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REVIEW

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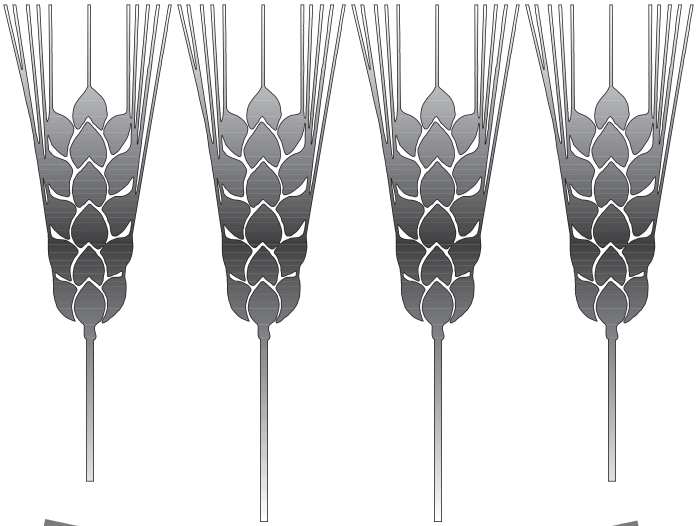

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GRAIN LEGUME CULTIVARS DERIVED FROM INDUCED MUTATIONS, AND MUTATIONS AFFECTING NODULATION

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ABSTRACT

Two hundred and sixty-five grain legume cultivars developed using induced mutations have been released in 32 countries. A maximum number of cultivars have been released in soybean (58), followed by common bean (50), groundnut (44), pea (32) and mungbean (14). Gamma or x-ray exposures of seeds led to the direct development of 111 cultivars, while neutron and chemical mutagen treatments resulted in 8 and 36 cultivars respectively. One hundred and three cultivars have been developed using mutants in cross breeding. Attempts have been made to estimate the successful dose range for gamma and x-rays, defined as the dose range, which led to the development, registration and release of a maximum number of mutant cultivars. Exposures to seeds ranging between 100-200 Gy in all grain legumes, except faba bean, resulted in 49 out of 111 cultivars being developed as direct mutants. Successful doses reported for faba bean are lower than 100 Gy. Modified crop plant characters are listed.

Besides the development of new cultivars, a large number of induced mutants that show altered nodulation pattern have been isolated in grain legumes. Such mutants have made a significant contribution in basic studies on host - symbiont interactions and towards cloning of plant genes related to symbiosis and nitrogen fixation. Their exploitation in breeding programs for enhancing nitrogen fixation, is just beginning. Available information on nodulation mutants in grain legume crops is summarised. Mainly, four types of nodulation mutants have been isolated. They show either: no nodulation (nod -), few nodules (nod +/-), ineffective nodulation (Fix-), hypernodulation (nod ++) or hypernodulation even in the presence of otherwise inhibitory nitrate levels (nts). Hypernodulating and nts mutants are of great interest. A soybean cultivar incorporating nts trait has been released in Australia.

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INTRODUCTION

Grain legumes include a wide variety of crops belonging to the family Leguminosae. All of them are valued for their protein rich grains, while soybean and groundnut seeds are important sources of vegetable fats, besides proteins. These crops, with symbiotically associated microbes, are able to fix atmospheric nitrogen and improve physical and chemical properties of soil. The importance of grain legume crops as a component of crop rotations in disease and pest management and in evolving sustainable cropping systems, was widely recognised in recent years due to the environmental problems caused by excessive use of chemical fertilisers, and pesticides. The grain legume crops display a wide range of climatic adaptability as well as growth habits. While all other grain legume crops are annual, pigeon pea is essentially perennial in habit but has been adapted as an annual crop. Earlier, induced mutations in peas was reviewed by Jaranowski and Micke [64], and an overview of genetic improvement of grain legumes using induced mutations was made by Micke [82] which included information on the cultivars developed till 1986. The overall importance of grain legumes in agriculture, the breeding problems and the prospects of induced mutations for grain legume improvement were also covered extensively. Since then, considerable progress in the development of new cultivars using induced mutations has been made. This review presents the current status of the cultivars developed using induced mutations and mutations affecting nodulation in grain legume crops.

METHODOLOGY

The data included is based on the information appearing in the Mutation Breeding Newsletters Vol. 1 (May 1972) to Vol. 43 (October 1997) and in the records of the Plant Breeding and Genetics Section of the Joint FAO/IAEA Division (1999 data). Successful dose has been defined in the presented paper as the dose, which directly led to the development, registration and release of a mutant variety, without using the mutant as a parent in a cross. However, considering all the variables, it is more useful to present a dose range, which led to the successful development of the maximum number of new cultivars The potential sources of errors in the presented paper are:

- insufficient or incorrect information provided by the breeders responsible for developing the new cultivar
- incorrect measurement of the radiation dose.

The dose in chemical mutagen treatments is much more complex. It is expressed as mutagen concentration x time (duration of soaking). Temperature, pH, post-treatment washing and soaking alter the actual mutagen concentration. Most breeders just mention the mutagen concentration without stating the duration of treatment. Hence, with the available information it is not possible to draw any conclusions regarding the successful dose.

GRAIN LEGUME CULTIVARS DEVELOPED WITH THE HELP OF INDUCED MUTATIONS

Grain legume cultivars developed with the help of induced mutations are listed in Table 1. Crops, and countries are in alphabetical order, while within a country the listing is based on the year of approval in an ascending order. Data on the number of cultivars in each crop is summarised in Table 2. A total of 265 cultivars have been released in 32 countries given in

Table 3. A maximum number of cultivars have been released in soybean (58), followed by common bean (50), groundnut (44), pea (32) and mungbean (14). In 1986 there were 100 mutant cultivars of grain legumes – now there are 265 (Table 2). A maximum increase is seen in common bean, white lupine, groundnut, pea and soybean. Most crops, other than those where only one cultivar has been developed, show an increase. However, in pigeon pea no new mutant cultivar has been released since 1986.

MUTAGENS USED TO PRODUCE NEW CULTIVARS

Mutagens used in the breeding programs for the development of new cultivars are listed in Table 4. Out of 265 cultivars developed, 111 were obtained as direct mutants following gamma or x-ray exposures, 36 after chemical mutagen treatments, and eight after exposure to neutrons. One hundred and three cultivars have been developed using induced mutants in the crossing program. Data for the major crops shows considerable variation with respect to the derivation of the new cultivars. While in soybean 91% (53/58) of the cultivars have been developed as direct mutants, the percentage of direct mutant cultivars is 50 in groundnut (22/44), and pea (16/32). Two induced mutants and cultivars derived from them have been extensively used for the development of new cultivars in common bean. In pea *afila* mutants in the crossing program have contributed to the development of new cultivars.

SUCCESSFUL DOSE OF GAMMA/X RAYS

Successful doses defined as the doses which led to the development, registration and release of a mutant variety directly without using the mutant as a parent in a cross breeding program for gamma and x-rays are listed in Table 5. The number of cultivars resulting from the exposure dose in Gy is given in brackets. The successful doses show a wide variation for all the crops. In soybean, where 38 cultivars have been developed as direct mutants, selected following gamma or x-ray irradiation, exposures to 100 Gy resulted in 11 cultivars. The same radiation dose resulted in five cultivars in mungbean, four in pea, two in chickpea and one each in common bean and cowpea. In groundnut exposure to 200 Gy resulted in 4/16 cultivars. Exposures ranging between 100 - 200 Gy in all grain legumes, except faba bean, resulted in 49/111 cultivars developed as direct mutants. Successful doses reported for faba bean are much lower than 100 Gy.

CHARACTERS MODIFIED IN MUTANT CULTIVARS

The most frequent and other characters of the new cultivars are listed in Table 6. After higher yield, which is mandatory for the approval and release of new cultivars, most common improved traits of the new cultivars are altered plant type, early flowering/maturity and large seed size. Plant type alterations include all changes in plant architecture such as dwarf, semi-dwarf and bushy growth habit. Plant architecture is recognised as one of the important traits for higher productivity of the grain legumes [61]. Days to flowering and maturity have been modified in many new cultivars. Mutations affecting flowering time are often observed at relatively higher rates in mutagenized populations. In *Arabidopsis thaliana*, mutants affecting flowering time have been extensively investigated [70]; at least, 80 loci affecting flowering time have been identified, 54 mutants have been characterised and 22 genes have been cloned

[72]. In pea, plant type alterations caused by *afila* mutant, characterised by modification of leaves into tendrils, have been extensively utilised in the development of new cultivars. Early, medium, and late maturing cultivars have been developed to extend the periods of harvest. In groundnut several cultivars with large pods and kernels have been developed. In *Lupinus* species, low alkaloid content is the key trait of the new cultivars.

A large number of other traits have also been altered in the mutant cultivars (Table 6). Resistance to various biotic and abiotic stresses, alterations in seed size, seed coat colour are common to several crops. Hyper nodulation, nitrate tolerance, and alteration of root pattern in soybean cultivars, thick or thin shell, which also determine the shelling percentage in groundnut cultivars are reported. Day length insensitivity, which determines vegetative and reproductive growth of the crop, is reported in pigeon pea and mungbean.

NODULATION MUTANTS IN GRAIN LEGUMES

Besides the grain yield, legume crops are valued for their endowment to grow in nitrogen (N) poor soils, and their ability to meet part of their N requirement through fixation of atmospheric N to ammonical N that can be used by the plants. Biological N fixation (BNF) by leguminous crops is an important component of N cycle in the agro-ecosystems. In plant growth and development N acquisition and assimilation is only next to photosynthesis in importance [138]. The two processes are interlinked and determine the crop productivity. Fixation of atmospheric N by leguminous plants is an extremely complex process that has been extensively investigated. There is a vast amount of published literature on different aspects of N fixation by grain legume crops. Readers should refer to comprehensive reviews available on the subject [1; 2; 7; 9; 13; 16; 30; 33; 47; 76; 83; 104; 118; 131].

