Indian J. Genet., 76(4): 593-607 (2016)
DOI: 10.5958/0975-6906.2016.00075.4

Improvement of minor pulses and their role in alleviating malnutrition

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(Received: October 2016; Revised: November 2016; Accepted: November 2016)

Abstract

Pulse crops constitute a significant source of protein for the resource-poor population of Asia, Africa and Mediterranean regions of the world. However, these crops are usually grown in marginal lands with low inputs and therefore their production and productivity remains very low. Per capita availability of pulses in India is lower than the recommended quantity. Therefore, it is imperative to increase production, productivity and availability of pulses to meet the nutritional requirement of a large section of human population. The minor pulses namely mothbean and horsegram, which are grown in limited area in dry and hot conditions of semi-arid regions of tropics in South Asia, Africa and Mediterranean regions also plays a great role in supplementing the diet of the resource poor farmers and consumers. Ricebean is another important minor pulse crop which is cultivated in humid sub-tropical to warm to cool climate under range of soil types also contribute hugely towards pulse production. The present paper provides information with respect to area of cultivation, productivity of the minor pulses and their importance as a source of nutritional ingredients to human and livestock populations.

Key words: Horse gram, mothbean, rice bean, varieties, breeding, nutritional value

Introduction

In the green revolution era major focus was given on staple food like rice and wheat, pulses were mostly grown on marginal land with low inputs, which resulted in reducing per capita availability of pulses to the masses. As per ICMR (Indian Council of Medical Research) recommendation per capita per day availability of pulses should be 69.0 g but at present only 41.9g per capita per day pulses is available. So as to meet the required demand, we have to increase the pulses production. It is important to note that UN has proclaimed 2016 the International Year of Pulses (IYOP 2016) to increase public awareness of the nutritional benefits of pulses. They also contribute to sustainable agro-food value chain as, just 50 litres of waters are needed to grow 1 kg of pulses, whereas almost 13,000 litres are needed to produce 1 kg of beef. Pulse crops also fix atmospheric nitrogen symbiotically with the help of rhizobium bacteria. This reduces the requirement for hydrocarbon based nitrogen fertilizers and maintaining soil health status. Pulses produces about 21 million tons of nitrogen per year.

There are a number of minor pulse crops being grown world over. However, moth bean, horse gram and rice bean are the prominent among them being grown in marginal soils under rainfed conditions. In some ecological conditions, these crop play a major role in sustaining the food nutrition and thus providing security to children suffering from malnutrition. This paper present the the porogress made in the genetics and breeding to improve the mothbean, horse gram and rice bean minor pulse crops.

Moth bean (*Vigna acounitifolia*)

Moth bean [*Vigna acounitifolia* (Jacq.) Marechal] is a minor pulse crop of family Fabaceae (Leguminoceae) and sub family Faboideae (papilionideae) having 2n=22, somatic chromosomes. Moth bean is also known as math, khari, kumkuma, matbean, matki, Turkish gram and dewbean, bobbarlu and taittai pairu in different places of the world. It evolved in dry and hot regions of western Indian subcontinent with inherent mechanism to adapt restrictive water and environment. It is grown in arid and semi arid regions of tropics and sub-tropics with high temperature

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Published by the Indian Society of Genetics & Plant Breeding, F2, First Floor, NASC Complex, PB#11312, IARI, New Delhi 110 012
Online management by indianjournals.com; http://epubs.icar.org.in/journal/index.php/IJGPB

(~40^{o}C). States like Rajasthan, Gujarat and Maharastra occuping about 16.2 lac hectares area and with production of 7.9 lac tonnes with an average yield of 486 kg ha^{-1}. Rajasthan alone contributes over 95 per cent both in area (13.6 lac hectares) and production (3.7 lac tonnes) at the country level. The productivity in Rajasthan (279 kg ha^{-1}) is comparable to national average during the current year 2016-17; however, during drought years it remains considerably low. Due to its low productivity potential and vulnerability to bird damage its share is reducing from other resource rich states increasing the share of Rajasthan in area from 90.0 to 93.0 % and production from 78.7 % to 85.5 % in the decade 2001-2010 as compared to 1991-2000, escalating to more than 98 % during certain periods. In Rajasthan cultivation of moth bean remains more or less static due to unavailability of choice.

It is an indispensable component of resource poor arid agriculture with multiple uses and applications complementing the food and feed requirements. Dry, soaked or sprouted whole seed are cooked in various ways making normal meal course or vegetable while split is usually used as *dal*. Fresh green pods are consumed as fresh vegetables or dried for future use. Integrating moth bean in human diet and animal feed helps balance the nutrition for it being rich in protein, essential aminocids and minerals. Several food and confectionary items adding flavor to routine use evolved from moth bean *viz*., *papar, bhujia, mangori, mogar, namkins* (Henry and Singh, 1985). While rich in protein most stem and leafy plant parts are soft and palatable serving as fodder for cattle. Spreading and indeterminate growth compensates the poor plant stand while preventing soil erosion in sandy areas. Being a leguminous crop it plays important role in improving soil health in a bajra based cropping system by adding atmospheric nitrogen, improving, organic matter.

Area production and productivity

A number of pulse crops are cultivated in India on an area of about 23-24 m ha to produce 14-15 m t of grain. Moth bean does not claim a high place amongst pulses at the national level, as its contribution in area and production is 5.9 and 1.6 %, respectively (Table 1). However, it is the major pulse crop of hot arid zone of the country. Rajasthan is the most important moth bean growing state of the country contributing about 85-90 % in area and 55-60 % in production. Major moth bean growing states are Rajasthan, Maharashtra, Gujarat, Jammu & Kashmir, Haryana, Himachal Pradesh, Punjab and Uttar Pradesh occupying about 3.81 % area of total pulses with 3.80 % of total pulse production.

