.</td>
<td>29:20</td>
</tr>
<tr>
<td>2</td>
<td>Trombay Vishakha-1</td>
<td>1983</td>
<td>Fast neutrons (fN).</td>
<td>Increased seed size with all desirable traits of parent variety T-21.</td>
<td>23:16</td>
</tr>
<tr>
<td>3</td>
<td>Co 5</td>
<td>1984</td>
<td>Gamma rays (160 Gy).</td>
<td>Early maturity, photoperiod insensitivity and drought tolerance.</td>
<td>29:20</td>
</tr>
<tr>
<td>4</td>
<td>TAT 5</td>
<td>1984</td>
<td>Fast neutrons (fN).</td>
<td>Increased seed size (50%), high TGW and early maturity (140 days).</td>
<td>28:19</td>
</tr>
<tr>
<td>6</td>
<td>PUSS 855</td>
<td>1993</td>
<td>Gamma rays 600 Gy.</td>
<td>Earliness, large seed.</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>TT-401</td>
<td>2007</td>
<td>–</td>
<td>Variety with high yield, tolerance to pod borer and pod fly damage.</td>
<td>–</td>
</tr>
<tr>
<td>8</td>
<td>TJT-501</td>
<td>2009</td>
<td>–</td>
<td>Variety is high yielding, early maturity and tolerance to Phytophthora blight.</td>
<td>–</td>
</tr>
</tbody>
</table>

Several researchers have induced viable mutations employing physical and chemical mutagens in pigeonpea and other legumes. Mutagenesis has been reported to be fruitful leading to improvement in various qualitative and quantitative agronomic traits in various crop plants and the mutation breeding has contributed significantly in releasing several novel varieties of crop plants. Micke (1995) concluded that the proper use of induced mutations in plant breeding has become a profitable approach.