Mutational analysis has proven to be a powerful tool in genetic analysis of microbial functions. This is also true for the symbiotic interactions between the root nodulating bacteria and the legume host. The advance in the understanding of *Rhizobium* and *Bradyrhizobium* genetics has been rapid where the symbiotic genes are located on large plasmids and on the chromosome respectively. Progress has been slow in legume plants, 80 genes affecting symbiosis have been identified in different legumes [137].

Genetic control of nodule number in pea was first reported by Gelin and Blixt [42]. Two nodulation resistant varieties of pea, one from Iran and the other from Afghanistan were discovered by Lie [73]. These varieties did not nodulate at 20^{o}C after inoculation with a temperature sensitive strain of *R. leguminosarum* though normal nodulation was observed at 26^{o}C. Another stock from Afghanistan showed strain specific restriction and did not nodulate after inoculation with the temperate strains. However, it showed normal nodulation after inoculation with the Middle-Eastern strain. Incompatibility between host plants of one region with the *Rhizobium* strains from a different region and strain specificity became evident from other studies [74]. These observations lead to the search for similar mutant types in the germplasm collections, and the use of chemical, and later physical, mutagens for inducing mutations affecting nodulation. The nodulation mutants were progeny tested, crossed with the parent and other lines to follow their inheritance, and appropriate gene symbols have been assigned. Mutants that nodulate in the presence of high nitrate concentration were first isolated by Caroll *et al.* [21] after treatment of soybean seeds with ethyl methanesulfonate. The available information on nodulation mutants in different grain legumes is summarised in Tables 7-9 for pea, soybean and other grain legumes respectively. Pea and soybean are the most intensively investigated crops for nodulation mutants. It is pertinent to mention that such mutants have also been obtained in forage legumes, but they are not included in the present context of grain legumes.

The nodulation mutants are broadly classified into following classes [115]:

nod-	no nodules
nod$^{+/-}$	few or no nodules
fix $^{-}$	ineffective nodulation
nod ++	supernodulation or hyper nodulation
nts(***n***itrate ***t***olerant ***s***ymbiosis)	nitrate tolerant nodulation.

In additions, other identified mutants showing resistance to mycorrhiza, and a deficiency in nitrate reductase, are included in Tables 7-9:

myc-	resistant to mycorrhiza
nar-	nitrate reductase deficient
etr	ethylene insensitive.

Ethylene insensitive mutants are gaining importance in basic studies. Ethylene-insensitive mutants isolated in soybean show altered pathogen susceptibility [56]. Nodulation mutants in pea can be reverted to normal nodulation by ethylene inhibitors [39; 50]. However, in soybean no differences in the nodule number on a variety of soybean mutants showing strong, intermediate and weak ethylene insensitivity were found [117].

Investigators who have recorded nodulation in field experiments with native soil microbes have used more descriptive classification [142]:
Non nodulating with native root nodulating bacteria (RNB)
Non nodulating with a specific strain, low nodulating with native RNB
Low nodulating at low N
High nodulating at low N but low nodulating at high N
High nodulating at high N

INHERITANCE OF NODULATION MUTANTS

Spontaneous as well as induced nodulation mutants are mostly monogenic recessive (see Tables 7-9), though involvement of two and more genes [36], and some dominant [17; 31; 38] mutations are also reported. Many of the induced hypernodulating mutants in different cultivars of soybean have been found to be allelic [32]. Non-nodulating soybean mutants (nod49 and nod 772) were allelic but not nod 139. Hypernodulating nts382 was not allelic to any of these non-nodulating mutants, and non-nodulation was found to be epistatic over hypernodulation [80]. No spontaneous hypernodulating mutant has been reported. Earlier, most hypernodulating mutants were obtained after treatment with chemical mutagens [16]. However, a fast neutron induced hypernodulating mutants in soybean has recently been reported recently by Gresshoff *et al.* [48].

Natural and induced mutations isolated in different grain legume crops show no, decreased, ineffective, hyper and nitrate tolerant nodulation. The observed outcome results from the interactions of two genetic systems and is bacterial strain dependent. The non-nodulation mutants restrict nodule formation after inoculating either with a specific or with many different bacterial strains. In nod-, and fix- mutants the nodulation process is blocked at different stages of nodule development. Some of the nod- mutants show no differences in early signal exchange or other pre-infection events. Non-nodulation is totally controlled by the root genotype [23; 81]. The root exudates of nod- mutants show similar *nod* gene inducing activity. Others show few subepidermal cell divisions but infection threads are not formed. Beside mutants with developmentally defective root hair development, low rate of nodule meristem emergence, and pre-mature senescence of nodules have been isolated. Many nodulation mutants have altered root characteristics and many plant hormones known to influence root development also affect nodulation.

USE OF NODULATION MUTANTS

Mutants affecting nodulation have been used to understand the role of specific genes in the development and functioning of the root nodules. Suggestions have been made to make use of the restrictive nodulation mutants and combine several genes to eliminate competition with the native soil *Rhizobia* [75]. Low competitive ability of the selected or genetically tailored strains in field is widely recognized as the major constraint in enhancing BNF by the grain legume crops [41]. A crop cultivar having gene(s) that restrict nodulation from the native soil *Rhizobia* will be nodulated only by the identified inoculated strain.

Inhibition of nodulation and N fixation in the presence of soil nitrates is the second major constraint in the utilization of BNF. Presence of nitrate inhibits early steps of nodulation as well as N fixation [20; 132]. Hence, hypernodulating and *nts* mutants are of great interest. Pierce and Bauer [105] and Caetano-Anolles and Gresshoff [16] have discussed the evidence that suggests feed-back control of nodule development after the formation of a critical number of nodules. This is referred to as autoregulation and was first observed by Nutman [92] in red clover; surgical removal of functional nodules restored formation of new nodules. *nts* mutants in soybean are reported to diminish autoregulation. Hypernodulation was observed when the shoots of hypernodulating mutants of soybean and common bean were grafted on normal and non nodulating genotypes, indicating that hypernodulation is primarily controlled by the shoot [23; 29; 28]. Grafting of the shoots of a hypernodulating soybean mutant on normal nodulating soybean, mungbean and hyacinth bean, has shown that a common ‘shoot-generated’ signal that is translocated through the graft, induces hypernodulation in all species [53]. Substances involved in autoregulation or the mechanisms are reported to be different in soybean and common bean [51]. Hypernodulation mutants have been used to find answers to many questions related to nodulation [16; 48]. The *nts-1* gene has been mapped on the linkage group H of the USDA soybean map, 0.3 to 0.4 cM from pUTG132a marker [48] and efforts are on map-based cloning of the gene. No host nodulation genes have been cloned nor has their product been identified yet.

FIELD ASSESSMENT OF THE HYPERNODULATING MUTANTS

The initial performance of the hypernodulating mutants NOD1-3, NOD2-4 and NOD3-7 [144] and NOD4 and NOD1-3 [108] in field experiments were disappointing. Yield of normal nodulating parent ‘Williams’ and other cultivars were significantly higher than the hypernodulating mutants. Similarly the yield of the *nts* mutants, though producing five times the number of nodules and eight times the nodule weight in comparison to the check cultivar ‘Centaur’, did not show a consistent increase in productivity. Grain yields ranged between 25% less to equal those of the normal nodulating cultivars. However, the carry-over effect on the following crop of oats and barley was significantly higher after the hypernodulating genotypes, in comparison to the normal nodulating cultivars [130]. Subsequently, a hypernodulating (*nts*) cultivar ‘Nitrobean-60’ has been released in Australia [3; 32]. Low productivity of the hypernodulating types have been attributed to physiological growth limitation due to excessive nodulation. Other deleterious mutations, unrelated to hypernodulation, could also be responsible for low productivity [108]. Reduction in yield of the selected mutants, relative to the parent, has often been observed in induced mutation experiments. Usually it is possible to recover the yield losses after backcrossing the mutant to the parent and other cultivars. The same may be true for the hypernodulating mutants.

TABLE 1. CULTIVARS DEVELOPED WITH THE HELP OF INDUCED MUTATIONS IN DIFFERENT GRAIN LEGUME CROPS

Name of new variety	Country and year of release	Mutagenic treatment or cross with mutant	Main improved attributes of the variety	Reference MBNL (Issue:page)
***Arachis hypogaea* L. (groundnut)**				
Virginia No. 3	Argentina 1979	Gamma irradiation, seed	Large pods; higher oil yield	30:20
Colorado Irradiado	Argentina 1972	x-rays, 200 Gy	Higher yield; higher oil content; better resistance to disease	7:13
Virginia No.5	Argentina 1980	Selected from segregating material from Florida	n/a	15: 9
Yueyou No. 22	China 1968	Cross: (Fushi x Fuhuasheng) Fushi is beta-ray induced mutant	Dwarf plant type; higher pod number and yield	19: 2
Yueyou No. 33	China 1971	Selection from Yueyou 22	Higher yield	37:20
Changua No. 4	China 1972	Gamma rays, 150 Gy recurrent irradiation	Early flowering; cold and drought tolerant; ‘dense’ pods	27:19
Yueyou 551	China 1972	Cross: Yueyou 22 x Yueyou 431	Dwarf type; larger number of pods, higher yield	25: 9
Yueyou 551-38	China 1975	Selection from Yueyou 551	Higher yield	37:21
Yueyou 551-116	China 1975	Selection from Yueyou 551	Higher yield; 6.6 to 12.8 % over Yueyou 551	37:21
Yueyou 551-6	China 1975	Selection from Yueyou 551	Higher yield; large pods	37:21
Yangxuan 1	China 1978	Cross: Yueyou 1 x Yueyou 551	n/a	37:20
Yuexuan 58	China 1978	Selection from Yueyou 551	Higher yield, 8.5% over Yueyou 551	37:21
Yueyou 169	China 1980	Cross: Yueyou 551-6 x 76/30	Luxurious growth; large and thick dark leaves, large pods; 5.6% higher yield over Yueyou	37:21
Yueyou 187	China 1981	Cross: (Yueyou 1 x Yangxuan 1) x Yueyou 551	Relatively tall; more flowers; large pods; 9-10% higher yield over Yueyou 551	37:21
Yueyou 187-93	China 1982	Cross: (Yueyou 1 x Yangxuan 1) x Yueyou 551	Relatively tall; more flowers and large pods; 9-10%, higher yield over Yueyou 551	37:21
Lainong	China 1984	Laser, seed	Early maturity, higher yield	37:19