Table 1. All India area, production and yield of moth bean 2011-12 to 2014-15

Year	Area (lac t /ha)	Production (lac t /ha)	Yield (q/ha)
2011-12	1318157	447179	3.39
2012-13	863927	236234	2.73
2013-14	927312	267392	215
2014-15	868914	341177	393

Genetic improvement

After initial selections from locally collected germplasm a number of early maturing dwarf mutants were released as varieties. Genetic improvement through conventional hybridization is limited due to problems in hybridization (tiny anthers) and poor pod setting (Sharma and Mathur 1982). However, a number of mutants (CZM-1, CZM2) have been developed at CAZRI, Jodhpur and SK Rajasthan Agricultural University, Bikaner *viz*., (RMO-40, FMM-96, RMO-225, RMO-257 and RMO-435). However, CAZRI Moth-2 a medium duration variety has been derived from a cross between RMO-40 (mutant of Jwala) and Jadia (Kumar 2008). Genetic studies indicated useful associations and direct effects of various traits for the improvement of yield (Tikka and Kumar 1976; Tikka et al. 1977, 1980; Sharma and Mathur 1982,1984). Although artificial pollination is difficult, the attempts of interspecific hybridization between *V. aconitifolia* and *V. trilobata* by Chavan et al. (1966) succeeded in harvesting 8 seeds, out of which of that only one grew to flowering with 90.86% pollen sterility. Subsequently, a few pods and polyploidized hybrids were obtained and restored the pollen fertility up to 89.7%. The use of Seredex-B along with GA3 was found effective in improving the pod setting in inter and intra specific hybrids. However, due to small flower size and high frequency of flower drop improvement strategies involving hybridization could not get acceptability and further developments depended on mutation breeding. Evaluation of differences among *Vigna aconitifolia* varieties for acquired thermo-tolerance was reported by Sharma et al. (2014).

History and varietal development

The improvement work in moth bean was probably initiated in late 1960 or early 1970s and a variety Baleshwar 12 (1967) and Type 1 (1969) were released before 1970. Further selections from the germplasm resulted in identification of high yielding varieties with long and medium duration (Maru Moth-1) maturity before the inception of AICRP on Arid legumes in 1992. The work on Arid Legumes *viz.*, clusterbean, moth bean, cowpea and horsegram was started in 1992, when moth bean, cow pea, and horse gram was transferred from under the purview of All India Pulses Improvement Programme to All India Coordinated Research Project on Guar Improvement as per the Rao Committee recommendations. The name of AICRP on Guar Improvement was changed to AICRP on Arid Legumes and it was continued with headquarters at NBPGR. Later on, the ICAR recommended RAU, Bikaner (Rajasthan) as headquarter. Subsequently, in later part of 1999 following the recommendations of the Jain Committee the AICRP on Arid Legumes was brought under National Network Project on Arid Legumes and its headquarters was shifted to CAZRI, Jodhpur and since then it was continuing as the headquarters of the project till recently before its transfer to IIPR, Kanpur in 2015 as All India Network Project on Arid Legumes.

In Rajasthan, considering the importance of moth bean in rural economy and necessity to develop new genotypes moth bean improvement work was initiated under All India Coordinated Research Project on Arid Legumes (Moth bean) at SKN College of Agriculture, Jobner. In the beginning, high yielding varieties, Jawala and Jadia were developed through direct selection from landraces. Later on, improvement work through tissue culture and mutation breeding was also initiated. Moth bean varietal improvement work at Bikaner was initiated in the year 1992. Since then continuous efforts are being made to develop new genotypes, donors and germplasm to cater the emerging needs of area responsibility. Bikaner Centre has released four high yielding, disease resistant, short duration and drought tolerant varieties for different moth bean growing conditions in the country through mutation and selection. Since then, several varieties have been released for general cultivation (Table 2).

Biotechnological and molecular studies

Biotechnological work in moth bean was initiated in early eighties with standardization of in vitro regeneration protocols using various tissues. Successful regeneration of complete plantlets has been reported from diverse explants including roots (Eape and Gill 1986), hypocotyle (Bhargava et al. 1983; Gill et al. 1986; Eapen et al. 1986 and Gill et al. 1987), leaf Eapen et al. 1986 and Bhargava and Chandra 1989a). Regeneration from these tissues was indirect via callus (Bhargava and Chandra, 1983, Godbole et al 1984, Krishnamurthy et al 1984). Embryogenesis was also reported during the same period using suspension cultures (Bhargava and Chandra, 1983) and later on from callus cultures (Eapen and George, 1990). While, leaf explants were reported to be most suitable for plantlet regeneration via callus (Bhargava 1986 and Bhargava and Chandra 1989b), protocol for shoot tip proliferation was also standardized in variety Jwala for fast multiplication (Bhargava and Chandra 1989c).

Protoplast culture was considered to be prerequisite for effective transformation in plant species, hence work on protoplast culture was initiated in moth bean simultaneously with tissue culture. Attempts have been made to isolate culture and regenerate plants from multiple shoot buds for protoplast culture and from mesophyll cells (Shekhawat and Galston 1983; Krishnamurthy et al. 1984; Gill and Eapen, 1986; Arya et al. 1990). Kohler et al. 1987, transformed isolated protoplasts from primary leaves of moth bean by PEG induced uptake of DNA and derived plantlets. Direct gene gun mediated transformation of ungerminated mature embryos was later on achieved (Bhargava and Smigocki 1994). Far easier techniques for transformation in moth bean have recently been reported through co-cultivation with *Agrobacterium* (Kumar 2008) and simply by vacuum infiltration of cotyledonary nodes (Kumar et al. 2010).

Though protein profiling provides some idea about quantitative change in gene expression it doesn't tell about genes involved. Hence, in order to have insight about stressed induced genes a modified differential display of moth bean (using tolerant variety RMO-435) RNA was carried out. A total of 40 up-regulated or newly expressed bands were recovered from stressed samples and sequences were generated for Expressed Sequence Tags (ESTs) 35. Amongst EST sequences large proportion was of chaperons *viz*., HSP 70, HSP101 and DnaJ like protein along with stress responsive and nucleotide binding regulatory ESTs (Soni et al. 2013). Similarly, ESTs upregulated in response to heat stress at very early and early stages

Table 2.

Varieties	Characteristic features	Year of release
JADIA	Pure line selection from the local collection of Kolayat (Bikaner),30 cm tall with 3-8 primary branches and hairy, thick and angular stem, leaves are broad and shallow lobed with polyphyllous nature. It produces 6-8 pods/cluster, medium maturity (80-90 days), medium bold light brown seeds (2.7 to 3.2gm/100 seeds). Seed yield 5-8 q/ha and fodder from 12-16 q/ha	1980
Jwala	A semi spreading and yellow mosaic virus resistant variety selected from local collection of Raisar (Bikaner), broad leaves uniformly shallow lobed, medium bold (2.8-3.2 g/100 seeds). Matures in 80-90 days, seed yield of 6 q/ha, recommended for north-western Rajasthan	1985
IPCMO 880	Pure line selection from local collection of Jhunjhunu district, stem is 30 to 40 cm, broad leaves, heavy, leathery and deeply lobed with 6-8cm long peduncle, 3-4 pods/cluster and medium to bold seed (2.8-3.1 g/100 seeds), matures in 90-100 days, seed yield 4-5 q/ha,s 26.6% protein	1989
IPCMO 912	Selection from local material of Sikar district,. narrow leaflets,olerant to yellow mosaic virus and bacterial blight,matures in 75-80 days, seed yield of 5q/ha and is suitable for semi-arid regions of Rajasthan	1994
RMO-40	First early maturing (62-65 days), short statured, non-spreading plant type, synchronous maturity. Resistant to YMV in field conditions, seed yield 6-8 q/ha	1994
FMM-96	It is an extra early mutant variety maturing in 58-67 days. It was bred by mutagenesis at ARSM Fatehpur, Rajasthan. Plant stature is short (25-30 cm) and non-spreading with synchronous maturity	1997
RMO-225	Erect semi spreading early mutant, matures in 65-67 days, grain yields from 5-8 q/ha, broad leaves, shallow lobed with 2-3 clusters/leaf axis	1999
CZM-1	Suitable for western areas of India, medium maturity (75-80 days), seed yield 5-6 q/ha, field resistance to YMV disease	1999
CAZRI Moth-1	Earlier (72-75 days) then medium maturity group, semi-spreading dual purpose variety responding to inputs, Field resistance to YMV, bold grain with 25% protein, yield 4-5q/ha	1999
RMO 435	Short duration variety maturing in 64-68 days, 6-8 q/ha yield, high proteins contents (27%) with good fodder value. Suitable for all moth growing areas of India. Notification No. 937/E (4.9.2002)	2002
CAZRI Moth-2	First variety produced through hybridization (RMO-40 x Jadia) having an erect plant habit with good podding, matures in 75-85 days, yield potential of 10-12 q/ha	2003
RMO 423	Short duration (67-70 days), high yield with good fodder value, Rajasthan state release, resistant to YMV, Notification No. 161/E (4.2.2004)	2004
GMO-2	Semi-spreading, medium maturity (75-85 days), bold and brown seeds, yield ranges from 8-10q/ha. Being short duration it escapes YMV. It is a state release variety	2004
RMO 257	Early maturing (62-65 days) mutant with 53 % higher seed yield over Jwala (3.70 q/ha) and 13 % over RMO 40 (5.04 q/ha), spreading plant type with 3 to 6 branches/plant. Leaves are shallow lobed with 2-3 clusters/leaf axil. Seeds are medium bold (2.9-3.2 g/100 seeds), fodder yield about 18-20 q/ha, suitable for rainfed areas	2005
RMO 2004	Early maturing (67 days),high yield with field resistance against YMV, root rot, leaf crinkle virus and bacterial leaf spot as well as distinct resistance against Jassids and white flies. Less cooking time and IVPD was also observed in RMO-2004. State Release for all moth-growing areas. This variety is also known as RMB 25	2005
CAZRI Moth-3	An erect and early maturing (62-64 days), mutant of RMO-40 having drought tolerance and escapes YMV, bears pods heavily with grain yield in the range of 9-10q/ha	2005

of induction have also been identified (Rampuria et al. 2012; Gurjar et al. 2014). Construction and analysis of an SSH cDNA library of early heat-induced genes of *Vigna aconitifolia* variety RMO-40 has been accomplished by Sakshi et al. (2012).

Expecting efficient drought tolerance mechanism in moth bean Hu et al. (1992) cloned the first gene for proline synthesis from moth bean (*Vigna aconitifolia*), δ1-pyrroline-5-caboxylate synthetase (P5CS) which is a bifunctional enzyme catalyzing first step the activation of glutamate by phosphorilation and second the reduction of the labile intermediate γ-glutamyl phosphate into glutamate semialdehyde (GSA). To understand drought tolerance at molecular level, stress enzymes like catalase, glutathione peroxidase and sugar content were reported to be higher in tolerant moth bean genotypes Bhardwaj and Yadav 2012 a, b). However, some of the genotypes though recorded a reduction in these chemicals the level remained high in tolerant types. (Soni, 2012; Soni et al. 2011). SDS PAGE profiling of leaf proteins indicated that while some genes were expressed only under stressed conditions others either showed quantitative variation or remained unchanged. Up-regulation and down regulation of certain proteins was observed, whereas, two of the proteins of 54.5 KD and 17.0 KD size were induced only in tolerant genotypes.

Though protein profiling provides some idea about quantitative change in gene expression it does not tell about genes involved. Hence, in order to have insight about stressed induced genes a modified differential display of moth bean (using tolerant variety RMO-435) RNA was carried out. A total of 40 up-regulated or newly expressed bands were recovered from stressed samples and sequences were generated for 35 ESTs. Amongst EST sequences large proportion was of chaperons *viz*., HSP 70, HSP101 and DnaJ like protein along with stress responsive and nucleotide binding regulatory ESTs (Soni et al. 2013). Similarly, ESTs upregulated in response to heat stress at very early and early stages of induction have also been identified (Gurjar et al. 2014).

Nutritional value in moth bean

Moth bean is an important constituent of the diet of the people of arid and semi-arid areas of the country. The main contribution of moth bean as a food is based on its protein content, which ranges from 20 to 23 per cent. It is not only a source of inexpensive protein, but also a necessary supplement for people whose diet is cereal based. Moth bean protein is relatively rich in the two essential amino acids, lysine (5.77 %) and tryptophan (3.23%), that are lacking in cereals and thus complements the amino-acid profile available from cereal-based diet (Sathe et al. 2007). There have been varietal differences for abundance of these chemicals in seed. Detailed bio-chemical composition worked out by various scientists (Khokar and Chouhan 1986; Laura et al. 1999) has been provided in Table 3. Moth bean is a very important industrial crop. In Bikaner city alone there are more than 600 industrial units engaged in bhujia, papad, mogar and nugget preparation, giving employment to nearly one lac people involving annual transaction of over Rs 50 crores. It is also being utilized as *khheechada*/*kheech*, vegetable and sprouting. Moth bean preparations are now becoming popular not only in India but abroad, as well. Statistics of moth bean in Rajasthan for last three decades (1976 to 2010) showed that there was not much fluctuation in the area of moth bean indicating that farmers are growing moth bean consistently irrespective of climatic conditions.