Shanyou 27	China 1985	Cross: Yuexuan 58 x Yueyou 320-14	Uniform emergence, many branches; thin shell; rust resistance; 10% higher yield over Yueyou 551-116	37:20
Xianghua No. 1	China 1985	Cross: Yueyou 551 x Furong	Early maturity, yield	41:24
Fu 22	China 1985	Gamma rays	Resistance to *Aspergillus flavus* causing aflatoxin development	37:19
Fu 21	China 1985	Gamma rays, 200 Gy	Short stem; more branches; higher yield; better resistance to bacterial wilt	29:20
P-12	China 1986	Cross: (Changda 6 x ma 143) x Baisa 1016	Higher yield, reduced plant height, greater peg strength	37:20
Luhua 6	China 1986	Gamma rays, 240 Gy, seed	13.6% higher yield; and 10 days earlier than parent variety	34:26
Luhua No. 7	China 1986	Gamma rays	Improved lodging, water logging and shattering resistance; medium maturity; vertical plant type; large pods	32:19
78961	China 1988	Cross: ma143 x RH77-4-2	Early maturity; reduced plant height	37:19
Ganhua No. 1	China 1990	Gamma rays, 200 Gy	Early; higher yield	41:23
8130	China, 1993	Gamma rays, 250 Gy, Cross (Luhua 4 x RP1) x RP1	High yield, good flavour; export quality	44:31
Luhua 13	China 1994	Cross: involving Luhua 6 & MA 143	High yield, seed shape; leaf colour	44:31
Luhua 15	China, 1997	Gamma rays, 250 Gy, Cross involving irradiated Runner	High yield, maturity, improved seed quality	44:31
Huaya 16	China 1999	Gamma rays 250 Gy	Higher yield and shelling percent wider adaptability	44:31
MH-2	India 1973	n/a	Higher yield; semi-dwarf; resistant to *Cercospora personata*	37:20
TG 3	India 1973	x-rays, 150 Gy	Higher yield; more pods per plant	3:11
TG 1 (Vikram)	India 1973	x-rays, 150 Gy	Large pods and kernels; suitable for HPS export	3:11
TG 14	India 1976	Inter mutant cross	Uniform maturity; higher yield under irrigation	12:15
TG 17	India 1977	Inter mutant cross	Higher yield; short plants; no secondary branches	12:15

BP-2	India 1979	Gamma rays, 450 Gy	Higher yield; semi-erect; gigas type; large kernels	32:19
BP-1	India 1979	Gamma rays, 450 Gy	Higher yield; semi-erect; large kernels	32:19
Co-2	India 1985	EMS, 0.2%	Higher yield; and shelling %; resistance to “Tikka” disease	26:12
TAG 24	India 1989	Cross: (TG 18A x M-13) x (line x TG-9)	Higher yield; resistance to bud necrosis	41:24
Somnath	India 1989	Cross: TG 18A x M-13	Early; large kernel size; higher oil content	41:24
TG 26	India 1996	Cross involving mutant derivatives	Semi-dwarf plant type; early maturity; higher HI; seed dormancy; field tolerance to major diseases	43:25
Sin Padetha	Myanmar 1982	Gamma rays, 400 Gy	10-15 days early	20:16
ANK-G1(Tissa)	Sri Lanka 1995	Gamma rays, 200 Gy	Higher yield; low input requirements	43:39
N.C. 4-X	USA 1959	Seeds, x-rays	High yield; tough hulls - resists damage during harvest and transport; good quality	3: 7
B 5000	Vietnam 1985	Gamma rays, 50 Gy, seed	Vigorous growth; early maturity; higher shelling %; white testa	31: 9
***Cajanus cajan* Millsp. (pigeonpea)**				
Trombay Vishakha -1	India 1976	Fast neutrons	35% increase in seed size, with other characters (yield, maturity time, disease reaction equal to the parent variety T-21.	23:16
Co 3	India 1977	Seeds, 0.6% EMS	Higher yield; large seed size; higher shelling %; field dormancy for 15-20 days	29:20
Co 5	India 1984	Seeds, Gamma rays 160 Gy	Early maturity; day length insensitive; drought tolerance	29:20
TAT-5	India 1984	Seeds, Fast neutrons 150 Gy	Approximately 50% larger seed size; TKW 100-117 g; early maturity (140 days)	28:19
TAT-10	India 1985	Cross: TT-2 (large seeds, compact) x TT-8 (early) both induced by 250 Gy fast neutrons	Medium-large grain size; early maturity (115-120 days)	28:20

***Cicer arietinum* L. (chickpea)**				
Hyprosola (M-699)	Bangladesh 1981	Gamma rays, 200 Gy	Early maturity (10 days early); more pods; higher HI, and yield (19% higher); suitable for high density planting	19:14
Line 3	Egypt 1992	Gamma rays, 50 Gy + EMS 0.025%	Yield	43:43
Kiran (RSG-2)	India 1984	Seeds, fast neutrons 4.5 x 10^{12}	Erect habit, increased number of pods/plant, early maturity; tolerance to salinity; higher yield	26:12
Ajay (Pusa 408)	India 1985	Gamma rays, 600 Gy	Highest yield in NW India; resistant to *Ascochyta* blight; semi-erect; profuse branching; 140-155 days for maturity	29:21
Atul (Pusa-413)	India 1985	Gamma rays, 600 Gy	Highest yield in NE India; resistance to wilt; moderate resistance to *Ascochyta* blight; stunt virus foot rot, root rot; semi-erect; profuse branching; large number of pods; more than 2 grains/pod; maturity in 130-140 days	29:21
Girnar (Pusa-417)	India 1985	Gamma rays, 600 Gy	Highest yield in Central India; short; semi-erect; profusely branched; large number of pods; matures in 110-130 days; highly resistant to wilt; moderately resistant to stunt virus, collar rot, foot rot, root rot; low pod borer and nematode damage	29:21
CM 72	Pakistan 1983	Gamma rays, 150 Gy	Resistant to *Aschochyta rabiei*; high yield	23:16
NIFA-88	Pakistan 1990	Gamma rays 100 Gy	Moderately resistant to *Ascochyta rabiei*; 2 week earlier maturity; fixes greater amount of N; exceeds in yield all other commercial vars. in Pakistan	37:24
CM-88	Pakistan 1994	Gamma rays, 100 Gy	Disease resistance	43:43
NIFA-95	Pakistan, 1995	Gamma rays, 200Gy	Blight tolerance, higher yield and N fixation	44:34

***Dolichos lablab* L. (hyacinth bean)**				
Co 10	India 1983	Gamma rays, 240 Gy	Bushy plant type; greenish white tubular pods; higher yield	29:22
***Glycine max* L. (soybean)**				
Cerag No. 1	Algeria 1979	Gamma rays, 300 Gy	Mutant selected in 1974 in Romania by I. Nicolae; early; resistant to spring cold; very productive; drought resistant; short plant type; white flowers; yellow seeds	14:11
Nitrobean-60	Australia 1995	EMS 1%, 6 h	Hypernodulation; nitrogen carry over; nitrate tolerant nodulation	43:44
Boriana	Bulgaria 1981	Seeds, Gamma rays 100 Gy 1% EMS for 4 h	Maturing in 105-110 d; 30 d earlier; and 6% higher yield than parent cv Beeson; protein 5% higher	23:18
Zarya	Bulgaria 1984	Seeds, Gamma rays 80 Gy	Early; high yield and protein content	32:23
Bisser	Bulgaria 1984	Gamma rays, 100 Gy + EMS 0.1%; seeds	High yield, and protein content; early; stem resistant to lodging	31:20
Tainung No. 1 R	China (Taiwan) 1962	Thermal neutrons	Vigorous variety with less pod shedding tendency; long branches; higher yield	3:34
Tainung No. 2 R	China (Taiwan) 1962	x-rays	Vigorous variety with less pod shedding tendency; short internodes; large seeds; adaptable to acid or alkaline soils	3:34
Heinoun No. 4	China 1967	Seeds, Gamma rays, 100 Gy	Compact; branched type	25:10
Heinoun No. 5	China 1967	Seeds, Gamma rays, 100 Gy	Good root system; short internodes, larger number of branches and pods	25:10
Heinoun No. 7	China 1967	Seeds, Gamma rays, 100 Gy	Higher branch number; short internodes; drought tolerance; wide adaptability	25:10
Heinoun No. 8	China 1967	Gamma rays, 100 Gy	10 days earlier than the parent cv Dongnoun No. 4; humidity tolerance	25:10
Heinoun No. 6	China 1967	Seeds, Gamma rays, 100 Gy	Tall plants; tolerance to drought	27:20
Fengshou No. 11	China 1970	Seeds, Gamma rays, 140 Gy	Matures 30 days earlier than parent; strong stem; resistance to lodging; large number of branches	27:20