Constraints

Moth bean like other grain legumes have a long history of domestication almost as long as cereals and have all along been subjected to selection for adaptation, quality and yield. But progress in enhancing moth bean production has been rather very slow as compared with other *kharif* pulses. Despite the importance of this crop in arid and semi-arid regions, its adaptability to stress situations, ability for biological nitrogen fixation and amenability to fit in the mixed or sole cropping systems, the production of moth bean has remained stagnant since 1976. Production relates to inherent biological architecture of the crop for intercepting sunlight, sink-source ratio, susceptibility to a large number of insect pests and diseases, poor post harvest handling and poor institutional support etc. Keeping all these factors in view the major constraints are broadly grouped in to technological biological and socio-economic categories

Technological constraints

Generally moth bean, like some other pulses, is grown on marginal lands under rainfed conditions. The adaptation of moth bean to marginal areas has been detrimental to increasing its production. In this process there was greater accumulation of genes which conferred greater flexibility and thus adaptability to harsher environments rather than suitability to specific environments. The selection pressure under subsistence agriculture was somewhat responsible for erosion or dilution of genes for high yielding genes in such crops. Major technological constraints to moth bean production are - lack of improved and desirable genotypes, conservation and utilization of genetic

Table 3. Chemical composition of moth bean grains

Nutrients	Quantity	Nutrients	Quantity	Nutrients	Quantity
Moisture (%)	6.84- 7.74	Lignin	4.57+-0.35#	Phytate P as per cent of total phosphorus	68.48-72.97
Crude protein (%)	21.23-26.23	Fat (%)	1.99-3.58	Antinutritional factors	
Protein digestibility	58.69-62.06 (per cent)	Total (%) available carbohydrates	0.39-0.43	Phytic acid (mg/100g)	852.49-899.16
Albumin (%)	6.75-7.45	Thiamine (mg/100g)	0.39-0.43	Saponin (mg/100g)	2833.49-3349.33
Glutamin	4.15-4.8	Niacin (mg/100g)	1.20-1.50	Trypsin inhibitor activity (units/10g)	2718.66
Prolamines	3.05-3.35	**Minerals/ash**	(Mg/100g)	Polyphenols	3.08+-0.07#
Globulins	2.5-3.1	Calcium	272.83-289.99	**Vitamins**	
Total carbohydrates	61.8#	Iron	5.41-6.66	Vitamin A	30 i.u
Total starch (g/100g)	39.5+-1.74#	Manganese	0.63-0.68	Carotene (mg/100g)	9
Soluble sugars (g/100g)	8.29#	Zinc	13.95-23.75	Pantothenic acid	0.65
Total dietary fiber (g/100g)	18.54+-0.39#	Phosphorus	347.49-359.99	Ribiflavin	0.18
Crude fibre (%)	3.54-3.84#	Phytate phosphorus	240.22-253.37	Ascorbic acid	2.0-3.0

Khokar and Chauhan (1986); # Laura et al. (1999)

resources, low harvest index, production and distribution of quality seed, incidence of pests and diseases and poor agronomic practices**.**

Biological constraints

In moth bean, most of the varieties evolved and released for cultivation are selections from the landraces which are adapted to conditions of intercropping under low fertility and poor management. Inherent yield potential of such varieties is low. Unless new varieties with high yield potential are developed, the cultivation is shifted to more productive areas and unless better package of practices are evolved, desired yield levels shall not be attained. Bhargava (1991) has listed the bottlenecks such as photo and thermo-sensitivity, determinate growth habit, synchronous maturity, non-shattering of pods, compact/semi-erect growth, resistance to insects-pest and diseases, induction of new genes for earliness and resistance to various biotic and abiotic stresses. Hence the breeding efforts should be made considfering the above factors, which may help stabilize yields and increase adaptation of new genotypes to different environments.

Socio-economic constraints

Moth bean along with other pulses are often labeled as secondary crops because of their limited share in the total food grain production. Being restricted commercially and geographically due to lack of revolutionary technology, pulses have failed to generate enough enthusiasm and support for their development both by farmers and developmental agencies. Therefore, a separate mission should be set up for developmental and promotional activities of pulses including moth bean and all the activities starting from seed distribution to procurement at support price should be monitored by it. If sincere efforts are made, pulses on marginal lands may contribute substantially to our food grain production.

Diseases and pests and their control measures

Diseases are mainly are responsible for reduction and uncertainty in yield. Yellow mosaic virus, transmitted through white fly (*Bemisia tabaci*) a vector of this virus, Cercospora leaf spot caused by *Cercospora dolichi* Ellis & Everlast, leaf crinkle virus, dry root rot, incited by *Rhizoctonia bataticola* (Taub.) Butler and, *Macrophomina phaseolina* (Tassil Goid), bacterial leaf spot caused by *Xanthomonas campestris*, powdery mildew (*Erysiphe polygoni* DC) and root-knot nematode infestation by *Meloidogyne incognita* are some of the prominent diseases of moth bean. Black weevil Black weevil adults (*Cyrtozemia dispar*) attack plant leaves in advanced stage and grubs attack the roots in initial stage.

Control measures

The resistance breeding to obtain field resistance against insect-pest and diseases is an economic and nature friendly option to control the incidence. Although the use of chemicals and pesticides is not advocated but to control viral, bacterial and fungal diseases their use is one of the major option. Chemicals such as, Dimethoate (0.2%), Methyl Demeton (0.2%) Monocrotophos (0.4%) are effective in reducing the incidence of YMV. Varieties RMO 40 and RMO 257 developed by RAU scientists have field resistance against YMV while Jwala has moderate resistance to this disease. The application of other fungicides *viz*., Bavistin Captan CO, Topsin M, Streptocycline and their combination can reduce the disease incidence. Powdery Mildew could be controlled by Karathane (0.2%) while the incidence of root knot nematode by Aldicarb or Carbofuran in the soil. Jassids, whitefly, thrips, black weevil and pulse beetle are major insects while termite, red hairy caterpillar, leaf minor, aphids, green bug, grey weevil, galerucid beetle, mites and surface grass hoppers are of minor importance. The application of fungicides, insecticides at appropriate time enhanced seed yield by 66.2 per cent over control (4.42 q/ha) and gave monetary benefits.

Horse gram (*Macrotyloma uniflorum*)

Horse gram [*Macrotyloma unifl*orum (Lam.) Verdi syn. *Dolichos biflorus* (Auct) or *Dolichos uniflorus* (Lam)] having 2n=24 is known by various vernacular names *viz*., Kulaththa, Kulthi, Kurti-kala, Kalathi, Mutliva, Muthera, Ulavalu Kollu, Hurali and Kulith It is a slender semi-erect annual herb having a little twinning branches and attaining height of about 50 cm depending on varieties. Trifoliate leaves are yellowish green to green in color. Pods are short about 3-5 cm long, linear or curved bearing 5-7 seeds. Seeds are flattened, 3-6 mm long having various shades of color like, yellowish brown, light red brown, dark red to black or mottled with hard seed coat.