Heinoun No. 16	China 1970	Seeds, Gamma rays, 100 Gy	Large number of branches; short internodes; tolerance to drought; wide adaptability	25:11
Tiefeng 18	China 1970	Seeds, Gamma rays, 120 Gy	Suitable for high fertility soils; lodging resistance; higher yield; good quality	25:11
Heinong No. 26	China 1975	Cross: HAR 63-2294 x Xiaojinuang No.1	Good stature; tolerant to cold, drought, and water logging; good quality	25:11
Mushi No. 6	China 1980	Seeds; Gamma rays F_2 (Fengshou No.10 x Jilin No.3)	Early maturity; lodging resistance; strong plants; higher yield; better quality	25:11
Liadou No. 3	China 1983	Seeds, Gamma rays, (6405 x Amuson)	Early maturity; strong stem; resistant to lodging; resistant to virus and *Sclerophotora macrospora*; tolerant to water logging	27:20
Wei 7610-13	China 1983	Gamma rays and fast neutrons	Maturity 6 d earlier; resistant to sporotrichosis; 20% increase in yield	32:23
Heinong 28	China 1986	Seeds, thermal neutrons, 5×10^{11} n/cm^2 (Heinong No. 16 x Zyuushoo Nagaka)	Growth period 121 d; strong stem; higher yield; good quality; protein 38.7%; fat 21.3%	30:21
Heilong 32	China 1987	Thermal neutrons, 5×10^{11} thn/cm^2, dry seeds (F_4 of Har 70-5072 x Har No. 53)	High yield; resistant to virus; drought tolerant; good adaptability; 22.8% fat; 40.7% protein	32:22
Heilong 31	China 1987	Thermal neutrons 5×10^{11} thn/cm^2, dry seeds (F_4 of Har 70-5072 x Har No. 53)	Tolerant to diseases and drought; high yield; growing period 119 d; TGW 180 g; 41.4% protein; 23.2% fat.	32:22
Heinong 34	China 1988	Cross: Heinong 16 x Tokachinogaha	High yield, high protein	44:35
Liaonong 1	China 1988	Gamma rays, 200 Gy, F_2 seeds of [Heinong 11 x Tieefeng 9]	7-10 days earlier; 10% higher yield than check cv “Heihe 3”	34:29
Fengdou	China 1988	Gamma rays; 200 Gy; F_2 seeds of [(Qunxuan 1 x Qun Ying Dou) x Tiefeng 9]	110-120 d till maturity	34:29
Heinong 35	China 1990	Cross: Hei Nong 16	High yield, high protein content	44:36
Sui Nong 12	China 1996	Gamma rays, 120 Gy	Increased yield	44:36

Heinong 41	China 1997	Cross: mutant x mutant gamma rays; thN	Increased yield, large seed size, tolerance to alkaline soils	44:36
Aida	CSFR 1984	Seeds, EMS	Matures 10 days earlier than Dunajka (140 days)	26:13
Dorado	GDR 1988	Seeds, NMH 1mM	Higher grain yield; longer stem; higher insertion of the lowest pod	34:29
Noventa	Hungary 1989	Gamma rays, 100-300 Gy	Extremely early	41: 8
Muria	Indonesia 1987	Gamma rays, 200 Gy, seeds	High yield; short stature; beter lodging resistance	35:35
Tidar	Indonesia 1987	Selection from gamma ray induced mutant G-2120 from AVRDC	Early maturity (7 d); high yield; yellowish green seed coat colour	35:35
Tengger	Indonesia 1991	Gamma rays, 200 Gy	Earliness; eating quality; seed colour	42:27
Raiden	Japan 1966	Dry seeds, Gamma rays, 100 Gy	Earlier maturity; shorter stem; resistance to lodging; maintains high yield and nematode resistance of the parent cv.	6: 8
Raiko	Japan 1969	Gamma rays, 100 Gy, dry seeds	Early maturity; short stem; resists lodging; higher yield; maintains nematode resistance of the parent cv. Nemashirau	[82]
Nanbushirome	Japan 1977	Raiden x Kitaminagaha	Intermediate maturity; long leaves; high yield; resistant to cyst nematode	12:13
Wase-suzunari	Japan 1983	Gamma rays, 100 Gy	Very early; maintaining good quality and high yield of parent cv. Okushirome	32:23
Kosuzu	Japan 1986	Gamma rays, 100 Gy; seeds	Early; lodging resistance; maintaining most of the other characters of parent cv. Natto-Kotubu	32:22
Ryokusui	Japan 1990	Gamma rays, 200 Gy	Lateness; eating quality	42:27
KEX-2	Rep. of Korea 1973	X-rays, 240 Gy	Early maturity; 11 days early; higher yield (16%); large seed size	4:14
Bangsa-Kong	Rep. of Korea 1985	Seeds, x-rays, 250 Gy	High yield due to large number of pods; smaller seed size for good soybean sprout; resistant to soybean virus N	26:13

Doi Kham	Thailand 1986	Gamma rays, 300 Gy, seeds	High resistance to rust (*Phakospora pachyrrhizi*); 15% higher yield than the parent SJ4 in rainy season with rust incidence; larger seed size	33:24
TAEK C10	Turkey 1994	Gamma rays, 100 Gy	Oil content; earliness; yield	43:45
TAEK A3	Turkey 1994	Gamma rays, 200 Gy	Yield; protein; pod position	43:45
Universal 1	USSR 1965	Gamma rays	Lodging resistance; can be used as grain crop or as green fodder. Surpasses initial variety by 500 kg/ha in grain yield	19:14
Chudo Gruzil 7	USSR 1974	Gamma rays	n/a	37:25
Dioskuriye	USSR 1980	Gamma rays	n/a	37:25
Kartuli 7	USSR 1980	Gamma rays	n/a	37:25
Mutant 2	USSR 1980	Gamma rays	n/a	37:25
Arkadiya Odes	USSR 1986	DMS, 1mM, seeds	Early ripening; good for rainfed conditions	31:20
Luchezarnaya	USSR 1990	MNH	Earliness	40:13
Paripatskaya	USSR 1991	ENH, 0.125%	Disease resistance - bacteriosis, ascochytosis and peronosis	40:13
Mageva (Lastochka-out)	USSR 1991	Chemical mutagen	Earlyness; disease resistance	40:13
DT 83	Vietnam 1987	EI, 0.04%	Seed colour; yield	43:44
DT 90	Vietnam 1993	Gamma rays, 180 Gy F_1 from (G7002 x Cocchum)	Yield; protein content	43:44
DT 84	Vietnam 1994	Gamma rays, 180 Gy F_1 from (DT-80 x DH-4)	Yield; cold tolerance	43:44
S-31	Vietnam 1995	Gamma rays, 180 Gy +EI 0.04%	Yield; cold tolerance	43:44
***Lathyrus sativus* L. (plavine)**				
Poltavaskaya 2	USSR 1980	ENH, 0.01%	Drought tolerant, disease and insect resistance	40:14
***Lens culinaris* Medik. (lentil)**				
S-256 (Ranjan)	India 1981	Radiation	Spreading type; higher yield; 110 d for maturity	20:17

***Lupinus albus* L. (white lupine)**				
Keivsky mutant	USSR 1969	F_1 250 Gy, F_2 25 Gy (fractionally 30-40 Gy) [Hvanchkoly x sample from Syria]	Higher grain and forage yield; less alkaloid: higher protein (44%) and lysine (6.8%) content	[82]
Gorizont	USSR 1977	Cross with alkaloid-free mutant induced by EI	Low alkaloid content	13:20
Dnepr	USSR 1978	Cross with mutant induced by EI		13:20
Solnechnyi	USSR 1980	Chemical mutagen	Alkaloid content; disease and insect resistance	40:15
Slavutich	USSR 1980	Cross: M-70VA x VI-M-70-S	Alkaloid content; earliness; disease resistance	40:15
Ukrainiski	USSR 1981	MNH, EI and DMS repeated treatments	Alkaloid content	40:15
Vympel	USSR 1982	EI	Earliness	40:15
Start	USSR 1983	Gamma rays	Ripening 15 days earlier than the standard; disease resistance	31:27
Druzhba	USSR 1984	EMS, 0.5%	High yield	31:26
Pichevoy	USSR 1987	Chemical mutagens	Good plasticity	31:26
Olezhka	USSR 1989	ENH, MNH	Alkaloid content; earliness	40:14
Sini parus	USSR 1991	Cross: mutant x mutant	Lodging resistance; protein content; seed productivity	40:15
***Lupinus angustifolius* L. (blue lupine)**				
Chittic	Australia 1982	Seeds, 024% EI, several crosses with early flowering mutants	Early flowering	20:17
***Lupinus cosentini* Guss. (sandplain lupin)**				
Eregulla	Australia	EI, crossing of mutants	Early flowering; low alkaloid content; white flowers and seeds; non shattering pods	12:14

***Lupinus luteus* L. (yellow lupine)**				
Aga	Poland 1981	Seeds, x-rays mutant population x Afus	Early maturing; resistant to *Fusarium*; high yield potential	19:15
Narochanski	USSR 1983	Gamma rays	*Fusarium* resistance; early; high yield; good fodder quality	31:27
Martin 2	USSR 1984	Hybridization of mutants resistant to *Fusarium*	Resistance to disease; green mass yield 50-70 t/ha	31:27
Kopiloviski	USSR 1985	Niko x mutant line	*Fusarium* resistant	31:27
***Phaseolus coccineus* L. (scarlet runner)**				
Eureka	Poland 1991	Gamma rays	Dwarfness	41:28
***Phaseolus vulgaris* L (common bean)**				
Carioca Arbustivo	Brazil 1986	Gamma rays, 320 Gy	Bush type; 5-14 d earlier maturity	34:33
FT-Paulistinh	Brazil 1992	Cross A-252 x Carioca	Yield; *Anthracnose* and leaf spot resistance	42:33
Mitchell	Canada 1986	Cross: Seafarer x Tuscola	n/a	34:33
Alfa	CSSR 1972	EMS, 0.2%	White seed colour; improved seed and protein yield; earliness; resistance to *Coletotrichum lindemuthianum*;cooking quality	10:16
Giza-80	Egypt 1980	Seeds; Gamma rays 100 Gy	Rust resistant; 12% higher yield; higher TGW; white seed coat; higher protein content; reduced cooking time	17:14
Universal	FRG 1950	X-rays, 30 Gy	Early maturity; higher yield; resistance to *Colletotrichum lindemuthianum*	[82]
Unima	FRG 1957	Selection from Granda x Universal	Immune to *Colletotrichum lindemuthianum*	[82]
Pusa parvati	India 1970	Seeds, x-rays	Early; bushy type; round, meaty, light green pods; higher yield	[82]
Montalbano	Italy 1985	EMS	Uniform white seed instead of variegated; otherwise same characters as Mogano	31:31