Horse gram cultivation is mainly concentrated in drier parts of Southeast Asian countries including Australia, Burma, India, Bangladesh and Sri Lanka. It is also considered as a drought hardy crop grown rainfed conditions without supplemental water. It is grown throughout India covering diverse agro-climatic regions. Crop is grown in *kharif* as well as *rabi* seasons in south zone including peninsular India representing tropical semi-arid (steppe) climate with maximum area in Karnataka 34.6 % (5.90 lakh ha) contributing about 30% to production. Horse gram is also growing in states of Maharashtra, Orissa, Andhra Pradesh and Tamil Nadu contributing to about 92.3 % of area including that of Karnataka. However, to a limited extent it is also grown in divergent climates of Rajasthan and Gujarat (dry and hot) on one hand and Jammu and Kashmir (cooler climate) on the other. The crop is grown as single as well as mixed with sorghum, pearl millet, finger millet, maize, pigeon pea, sesame or niger. Since long it has been recognized as crop of future under rising temperature (NAS 1978).

Nutritional quality and uses

Kulthi seeds are rich source of protein–22%, carbohydrate–57 %,phosphorus–311 mg/100 g, iron–7 mg/100 g, calcium–287 mg/100g with 321 calorific value (Kadam et al. 1985). A variety of products are prepared from seed, however, it is seldom split for *dal* (*dahl*) purpose. Both dry and sprouted seed are either boiled and cooked or fried for direct consumption or curry preparation especially the *rasam* a *dal* like preparation in south India. Ground with salt, chilli and coconut roasted seeds of horse gram are consumed with rice or chapatti (*roti*) prepared from millet flour. Its flour can be used to make various indigenous items including pappad. In addition, horsegram is known for medicinal uses. Daily consumption of seeds helps curing kidney stones, menorrhagia and urinary problems. Soup prepared from grains or sprouted grains is known to give relief in acidity, constipation, whopping cough, piles, cold and urinary problems. It is known to cure iron deficiency and keep body warm during winter (Ghani 2003). It is used as concentrated feed for animals and standing crop may be rotated in the soil for green manure.

Genetics resources

A total of 1721 accessions of horsegram are being conserved in different gene banks of the world. Of these, about 95% (1627) are conserved at NBPGR, New Delhi, India. The Regional Research Stations, Thrissur, Kerala, usually maintain some accessions in active form while taking up evaluation of horse gram germplasm. Characterization of 1161 accessions was taken up during 1999-2004 based on agro-mrophological traits. The genus *Macrotyloma* has 25 species available in wild forms mostly in Africa. Western ghats of India harbor *Macrotyloma ciliatum* (Willd.) a wild form of horse gram. While *M. sar-garhwalensis* is found in Central Himalayas of India. Being non twining annual herb with high protein content (38.35%) this species could be good source of desirable genes. Two other wild relatives *M axillare* and *M africanum* have been found important for forage purpose breeding. Some efforts to describe and identify useful traits from wild species were made using *M uniflorum* and *M axillare* and *M axillare.* Recently, Bhardwaj et al. (2013) and Reddy et al. (2008) made trancriptome analysis to understand mechanism of drought tolerance at molecular level in horse gram. A number of regulatory, stress related and metabolic path way related genes were identified.

Characterization of germplasm

The high yield with yield attributing traits were found in late maturing genotypes with per plant yield reaching up to 11.86 g as against about 7 g in early and medium maturity groups (Latha 2006). A wide range of variability for qualitative and quantitative characters was reported (Rana 2010). He found semi-erect to vine types varying for leafiness, leaf pubescence and stem color (between green and purple). The seed and pod showed even larger variations for color. Pods had various shades of straw, tan, and cream, light brown, brown, dark brown and brownish black. Variations for plant height (17-145 cm), primary branches (1.0-9.8), number of pods (4-148), pod length (3.07-6.17), 100 seed weight (0.92-4.1 g) and biological yield (0.21-11.86 g) were high. Describing 11 economical traits in 1426 genotypes by NBPGR, New Delhi which published a catalogue on germplasm based on the evaluation during 1984-1990 at New Delhi (506 accessions) and NBPGR, satellite research station Akola (920 accessions). Germplasm evaluation studies indicated wide variation for yield and yield components in horse gram with high heritability estimates for yield, 100 seed weight, days to flowering and days to maturity (Sood et al. 1994). Traits of economic importance have been evaluated by several workers on different germplasm lines or collections varying from 10 to a few hundred in number revealing good diversity and making effective selections (Prakash et al. 2008).

Varietal improvement

Number of pods/plant, number of seeds/plant and 100 seed weight are reported to be correlated with yield (Nagaraja et al 1999, Prakash and Khanure 2000, Parameshwarappa and Kumar 2002 and Prakash et al. 2008). Number of branches/plant and plant height were also found to have positive influence on yield in some studies (Prakash et al. 2002, 2008). Highest positive effect of pods per plant on yield was indicated through path analysis (Prakash and Khanure, 2000). High heritability has also been reported for pods per plant, and clusters per plant. In order to improve harvest index and utilize scanty water usually available for limited period need for early maturing with synchronized maturity have been desired in arid legumes. Consequently, early maturing mutants were induced in horse gram. Earlier selection efforts were successful in reducing the maturity by 20-30 days. Two varieties Habbal Hurali 1 and 2 matured in 90-100 days as against 120 days of the collection PLKV 32 from which they were selected. A selection PHG 9 from Palampur Local was endowed with early maturity (100-105 days) and improved plant type. Subsequently two early maturing (80-90 days) varieties AK 21 and AK 42 were released with improved plant type in 1999 and 2004 respectively (Kumar, 2008). As expected these early flowering and maturing genotypes *viz*., Hubbal Hurali 1 and 2, PLKV 32 and EC 1460 were photo-insensitive conferring wide adaptability and also successful selection of early maturing and photo-insensitive mutant having low polyphenols was obtained by irradiating a photosensitive varieity (Dapali-1) with 20 KR. Bolbhat and Dhumal (2009) generated mutant lines and also induced variation for agronomic characters was recorded in variety HPKC-2. The superior mutants namely, CRIDA-18R, CRHG-4 and CRHG-19 were released as variety for South India. CRIDA-18R and CRGH-19 mutants were derivative of K-42, and released in 2009 and 2014 respectively for multiple resistance and early maturity. Released in 2010, CRHG4, mutant was derived from Hyderabad Local (Salini et al. 2014).

Rice bean (*Vigna umbellata* (Thunb.) Ohwi and Ohashi)

Rice bean (Azuki bean) is mainly cultivated in its region of origin and domestication under very wide climatic and geographical adaptability from humid sub-tropical to warm and cool temperate climate as well as on a range of soils (Khadka et al. 2009). It is sown twice a year in the traditional areas of cultivation in India and Nepal. Though rice bean is considered one of the hardiest crops least affected by diseases and mostly grown without any protective measures. It immensely contributes to food and feed basket in some of the developing and South Asian countries.