Mogano	Italy 1985	EMS	Uniform beige seed coat instead of variegated; dwarf;resistant to bean common mosaic virus; earlier and higher yielding than Cannelino, Impero or Opal	31:31
Sanilac	USA 1956	X-rays, selection from cross involving Michelite mutant, Robust, Crawford, Emerson 847 and Emerson 53	Bush type; early maturity; resistant to alpha, beta and gamma races of *Colletotrichum lindemuthianum*, and bean common mosaic virus 1 and 123; tolerant to *Sclerotinia sclerotiorum*	[82]
Seaway	USA 1960	Selection from cross involving Michelite, Michelite mutant and topcross	Short-season; upright; bush type; resistant to bean common mosaic virus 1, 15 and 123	[82]
Gratiot	USA 1962	Selection from cross involving Michelite, Michelite mutant and B 1788	Same as for Sanilac except stiffer straw; added resistance to bean common mosaic virus 1, 15, and 123	[82]
Seafarer	USA 1967	Selection from cross involving Michelite, Michelite mutant Trag 279-1, Florida Belle and Emerson 847	Very early maturity; bush type; resistant to alpha, beta and gamma races of *Colletotrichum*, *lindemuthianum* and bean common mosaic virus 1, 15 and 123	[82]
Ouray	USA 1982	Cross: (Sanilac x UI 111) x rust resistant Pinto selection	Bush habit derived from Sanilac; resistant to bean common mosaic virus; and some races of *Uromyces phaseoli*	28:22
Neptune	USA 1986	Cross: MSU 31906/ San Fernando/x Seafarer	Maintains plant architechture derived from Seafarer	30:25
Saparke 75	USSR 1967	Gamma rays, 7 krad, seeds	Surpasses parent cv Tzanava-31 by 5.5 t/ha in green pod yield and 0.52 t/ha in seed yield; green pods devoid of fibre; and 5-6 cm higher on stem, making mechanical harvest possible; improved resistance to bacterial diseases	[82]
Mukhranula	USSR 1982	EI, 0.015%	30 days early	40:16

Harkovskaya 8	USSR 1985	Gamma rays 15 kR, seeds F_1 Sanilac x 6590	White seeds; early ripening; high yield	31:31
Svetlaya	USSR 1992	MNH 0.006%	Yield; protein content	40:16

In addition:
Cultivars Kentwood (1973), Fleetwood (1977), Harofleet (1983), Harokent (1983), OAC Seaforth (1983), Centralia (1988), AC Skipper (1996), AC Hensall (1997), NC Alberta Pink (1998) have been released in Canada; NEP-2 (1975) released in USA; C-20 (1982) Midland (1983), Northland (1983), Wesland (1983), Laker (1983), Suncrest (1983), Stinger (1988), Norstar (1993), Huron (1994), Newport (1995), Arapaho (1995), have been released in US using induced bushy mutants of Michelite or its derivatives in crossing program. Cultivars Swan Valley (1981), Mayflower (1988), Black Magic (1981), Domino (1981), Black Hawk (1989), JM-126 (1986), Maverick (1997), Frontier (1998) and JM-24 (1986) have been released in US using NEP-2 or its derivatives in crossing program.
(See: Nichterlein, K., 1999. The role of induced mutations in the improvement of common beans (*Phaseolus vulgaris* L.). MBNL. **44**: 6-9)

***Pisum sativum* L. (pea)**

Caoyuan 10	Chian 1980	Seeds, x-rays, 200 Gy	Seeds yellow instead of green; taller; thicker stem; larger leaves and stipules; pod shape straight instead of sickle	37:38
Hans	India 1979	EI	Higher yield	15:13
Navona	Italy 1980	Pollen, x-rays; 7.50 Gy	Flowering one week later; reduced plant height; more contemporary pod setting; longer period for canning	19:17
Esedra	Italy 1980	Pollen, x-rays, 7.50 Gy	Flowering 4 d later; increased yield; more contemporary pod setting; better suited for mechanical harvesting	19:17
Trevi	Italy 1985	Cross: mutant 7238 from “Sprinter” x Mutant M235 from Parvus	Determinate type; short plant stature; early cycle; suitable for processing	35:40
Pirro	Italy 1988	Gamma rays, 100, Gy seeds	Determinate type; no need of staking; large pods; early	37:38
Priamo	Italy 1988	Gamma rays, 100 Gy, seeds	Determinate type; high yield	37:38
Paride	Italy 1988	Gamma rays, 100 Gy, seeds	Determinate type; early; high yield	37:38

Wasta	Poland 1979	Gamma rays, 50 Gy	Changes of leaflets into tendrils; higher HI early maturing (c. 103 d); high yield; lodging resistant; fodder pea; suitable for combine harvest	15:13
Sum	Poland 1979	Gamma rays, 50 Gy	Shorter plant type; larger seeds than Wasta; very high yield potential; edible pea	15:13
Hamil	Poland 1981	Cross: (Wasta x1.6L/78) x Porta	Change of leaflets into tendrils; early maturity; high yield lodging resistance; suitable for combined harvest	18:17
Mihan	Poland 1983	Cross: (Wasta x Biala) x Neugatersleben	Better resistance to lodging due to *afila* gene	26:14
Milveska	Poland 1983	Cross: Gome x (Wasta x Biala)	Better resistance to lodging due to *afila* gene	26:14
Ramir	Poland 1985	Cross: Sum (= Porta x Wasta) x Flavandar	Better resistance to lodging due to *afila* gene	26:14
Heiga	Poland 1986	Cross: Hamil x Delisa II	*Afila* character; garden or canning	30:26
Jaran	Poland 1986	Cross: Aschersleben x (Wasta x Wielkolistna)	*Afila* mutant; lodging resistant; suitable for cultivation in mixtures with oats for green forage for fodder and dry seeds	30:26
Miko	Poland 1989	Cross: Hamil x Cud Ameryki	*Afila* type	35:40
Diament	Poland 1989	Cross: (Kujawski Wczesny x Flavanda) x Stral	n/a	35:40
Bosman	Poland 1989	Cross: 1 34 x Allround	*Afila* type	37:37
Agra	Poland 1990	Cross: Sum x Karat	Lodging resistance	43:51
Kwestor	Poland 1991	Gamma rays, 100 Gy	Stem length; pod number	41:28
Piast	Poland 1995	Sum x Melzer	Stiffness; yield	43:51
Stral-ärt	Sweden 1954	Pre-soaked seeds, x-rays	Vigorous development; 2-6% higher seed yield; higher regenerative capacity; stable yield	[82]
Shikhan	USSR 1984	Cross with radiation induced mutant	Resistant to seed shedding	37:38
Moskovsy 73	USSR 1984	DES, 0.03%	Larger grains; higher protein content	12:15
Streletski 11	USSR 1985	EI 0.01% 12 h, seeds	Early ripening; moderate resistance to lodging	31:31

Nemchinovski	USSR 1986	Nemechinovskii 766 x Shtambovy mutant	High yield; good plasticity	31: 31
Orphei	USSR 1989	Chemical mutagen	Seed shedding resistance; disease resistance (for forage)	40:17
Tatrastan 2	USSR 1989	ENH, 0.05% [Ahalkalakskii mestnyi x Ramenskii 771] Hybrid seed treated	Earliness (for forage)	40:17
Bitug	USSR 1990	Cross: Orphei x Smaragd	Seed smoothness; seed size	40:16
Samara	USSR 1992	Chemical mutagen	Seed shedding resistance; disease resistance (for forage)	40:17
Talovets 60	USSR 1993	Cross: Orphei x Smaragd	Lodging resistance; wide adaptability	41:28
***Vicia faba* L. (faba bean)**				
Karna (H 448)	Austria 1983	Seeds, gamma rays	High yield; erect; indeterminate; TGW 400-450g; for grain and fodder	29:27
Ti nova	GDR 1986	Cross: with x-ray induced ti mutant	Terminal inflorescence 70-90 cm; improved lodging for combine harvest	30:27
Tuwaitha	Iraq 1994	Gamma rays, 40 Gy	Disease resistance; protein content	43:55
Babylon	Iraq 1994	Gamma rays, 30 Gy	Disease resistance; protein content	43:55
Stego	Poland 1987	Gamma rays, 70 Gy	Short stem; ca. 4 d earlier; lower TGW ca. 50 g	31:37
Dino	Poland 1987	Gamma rays, 70 Gy	Short stem; ca. 4 d earlier; lower TGW ca. 50 g	31:38
Bronto	Poland 1989	Gamma rays, 60 Gy; seeds	More stable yield	37:44
Tinos	Poland 1992	Cross: ti mutant x "Minden"	Determinate growth; early maturity; dwarf	41:30
Martin	Poland 1994	Cross: TJ 3177/77 x 3177/77	Earliness; uniform maturity	43:55
Chabaski	USSR 1987	NEU (Uladovskii x Fribo)	Early ripening; high grain, phytomass and dry matter yield	31:37
Severinovskie	USSR 1992	MNH (KYU-82 x Fribo) (hybrid seed treatment)	Yield; protein content	40:22
Parikapatskie 4	USSR 1986	ENH, MNH, DES, DMS, EI (repeated treatment)	Yield	40:22

KIU-82	USSR 1987	Chemical mutagen	Disease resistance; high yield	31:37
***Vicia sativa* L. (vetch)**				
Toplesa	CSFR 1995	Cross: Mutant T1 x CIVI	Vigour	43:55
Nikian	Italy	EMS	Branching, leaf shape, dwarfness	43:55
Nechinovskaya	USSR 1989	DES, 0.01%, 12h	Leaf size, yield, biomass	40:22
***Vigna angularis* (Willd.) (adzuki bean)**				
Beni-nambu	Japan 1978	Gamma rays	Early maturing; shorter stem; good seed colour; uniform seed size; higher yield	[82]
***Vigna mungo* L. (blackgram)**				
Binamah-1	Bangladesh 1994	Gamma rays, 600 Gy	Disease resistance; early maturity	43:55
Co 4	India 1978	MMS 0.025	Early maturity; day length insensitivity; drought tolerant	29:28
TAU-1	India 1985	Cross: T-9 x 4-196 (gamma ray induced mutant)	Higher yield - 8.6% over T-9, and 24.4% over No. 55; larger seed size; moderately resistant to powdery mildew	28:23
TPU-4	India 1992	Cross: UM-201 (gamma ray induced mutant from cv. No. 55 x T-9)	Grain weight; yield	42:34
***Vigna radiata* (L.) Wil. (mungbean)**				
Binamoong-2	Bangladesh 1994	Cross: MB-55(4) x V-2773	Seed size; synchronous maturity	43:56
TAP-7	India 1982	Gamma rays	5-7 d earlier maturity than parent cv. S-8; tolerant to powdery mildew and leaf spot diseases; 23% higher yield over check cv. Kopergaon	23:21
Co 4	India 1982	Seeds, gamma rays 400 Gy	High yield; matures in 85 days; drought tolerant	29:28
Pant Moong 2	India 1982	Gamma rays, 100 Gy	Moderately resistant to YMV; higher yield	23:21
ML-26-10-3	India 183	Gamma rays	High yield, tolerant to YMV	33: 3

MUM-2	India 1992	EMS 0.2%, 6 h	Yield; disease resistance	43:56
Camar	Indonesia 1987	Gamma rays, 100 Gy	*Cercospora* resistance; salt/acid tolerance; yield	42:35
NIAB Mung 28	Pakistan 1983	Gamma rays, 200 Gy, seeds	Early and uniform maturity; high yield	23:21
NIAB Mung 19-19	Pakistan 1985	Gamma rays, 400 Gy	Takes 60-65 d instead of 90-95 d to harvest; determinate type; 35% higher yield over the standard cv. 6601; recommended for spring and summer crops	[82]
NIAB Mung 121-25	Pakistan 1985	Gamma rays, 200 Gy	Takes 60-65 d instead of 90-95 d to harvest; determinate type; 44% higher yield than standard cv. 6601 recommended for spring and summer crops	[82]
NIAB Mung 13-1	Pakistan 1986	Seeds, gamma rays, 100 Gy	Early (56 d); shorter, more pods; HI 28%, TGW 40.5g,higher yield 44% over the parent cv 6601; suitable as catch crop	29:28
NIAB Mung 20-21	Pakistan 1986	Seeds, gamma rays, 400 Gy	Early (56 d); short; more pods; HI 31%; TGW 38.6; 65% higher yield over the parent Pak 22; better tolerance to YMV and *Cercospora* leaf spot; suitable as catch crop	29:28
NIAB Mung 51	Pakistan 1990	Gamma rays, 100 Gy [6601 x 1973A]	Earliness; non-shattering	42:35
NIAB Mung 54	Pakistan 1990	Gamma rays, 100 Gy [6601 x 1973A]	Earliness; non-shattering; profuse hairiness	42:35
Vigna unguiculata **Walp. (cowpea)**				
Uneca-Gamma	Costa Rica 1986	Gamma rays, 100 Gy	High yield	34:33
V-38 (Swarna)	India 1981	Seeds, DMS	Resistance to fungal and bacterial diseases; highest yielding cowpea cv. in India	25:21
V-37 (Shreshtha)	India 1981	Seeds, DMS	High yield; luxuriant vegetative growth; also suitable as green fodder	25:21

V-16 (Amba)	India 1981	Seeds, DMS	High yield; early maturity; synchronous flowering; better quality pods, and grains; almost immune to most diseases of the region	25:21
V-240	India 1984	Seeds, DMS	High yield; resistant to all major fungal, bacterial, and viral diseases	25:21
Co 5	India 1986	Gamma rays, 300 Gy	More nutritive; higher yielding (16%); forage legume	29:27
Cowpea 88	India 1990	F_1 seed irradiation (cowpea 74 x virus resistant strain H-2)	High grain and fodder yield; resistant to YMV	37:44
ICV11	Kenya 1985	Seeds, gamma rays	Semi-erect; large leaves; green stem and pods; matures in 65 d; 1100 kg/ha; resistant to cowpea aphids	28:23
ICV12	Kenya 1985	Seeds, gamma rays	Similar to ICV 11 but slightly higher yield; resistant to cowpea aphids	28:23

DES: Diethyl sulphate; DMS: Dimethyl sulphate; EMS: Ethyl methanesulphonate; MMS: Methyl methanesulphonate; NEU = ENH: Ethyl nitrosourea NMU = MNH: Methyl nitrosourea; n/a: information not available

TABLE 2. NUMBER OF CULTIVARS DEVELOPED WITH THE HELP OF INDUCED MUTATIONS IN DIFFERENT GRAIN LEGUME CROPS

	Number of cultivars	
	Developed till 1986	Developed till 1999
Arachis hypogaea	13	44
Cajanus cajan	5	5
Cicer arietinum	6	10
Dolichos lablab	1	1
Glycine max	23	58
Lathyrus sativus		1
Lens culinaris	1	1
Lupinus albus	3	12
Lupinus angustifolius	1	1
Lupinus cosentinii	1	1
Lupinus luteus	1	4
Phaseolus coccineus		1
Phaseolus vulgaris	12	50
Pisum sativum	13	32
Vicia faba	2	13
Vicia sativa		3
Vigna angularis	1	1
Vigna mungo	2	4
Vigna radiata	8	14
Vigna unguiculata	7	9
Total	100	265

TABLE 3. GRAIN LEGUME CULTIVARS DEVELOPED WITH THE HELP OF INDUCED MUTATIONS IN DIFFERENT COUNTRIES

Country	No.	Country	No.
Algeria	1	Indonesia	4
Argentina	3	Iraq	2
Australia	3	Italy	9
Austria	1	Japan	7
Bangladesh	3	Kenya	2
Brazil	2	Korea	2
Bulgaria	3	Myanmar	1
Canada	10	Pakistan	11
China	50	Poland	21
Costa Rica	1	Sri Lanka	1
CSFR	3	Sweden	1
Egypt	2	Thailand	1
FRG	2	Turkey	2
GDR	2	USA	28
Hungary	1	USSR	43
India	38	Vietnam	5

TABLE 4. MUTAGENIC TREATMENTS USED FOR THE DEVELOPMENT OF CULTIVARS IN GRAIN LEGUME CROPS

	Total No. of cultivars	Developed as direct mutants induced by:						Using induced mutations in crossing program
		Gamma or x-rays	Neutrons	Radiations not specified	Chemical mutagens	Radiations plus chemical mutagen	Others	
Arachis hypogaea	44	18		2	1		1(laser)	22
Cajanus cajan	5	1	2	1				1
Cicer arietinum	10	8	1		1			
Dolichos lablab	1	1						
Glycine max	58	38	5		8	2		5
Lathyrus sativus	1				1			
Lens culinaris	1			1				
Lupinus albus	12	2			6			4
Lupinus angustifolius	1							1
Lupinus cosentinii	1							1
Lupinus luteus	4	1						3
Phaseolus coccineus	1	1						
Phaseolus vulgaris	50	6			5			39
Pisum sativum	32	8+2(P)			6			16
Vicia faba	13	6			4			3
Vicia sativa	3				2			1
Vigna angularis	1	1						
Vigna mungo	4	1			1			2
Vigna radiata	14	12			1			1
Vigna unguiculata	9	5						4
Total	265	111	8	4	36	2	1	103

TABLE 5. SUCCESSFUL GAMMA OR X-RAY DOSES USED FOR THE DEVELOPMENT OF CULTIVARS IN DIFFERENT GRAIN LEGUME CROPS

Crop species (1)	No. of cultivars developed using gamma or x-rays (2)	Successful doses in (Gy). (No. of cultivars) (3)	Successful dose range (Gy) (4)
Arachis hypogaea	18	50 (1); 150 (3); 200 (5); 240 (1); 250 (2); 400 (1); 450 (2)	150-250 (11)
Cajanus cajan	1	160 (1)	
Cicer arietinum	8	100 (2); 150 (1); 200 (2); 600 (3)	100-200 (5)
Dolichos lablab	1	240 (1)	
Glycine max	38	80 (1); 100 (11); 120 (2); 140 (1); 200 (4); 240 (1) 250 (1); 300 (2)	100-200 (18)
Lathyrus sativus			
Lens culinaris			
Lupinus albus	2		
Lupinus angustifolius			
Lupinus cosentinii			
Lupinus luteus	1		
Phaseolus coccineus	1		
Phaseolus vulgaris	6	0.3 (1); 70 (1); 100 (1); 300 (1); 320 (1)	
Pisum sativum	8+2 (Pollen irradiation)	100 (4); 200 (1); 500 (2) (0.75Gy for pollen irradiation)	100-200 (5)
Vicia faba	6	30 (1); 40 (1); 60 (1), 70 (1)	
Vigna angularis	1		
Vigna mungo	1	600 (1)	
Vigna radiata	12	100 (5); 200 (2); 400 (3)	100-200 (7)
Vigna unguiculata	5	100 (1); 300 (1)	