Rice bean [*Vigna umbellata* (Thunb.) Ohwi and Ohashi, syn*. V. calcarata* (Roxb.) Kurz], 2n=22, a native of Southeast Asia is multipurpose grain legume (Burkill 1935) along with the wild species *V. Umbellata var. gracilis*, the probable progenitor (Tomooka et al. 1991), having various synonyms *viz*., *Azukia umbellata* (Thunb.) Ohwi, *Phaseolus calcaratus* Roxb. and *Phaseolus pubescens* B1, (Duke, 1981). It is commonly known as red bean, Japanese rice bean, climbing mountain bean, Mambi bean and oriental bean in English (Duke, 1981; Mejia, 1984). The cultivated *V. umbellata* and wild *V. umbellata* var. *gracilis* are found naturally growing from southern China to the north Vietnam, Laos and Thailand into Burma and India and two species are thought to be cross fertile (Tomooka et al. 1991; Ohashi et al. 1988). As many as five distinct botanically varieties, namely, *major*, *glabra*, *rumbaiya*, *gracillis* and *macrocarpa* are known to exist in the area (Chandel et al. 1988).

Rice bean is also a member of Asiatic *Vigna* species and belongs to common Ceratotropis subgenus (Marechal 1978). There appears to be three isolated secondary gene pools *vis* a *vis* sections shared by these cultivated species in the subgenus *Ceratotropis viz*., *Ceratotropis* (Mungbean group), *Angulares* (Azuki bean group) *and Aconitifoliae* (intermediate group) (Konarev et al. 2002; Doi et al. 2002; Tomooka et al. 2002ab). Ceratotropis gene pool is represented by inter-crossable species, *radiata* (mung bean, green gram and mungo (black gram, urdbean) domesticated in India. *Angulares* group includes *V. umbellata* (rice bean)-*V. angularis* (adzuki bean), domesticated in South East and North East Asia, respectively. The *Aconitifoliae* gene pool domesticated in South Asia included *V. aconitifolia* (moth bean, matbean)-*trilobata* (pillipesara bean, jungle bean), *Vigna glabrescence* (2n=44) is thought to be a cross between *V. radiata* and *V. umbellata*, domesticated in SE Asia (Lawn 1995).

Genetic resources

Largely rice bean is a self-pollinated crop with an evidence of some natural crossing (Sastrapradja and Sutarno 1977). The hybrid between *Vigna radiata* and *V. umbellata* is noteworthy among them for the transfer of bruchid resistance from *V. umbellate* (Tomooka et al 2014). Tetraploids produced by treating with colchicine 2g/L restored the fertility producing normal flowers and pods. Presently, about 2045 germplasm accessions are being maintained in long term repository at -18^{o}C of the national gene bank at NBPGR, New Delhi (Singh et al. 2013). Active collections are also maintained at Shillong (Meghalaya) and Shimla Himachal Pradesh). The World Vegetable Centre (formerly the Asian Vegetable Research and Development Center) based in Taiwan also maintains 197 accessions of rice bean, procured from Nepal (8) and India (24) (World Vegetable Center, 2007). Farmers recognize four naturally available types of land races; red (Rato Jhilinge), brown big (Khairo Thulo), White big (Seto Thulo), and early maturing small grained semi-determinate (Bhadaure). Rice bean has been recognized as one of the *Vigna* species harboring economically important genes including resistance to mungbean mosaic virus and bruchid (Tomooka et al. 2000; Kashiwaba 2003).

Characteristic features

General morphological features of rice bean resemble to that of azuki bean. It is an annual, highly branched, with erect or sub-erect fine stem becoming viny and tendrillar, growing up to three meter height. Leaves are small, typically trifoliate and hairy. Golden yellow flowers borne on axil raceme inflorescence, in clusters with slender and somewhat curved pods, oblong seeds with smooth seed coat with predominant and having wide range of colors *viz*., dark wine, green, yellow, brown, black, speckled or mottled types, however, red and yellow are more common. Wild traits like photo-sensitivity flowering under short day, indeterminate flowering and asynchronous maturity and pod shattering widely prevail in the germplasm.

Distribution

Rice bean is mainly cultivated in its region of origin and domestication, north east India, Nepal, Bangladesh, Thailand, Vietnam and Southern China (Gautam et al. 2007). It is grown chiefly on high altitudes (~1000 m above mean sea level), in the eastern and north eastern Indian states (Lawn 1995) under shifting cultivation for food, fodder and green manure specifically by the resource poor farmers in the marginal areas.

Rice bean has very wide climatic and geographical adaptability from 200 up to 2000 m above mean sea level, from humid subtropical to warm and cool temperate climate as well as on a range of soils (Khadka et al. 2009). It is sown twice a year in the traditional areas of cultivation in India and Nepal. The summer crop is sown in February and March for harvest during summer while rainy season crop is sown in July and August for harvest in December (Khanal et al. 2009; Oommen et al. 2002). It is raised as sole crop in small fields or sown along bunds of rice terraces. Rice bean benefits from being sown between rows of a tall cereal such as maize or sorghum that it can use for climbing however, overshadowing might reduce the yields. Being a warm season crop it performs well under humid and subhumid conditions with 1000-1500 mm rain fall. However, it tolerates drought (NAS 1979) and high temperature. The crop is grown on marginal and exhausted soils with minimal inputs surviving on residual fertility and moisture (Joshi et al. 2006).