Successful dose used is not known for some cultivars. Therefore the total number of cultivars in columns 2 and 3 are not same

TABLE 6. MOST FREQUENT AND OTHER CHARACTERS OF THE CULTIVARS DEVELOPED IN DIFFERENT GRAIN LEGUME CROPS USING INDUCED MUTATIONS

Crop species	Most frequent characters, after yield*	Other characters
Arachis hypogaea	Plant type, large pods and kernels, early flowering and maturity	Higher shelling percentage; thick or thin pod cover; higher HI, resistance/tolerance to diseases; oil content
Cajanus cajan	Large seed size; early maturity	Day length insensitivity
Cicer arietinum	Plant type; early flowering/maturity	Resistance to wilt and *Ascochyta* blight
Dolichos lablab	Bushy plant type	
Glycine max	Plant type; early flowering/maturity	Seed size; seed coat colour; non-shattering pods; hyper-nodulation; nitrate tolerance; root system; disease resistance; cold and drought tolerance; oil and protein content
Lathyrus sativus	Drought tolerance; disease and insect resistance	
Lens culinaris	Plant type	
Lupinus albus	Low alkaloid content; early flowering/maturity	Resistance to lodging, diseases and insects; higher protein content
Lupinus angustifolius	Low alkaloid content; early flowering/maturity	
Lupinus cosentinii	Low alkaloid content; early flowering/maturity	
Lupinus luteus	Early maturity; resistance to *Fusarium*	Fodder quality
Phaseolus coccineus	Dwarf plant type	
Phaseolus vulgaris	Bushy plant type; early flowring/maturity	Resistance to *Colletotrichum lindemuthianum, Uromyces phaseoli, Anthracnose, Pseudomonas phaseolicola,* and bean common mosaic virus; seed coat colour; seed size; pod with less fibre; reduced cooking time; protein content
Pisum sativum	Plant type - *Afila*; lodging resistance; early/late flowering/maturity;	Straight pods; seed size; seed coat colour; protein content; disease resistance; cold and drought tolerance
Vicia faba	Erect, dwarf, plant type; early maturity	Disease resistance; lodging resistance; TGW; terminal inflorescence; protein content
Vicia sativa	Leaf size, biomass	Dwarf plant type

Vigna angularis	Early maturity; shorter stem	Seed colour; uniform seed size
Vigna mungo	Large seed size; early maturity	Disease resistance; drought tolerance; day length insensitivity
Vigna radiata	Early flowering/maturity; plant type	Disease resistance; non-shattering pods, pod characters; seed size; HI
Vigna unguiculata	Plant type; forage yield	Resistance to bacterial, fungal, and viral diseases, superior nutritive value

*Higher yield is common to all the cultivars

TABLE 7. SYMBIOSIS MUTANTS IN PEA

Parent cv/mutagen used mutant (genes)	Main characteristics	Reference
Mutants identified from germplasm collections from Afghanistan, Iran and Turkey		
Sym-1	Temperature sensitive nodulation resistance to some strains below 20^{o} C	Lie [73; 74]
Sym-2	Nodulation resistance to a large number of European strains, dominance dependent upon Rhizobial strain, Ch. 1. Arrest in infection thread, if *Rhizobium* strain does not produce Nod factors	Holl [57] Kneen *et al.* [68] Lie [74] Kneen and LaRue [65] Geurts *et al.* [43]
sym-3	Ineffective nodulation, mr	Holl [57]
sym-4	Nodulation resistance to specific Rhizobial strain	Lie [74]
CV Prvus		Gelin and Blixt [42]
nod1	Decreased nodulation, mr	
nod2	Decreased nodulation, mr	
Induced mutants		
Sparkle (EMS, gamma rays, fast neutrons)		
	Eleven mutants with few or no root nodules all recessive to wild type	Kneen *et al.* [67]
E2 *(sym-5)*	Nodulates at low temp, mr, Ch. 1, increased ethylene sensitivity, can be reverted to nodulation by blocking etylene accumulation	Kneen and LaRue [65] Heidstra *et al.* [55] Fearn *et al.* [39]
sym-6	Ineffective nodulation, mr	Caetano-Anolles and Gresshoff [16]
sym-7	Non-nodulation, mr, Ch. 3	Caetano-Anolles and Gresshoff [16]
sym-8	Non-nodulation, Ch. 6, essential for the induction of early nodulin genes PsENOD5 and PsENOD12A	Albrecht *et al.* [6]
sym-9	Non-nodulation	Caetano-Anolles and Gresshoff [16]
sym-10	Non-nodulation, mr, Ch.10	Caetano-Anolles and Gresshoff [16]
sym-11	Non-nodulation, mr, Ch. 7	Caetano-Anolles and Gresshoff [16]
sym-12	Non-nodulation, mr	Caetano-Anolles and Gresshoff [16]
sym-13	Ineffective nodulation, mr, Ch.2	Kneen *et al.* [66]
E135f (*sym-13*)	Normal number of ineffective white nodules, influences expression of leghaemoglobins and level of haem	Suganuma and LaRue [134] Suganuma *et al.* [135] Borisov *et al.* [10]
E135N *(sym-14)*	Non-nodulation, mr	Kneen *et al.* [66]
sym-15	Decreased nodulation, mr, Ch.7	Caetano-Anolles and Gresshoff [16]
sym-16	Decreased nodulation, mr, Ch.5	Caetano-Anolles and Gresshoff [16]
sym-17	Decreased nodulation, mr	Caetano-Anolles and Gresshoff [16]

sym-18	Semi-dominant, nodulation	Caetano-Anolles and Gresshoff [16]
sym-19	non-nodulation and resistance to Mycorrhizal infection, Ch. 1	
E107	Mutation at single recessive gene brz, has pleiotropic effects, along with low nodulation, partly restored by treatment with ethylene inhibitors	Guniel and LaRue [49; 50]
E132 (*sym21*)	Pleiotropic mutant with few nodules due to low rate of nodule meristem emergence	Markwei and LaRue [77]
Frisson (EMS)		
	Seven nodulating, non-fixing mutants	Sagan *et al.* [114; 116]
P12 (*sym-27*) P58 (*sym-13*) P61 (*sym-25*) P63 (*sym-26*)	Nodule development normal followed by premature senescence	Sagan *et al.* [115] Sagan and Duc [112]
P64 (*sym-28*), P88 (*sym-29*)	Supernodulating, eight nitrate tolerant nodulation (Nod++Nts) mutants were identified, mr, genes	Sagan and Gresshoff [113]
P6, P53, P54, P55, P56	Non-nodulating, root hairs resistant to infection	Sagan *et al.* [115]
P57	Low nodulating, root hair infection normal but early nodule development affected	
P59 (*sym-23*) P60 (*sym-24*)	Early arrest of nodule development	
P62	Developmentally defective root hairs	
myc-(1)	Mycorrhiza-resistant, VAM is blocked immediately after formation of apprasoria, mr, associated with nod, probably a common mechanism	Dumas-Gaudot *et al.* [35] Gianinazzi-Pearson *et al.* [44]
myc-(2)	Intracellular hyphal development of VAM but no arbuscule formation	
Rondo (EMS)		Jacobsen [62] Jacobsen and Feenstra [63] Postma *et al.* [106]
Nod3	Super nodulating, changed root and shoot morphology	
K5	Nodulation resistant, non-strain specific, infection thread formation	
K24	Nodulation resistant, only curling of root hair is observed	
Ramonskii 77 and K551 (EMS and NEU)		Sidorova and Uzhintseva [126] Sidorova *et al.* [122; 124; 125] Sidorova and Shumny [123]
K301 (nod4)	Supernodulating, nts nodules	
K287 (fix1)	Normal nodulation, white, ineffective nodules	
K1005m (sym)	Non-nodulating	
	All three are mr, non allelic	

Sprint (EMS)		Borisov *et al.* [10; 11] Sherrier *et al.* [119]
Sprint 2 Nod-1 *(sym-8)*	Inability to form nodules and associations with vesicular-arbuscular mycorrhiza	
Sprint 2 Nod-2 *(sym-8)*		
Sprint 2 Fix$^-$ *(sym-31)*	Impaired symbiosome development, Ch. 3	
RBT *(sym-13, sym-31)*	E135f x Sprint-2 Fix-, abnormal symbiosomes, suppresses manifestation of *sym-13* mutant allele.	
SGE (EMS)		Tsyganov *et al.* [137]
SGEFix$^-$1 *(sym40)*	Numerous white and some pink nodules, hypertrophied infection thread, premature degradation	
SGEFix$^-$2 *(sym33)-*	White nodules with dark pits, some pink nodules, characterised by “locked” infection thread.	
Finale (EMS, DES, ENU, Na N_3)		
	Thirty-six non-nodulating and 24 mutants, with inefficient nodules	Engvild [37]
	Twenty-one non-nodulating and 1 super nodulating	Novak *et al.* [87; 88; 89; 90; 91]
RisfixC	Supernodulating, 5-6 times more nodules effective, nitrate resistant nodulation	
RisfixV	Hypernodulating, on low nitrate level, ineffective nodules, nodulation suppression by nitrate, traces of nitrogenase activity nodules, mr	
RisfixO (*sym32*)	Ineffective nodulation, symbiotic tissue development arrested before formation of late symbiotic zone (LSZ)	
RisfixT	Ineffective nodulation, loss of LSZ after full differentiation	
Double Mutants	Obtained by crossing RisFixC x RisfixV	

mr: monogenic recessive

TABLE 8. NODULATION MUTANTS IN SOYBEAN

Parent cv/mutagen used mutant (genes)	Main characteristics	Reference
Hypernodulating mutants		
Bragg (EMS) *nts* (**n**itrate **t**olerant **s**ymbiosis)	Super nodulating, NO3 tolerant. 15 independent nts mutants, all allelic and inherited as monogenic recessive, except *nts* 1116; *nts* 382, 183, 1007 and 1116 studied extensively. Absence of nodule autoregulation. Higher nodule number and biomass. *nts* 382 and 1007 are allelic. Not linked to non-nodulation mutants described later.	Caroll *et al.* [19; 21; 22] Delves *et al.* [29] Mathews *et al.* [80] Hansen and Akao [52] Lee *et al.* [71]
Williams (EMS and NMU)		
NOD1-3 (rj_7)	2 - 4 times nodule number, nodules randomly distributed on both tap and lateral roots. Allelic to en6500.	Gremaud and Harper [46] Wu and Harper [144] Ohmaya *et al.* [93] Pracht *et al.* [107]
NOD4 (rj_7)	Single recessive locus, densely packed nodules, predominantly distributed along the entire length of the tap root. NOD1-3 and NOD4 are allelic.	Koornneef *et al.* [70] Vuong *et al.* [141] Bacananamwo and Harper [8] Acott Schmidt *et al.* [4]
NOD2-4 (rj_8)	Independent allele, Crosses between NOD1-3 and NOD2-4 x NOD4, all F_1 were normal nodulation, in F_2 9 normal :7 hypernodulation was not observed. Authors speculate that rj_7 and rj_8 interact in an unknown manner.	
NOD3-7	Like other NOD mutants but no genetic analysis	

(All NOD mutants were selected under zero N conditions, but also show partial tolerance to NO_3. They are similar to the nts mutants obtained in cv. Bragg)

Enrei (EMS)		
En6500 (rj_7)	Super nodulating, 6 fold increase, larger number of nodules, with higher nodule dry wt. in presence of NO3, single recessive gene allelic to *nts*382	Akao and Kouchi [5] Kokubun and Akao [69] Takahashi *et al.* [136] Vuong *et al.* [141]
Elgin 87 (EMS 0.04 M for 12h)		
E300, E 420, E592	Super nodulating, allelic, recessive 6 -10 x increase in nodule number	Buzzell *et al.* [15] Buttery and Buzzell [14]
E391	Characters as above, but a second allele	
Sinpaldalkong 2 (EMS 30mM)		
SS-2	Super-nodulation at early stages than *nts*1007 and *nts*1116, more nodule mass, higher C2H2 activity	Hong Suk *et al.* [60] Hong Suk and Suk Ha [58] Hong Suk *et al.* [59]
Ineffective nodulation mutants		
Rj_2	Monogenic dominant	Caldwell [17] Caldwell *et al.* [18]
Rj_3	Monogenic dominant	Vest [139] Vest and Caldwell [140]
Rj_4	Monogenic dominant	Devine [31]
Rj_5	Monogenic dominant	
Non-nodulating mutants		
rj_1	A non-nodulating spontaneous mutant monogenic recessive, blockage at the stage of root hair curling	Williams and Lynch [143] Suganuma *et al.* [133]
Williams (NMU)		
NN5 (rj_5, rj_6)	Does not form nodules in the field Does not form nodules when inoculated with *Bradyrhizobium japonicum,* recessive, non allelic to *rj1*, allelic to *nod*139, a non nodulating mutant of Bragg.	Pracht *et al.* [107] Mathews *et al.* [79]
Bragg (EMS, gamma rays)		
*nod*49 (rj_1) *nod*772 (rj_1)	No nodulation after inoculation monogenic recessive inheritance in crosses with Bragg. Epistatically supress supernodulation in crosses with *nts* mutants. Shows few centres of sub-epidermal cell division after inoculation, but devoid of inocluation thread.	Caroll *et al.* [22] Mathews *et al.* [79] Mathews *et al.* [81]

*nod*139 (rj_5,rj_6)	Non allelic to *nod*49 and *nod*772 Devoid of infection thread and no subepidermal cell divisions after inoculation.

See also Caetano-Anolles and Gresshoff [16]

It is estimated that 40 genes are responsible for nodulation in soybean [110]. *nts* mutants from Bragg, NOD mutants from Williams, and En6500 mutant from Enri revealed that all mutants expressed similar levels of increased nodulation when grown under identical conditions [40]. All mutants have been designated as hypernodulating by Vuong *et al.* [141]. No spontaneous hypernodulating mutants have been reported.

TABLE 9. NODULATION MUTANTS IN OTHER GRAIN LEGUMES

Parent cultivar/mutagen used mutant (genes)	Main characteristics	Reference
CHICKPEA (*Cicer arietinum*)		
P502(ICC 640) gamma rays		
PM 233 (rn_1) ***r**oot **n**odule*	Nod-, mr	Davis *et al.* [24; 26; 27]
PM 665 (rn_2)	Nod-, mr	Davis [25]
PM 679 (rn_3)	Nod-, mr, linked to simple leaves (*slv*)	
PM405 (rn_4)	Nod + fix -, mr, small white nodules	
PM796 (rn_5)	Nod +, fix -, mr, green nodules with narrow band of leghemoglobin	
ICC 640		
PM 233B	Nod-, blockage of *Rhizobium* infection process subsequent to root hair absorption but prior to formation of infection thread and root cortical cell division	Mathew and Davis [78]
The following are spontaneous mutants, identified in frequencies ranging between 120-490 per million plants.		
ICC 435		
ICC 435M (rn_6)	Nod-, mr, non allelic to PM 233, does not show N deficiency symptoms when grown in field	Rupela [111] Singh *et al.* [129]
ICC4918		
ICC4918M	Nod-	
ICC4993		
ICC4993M	Nod-	
ICC5003		
ICC 5003M	Nod-	
Rabat		
Rabat NN (rn_8)	Nod-, mr	Singh and Rupela [128]
Annigeri		
Annigeri NN	Nod-, mr	Singh and Rupela [128]
P319-1NN	Nod-, mr, allelic to Annigeri NN, different gene for Nod- trait than that of RabbatNN and PM233	
GROUNDNUT (*Arachis hypogaea*)		
All spontaneous mutants, or selected in the progenies of crosses between different normal nodulating genotypes.		
F3 progenies of cross 487A-4-1-2 x PI 262090	Nod-, more than one gene	Gorbet and Burton [45]

ICGL1		
(Mutants selected in the F_2 generation of crosses involving ICGL1)		
ICGL1 (GP-50, PI 544348) (GP-51, PI 544349)	Nod-, duplicate genes	Nigam *et al.* [84; 85; 86]
ICGL3 (GP-52, PI 544350)	Nod-	
ICGL4 (GP-53, PI, 544351)	Nod-	
ICGL5 (GP-54, PI, 544352)	Nod-	
PI 109839	Trigenic	Dutta and Reddy [36]
Georgia Non-Nod		
(Selected as a segregant in F_5 of a double cross)		
(GS-6, PI 595385)	Nod-, allelic to six diverse Nod-types from Georgia, Florida and ICRISAT, duplicate recessive.	Branch [12]
COWPEA (*Vigna ungiculata*)		
Iron & Clay varietal mix		
IC-1 (*cpi*)	Fix-, ineffective nodulation, small size,no nitrogenase activity, mr, nodule anatomy similar to wild type, reduced size of the infected cells, number of bacteroids reduced, premature scenescence	Pemberton *et al.* [103] Purdom and Trese [109]
JRW3-SmD	40-80% suppression of nodule formation depending upon strain and time of inoculation	Singh and Ahmad [127]
FABA BEAN (*Vicia faba*)		
Feverole Ascott		
Feverole 13 (*sym-1*)	Fix-, ineffective nodulation, no acetylene reduction activity, effects either release of infective thread or differentiation of bacteria into bacteroids	Haser *et al.* [54]
I 40		
I 40 (*Sym-2*)	Nod-, monogenic dominant	Esser-Monning *et al.* [38]
I 25		
I 25 (*sym-3*)	Nod-, mr	
Cultivar ? (EMS)		Duc [34]
f13 (*sym-1*) f73 (*sym-2*)	Nod+/Fix-, mr	

f245 (*sym-3*)		
f48 (*sym-4*)	Nod-, mr	
f32 (*sym-5*)	Nod+ +, nts, 3-5 times more nodules than control, in absence of combined nitrogen and nitrate tolerant nodulation, mr	
COMMON BEAN (*Phaseolus vulgaris*)		
RIZ30 (EMS)		
NOD238 (*sym-2*)	Fix -, ineffective nodulation, small nodules	Pedalino and Kipe-Nolt [101] Pedalino *et al.* [102]
NOD125 (*sym-1*)	Nod-.	Park and Buttery [94; 99]
RIZ36 (EMS)		
NOD109	Fix -, late formation of pink nodules,low AR activity, poor pod fertility	Pedalino and Kipe-Nolt [101] Pedalino *et al.* [102]
R69 (nie)	Ineffective nodulation, mr epistatic to nts, non allelic to sym-2.	Park and Buttery [99] Pedalino *et al.* [100]
R99 (nnd-2)	Non-nodulation, mr. epistatic to nts and nie	
OAC Rico (EMS)		
R699 (*nie*)	nod+/fix-, Myc-small, white nodules	Park and Buttery [94; 95; 97; 98]
R99 (*nnd-2*)	nod-, NN, Myc+	Shritliffe *et al.* [121] Shritliffe and Vessey [120]
R32 (GP-88, PI 536541) (*nts*)	Nitrate tolerant super nodulation (NTSN), mr, delayed maturity, and slightly lower yield	
Swan Valley (EMS)		
SV145	NTSN, mr	Park and Buttery [96; 98]
PIGEONPEA (*Cajanus cajan)*		
Non-nodulating with native root nodulating bacteria (RNB) Low nodulating at low N High nodulating at low N		Wani *et al.* [142]

AR: acetylene reduction; NN: non-nodulating; NTSN: nitrate tolerant super nodulation; mr: monogenic recessive

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