Varietal improvement

Rice bean usually matures in 120-150 days after sowing that might get delayed at higher altitudes. The crop harvested when 75% of the pods turn brown. Average global yield of rice bean have been very low about 225 kg/ha (Duke, 1981). Production of as high as 1979 kg/ha (Zaman and Malik 1999) and 3000 kg/ ha seed and 8000 Kg/ha dry herbage has been reported by Mukherjee et al. (1980). Systematic improvement work has not been pursued to develop high yielding varieties. A number of varieties have been released in rice been along with numerous cultivars namely, RBL-1 (1996), RBL-6 (2002), RBL-35 (2003) and RBL-50 (2003) have also been released. RBL-6 is a photosensitive variety having vigorous spreading growth habit with many lateral intertwining branches having resistance to fungal, bacterial and viral diseases especially yellow mosaic virus. Light green seeds of this variety are bold. PRR-1 (PRR 8801) and PRR-2 (PRR 8901) developed by G.B. Pant University of Agril. & Tch., (GBPU&AT in 1995 and 1997 respectively. BRS-1, BRS-2 were released by NBPGR Research Station, Bhowali, Uttrachand, for hill regions. Regional Office of NBPGR, Shimla nd VPKAS, Almora recently released 'Himshkati' (VKB-3) variety for Northwest and North east hill region of India in 2012., Bidhan-1 (K-1) from Bidhan Chandra Krishi Viswavidyalaya, kalyani. Bidhan 1, Bidhan2 and Bidhan 3, were suitable to grow in North Eastern Region WB, Orissa, Jharkhand, Assam, Sikkim, Mizoram, Manipur, Nagaland & Bihar, BCKV, Kalyani. A fodder type variety Konkan rice bean-1 (KRB-1) was released . In addition to these a number of cultivars, land races are popularly grown which include; Naini, Megha Rumbaiza 1(RCRB 1-6), MNPL 1, MNPL 2, MNPL 3, MNPS 2 and MNPS 3, Chaukhamba etc.

In order to understand underlying molecular mechanism and utilize such useful genes genetic map has been developed utilizing azuki bean SSR markers (Kaga et al. 2000; Isemura et al. 2007b) Interspecific mapping populations using rice bean as one parent and azuki bean (Kaga et al. 2000) and *V. nakashimae* (Somata et al. 2006) as another parent were developed. Using these maps a number of qualitative traits (Kaga et al. 2000) and QTLs for resistance to storage pest (bruchids) and seed weight (Somata et al. 2006) were mapped. The genes related to domestication of rice bean have been analyzed in crosses among cultivated and wild rice beans (Isemura 2007a, Isemura 2010). Recently Chen et al. (1016) developed a set of more than 9000 gene based SSR markers using transcriptome data.

Nutritional value and uses

All above ground plant parts (young pods, leaves and seed) of rice bean are considered edible and used for preparing vegetables, curies and soup and consumed with or without rice. Moreover, ricebean *dal* is not preferred over that made from other pulses probably due to its strong taste and pungency. Hitherto, rice bean remains an underutilized crop with high nutritional value having potential to address malnutrition in addition to feed and fodder requirement. The dry seed of rice bean are good source of carbohydrates, proteins, minerals and vitamins. Rice bean grains contain 58-72% carbohydrate, 18-32% crude protein, 4-6% fibre and 3-5% ash (Buergelt, 2009). The seed has high starch concentration (52-57%) (Kaur et al. 1990; Chavan et al. 2009) with highly variable proportions (20-60%) of amylose (Kaur et al. 2013). Protein up to the extent of 25.57% was reported by Katoch (2013) with in vitro digestibility of 54.23 %. A very high in vitro digestibility (82-86 %) of rice bean protein was however, recorded by Rodriguez and Mendoza (1991). It is rich in limiting amino acids methionine and tryptophan (de Carvalho and Vieira, 1996). Ricebean contains a number of ant nutritional factors including phytic acid, polyphenol, tannins, saponins, trypsin inhibitors, and flatus producing oligosaccharides.

This is also used as fodder crop sown in February-March or July-August is harvested at flowering when the crop attains maximum vegetative growth. Green or dry fodder of rice bean consisting of leaves, pod coat and stem is fed to animals (Chaudhuri et al. 1981). Indeterminate luxurious growth of rice bean efficiently produces good amount of biomass. However, because of the coarse leaves and beans its use as green fodder is limited in Nepal. Alternatively, farmers prefer to use dry straw of the bean for livestock feeding in the dry season. Dual-purpose land races are preferred in the marginal hilly regions of Nepal (Khanal et al. 2009). In order to have better quality fodder, late maturing and photo-sensitive landraces of rice bean are preferred in India. They are sown during long-day periods (Feb-March) in order to prevent the plant from flowering (Oommen et al. 2002). Comparatively less (5-7 t dry matter (DM)/ha) fodder yield was reported in summer (May and June) than rainy season crop (8-9 t DM/ha) in November and December (Chatterjee et al. 1977).

Resistance to biotic and abiotic stresses

Though rice bean is considered one of the hardiest crops least affected by diseases and mostly grown without any protective measures. A number of fungal and bacterial diseases infect the crop at various stages of growth. Rust [*Uromyces appendiculatus* (Pers) Unger], powdery mildew [*Oidiotaurica taurica* (Lev.) salmon], rhizoctonia blight (*Rhizoctonia solani*), Cercospora leaf blight (*Cercospora* spp.), Bacterial blight (*Pseudomonas* spp.) are a few more common diseases of the rice bean. It is relatively remains free from pests especially from storage pests (Duke, 1981). However, a number of insects infest the crop and become economically important e.g. pod borer (*Helicoverpa armigera* Hubner), Soybean hairy caterpillar (*Spilarctia casignata* Kollar), banded blister beetle (*Mylabris pustulata* Thunberg), aphid (*Aphis craccivora* Koch), pod sucking bugs (*Anoplocnemis* spp.), pod weevil (*Apion* spp.), Green stink bugs (*Nezara* spp.), leaf folder (*Hedylepta* spp. Fab.) (Khadka and Acharya 2009).

Very limited work has been undertaken to incorporate resistance in rice bean. However, the screening of germplasm has helped inidentification of some genotypes exhiting resistance to drought, and some of the diseases. The mature plants have been reported to be tolerant to water logging to some extant (de carvellho and Veira 1996) and acid soils (Dwivedi 1996) and resistant to many pests and diseases rice bean is usually grown without much care and inputs. The average temperatures range from 18 to 30°C, suites most to its growth but tolerates 10-40°C however, frost affects it adversely (Rajerison 2006; Ecoport 2014). RBL-6 is resistant to fungal, bacterial and viral diseases especially yellow mosaic virus.

Future thrust areas

Since moth bean is an important crop of marginal lands with hot, dry-arid conditions, the improvement in production can be brought about by introducing irrigated farming system in this crop. Concerted efforts should me made to breed high yielding genotypes utilizing diverse germplasm for diverse conditions. Additional areas may be enhanced under short/medium duration genotypes such as RMO 40, RMO 435 and RMO 257. Photosynthetically efficient genotypes may be developed and multiplication and distribution of quality and certified seed of improved varieties should be increased. Inter/mixed cropping with pearl millet, cluster bean, sesame and castor may be encouraged. Concerted effort should be made to improve genetic potential of the Horse gram and Rice bean varieties. Development and application of molecular techniques should be promoted for rapid improvement of these minor pulses. Improvement in the agronomic practices and cropping systems should be followed. Adoption of minimum plant protection measures like seed treatment with agrochemicals is necessary. To minimize harvest and post-harvest losses, improved harvesting technology should be developed and adopted.

Declaration

The authors declare no conflict of interest.

References

Arya I. D, Arya S., Rao D. V. and Shekhawat N. S. 1990. Variation amongst protoplast-derived moth bean *Vigna aconotifolia* plants. Euphytica, **47**: 33-38.

Bhardwaj J. and Yadav S. K. 2012a. Comparative study on biochemical and antioxidant enzymes in a drought tolerant and sensitive variety of horse gram (Macrotyloma uniflorum) under drought stress. Am. J. Plant Physiol., **7**: 17-29.

Bhardwaj J. and Yadav S. K. 2012b. Genetic mechanisms of drought stress tolerance, implications of transgenic crops for agriculture. Agroecology and strategies for climate change. Sustainable Agriculture Reviews 8. Edited by: Lichtfouse E., Netherlands: Springer, 213-235.

Bhardwaj J., Chauhan R., Swamkar M. K., Chahota R. K., Singh A K., Shankar R. and Yadav S. K. 2013. Comprehensive transcriptomic study on horse gram (*Macrotyloma uniflorum*): De novo assembly, functional characterization and comparative analysis in relation to drought stress. BMC Genomics, **14**: 647.

Bhargava S. and Chandra N. 1983. In vitro differentiation in callus cultures of moth bean, *Vigna aconotifolia* (Jacq) Marechal. Pl. Cell Rep., **2**: 47-50.

Bhargava S. and Smigocki. 1994. Transformation of tropical grain legumes using particle bombardments. Curr. Sci., **66**: 439-42.

Bhargava S. and Chandra N. 1989a. Factors affecting regeneration from leaf explants of moth bean *Vigna aconitifolia* (Jacq) Marechal. Indian J. Exp. Biol., **27**: 55-57.

Bhargava S. and Chandra N. 1989b. Effect of sodium chloride on callus cultures of moth bean *Vigna aconitifolia* (Jacq.) Marechal Cv. IPCMO 926. Indian J. Exp. Biol., **27**: 83-84.

Bhargava S. and Chandra N. 1989c. In vitro regeneration of shoot apices of *Vigna aconitifolia* (Jacq) Marechal. Legume Res., **12**: 170-172.

Bhargava S., upadhyaya S., Garg K. and Chandra N. 1983. Differentiation of shoot buds in hypocotyls explants and callus cultures of some legumes. *In*: Sen S. K. and Giles K. L. (Eds.). Plant cell cultures in Crop Imp. Pp 431-33, Plenum Press, New York.

Bolbhat S. N. and Dhumal K. N. 2009. Induced macromutations in horse gram [*Macrotyloma uniflorum* (Lam.) Verdc]. Legume Res., **32**: 278-281.

Buergelt D., von Oppen M. and Yadavendra J. P. 2009. Quality parameters in relation to consumer's preferences in rice bean. Presentation at the International Conference on Grain Legumes: Quality Improvement, Value Addition and Trade, February 14-16, 2009, Kanpur, India.

Burkill I. H. 1935. A dictionnary of the economic products of the Malay peninsula. Edited by: Ministry of agriculture (Malaysia). Crown Agents for the Colonies. London. 839.

Chandel K. P. S., Arora R. K. and Pant K. C. 1988. Rice bean: A potential grain legume. NBPGR Sci. Monograph No.12, National Bureau Of Plant Genetic Resources , New Delhi.

Chatterjee B. N. and Dana S. 1977. Rice bean (*Vigna umbellata* (Thumb.) Owhl and Ohashi. Trop. Grain Legume Bull. N°10, International Grain Legume Information Center.

Chaudhuri A. B., Singh R. P. and Gupta B. N. 1981. Chemical composition and nutritive value of rice bean straw. Indian J. Dairy Sci., **33**(4): 438-442.

Chavan V. M., Patel G. D. and Bhaskar D. G. 1966. Improvement of cultivated Phaseolus species need for interspecific hybridization. Indian J. Genet., **26A**; 125-131.

Chavan U. D., Momin A. Chavan J. K. Amarowicz R. 2009. Characteristics of starch from rice bean (*Vigna umbellata* L.) seeds – A short report. Polish J. Food Nutr. Sci., **59**(1): 25-27.

Chen Honglin, Xin Chen, Jing Tian, Yong Yang, Zhenxing Liu, Xiyu Hao, Lixia Wang, Suhua Wang, Jie Liang, Liya Zhang, Fengxiang Yin and Xuzhen Cheng. 2016. Development of Gene-Based SSR Markers in Rice Bean (*Vigna umbellata* L.) Based on Transcriptome Data. PLoS One. 2016; **11**(3): e0151040.

De Carvalho N. M. and Vieira R. D. 1996. Rice bean (*Vigna umbellata* (Thunb.) Ohwi et Ohasi) *In*: E. Nwokolo and J. Smartt (Eds.) Legumes and Oilseeds in Nutrition. Chapman and Hall, ISBN 0-412-45930-2, pp 222-228.

Dobhal V. K. and Gautam N. K. 1994. Stability analysis for yield and component characters in rice bean (*Vigna umbellata*). Indian J. Agric. Sci., **64**: 237-239.

Doi K., Yoshimura A. and Iwata N. 1998. RFLP mapping and QTL analysis of heading date and pollen sterility using backcross populations between *Oryza sativa* L. and *Oryza glaberrima* Steud. Breed. Sci., **48**: 395-399.

Doi K., Kaga A., Tomooka N. and Vaughan D. A. 2002. Molecular phylogeny of genus *Vigna* subgenus *Ceratotropis* based on rDNA ITS and atpB-rbcL intergenic spacer of cpDNA sequences. Genetica, **114**: 129-145. doi: 10.1023/A:101 5158408227. PMID: 12041826.

Duke J. A. 1981. Handbook of legumes of world economic importance. Plenum Press, New York, London.

Dwivedi G. K. 1996. Tolerance of some crops to soil acidity and response to liming. J. Indian Soc. Soil Sci., **44**: 736-741.

Eapen S. and George L. 1990. Outogeny of somatic embryos of *Vigna aconitifolia, Vigna mungo* and *Vigna radiata.* Ann. Bot., **66***:* 219-26.

Eapen S. and Gill R. 1986. Regeneration of plants from cultured root explants of moth bean (*Vigna aconitifolia* (Jacq) Marechal). Theor. Appl. Genet., **72**: 384-87.

Eapen S. and Gill R. and Rao P. S. 1986. Tissue culture studies in moth bean. Curr. Sci., **55**: 707-709.

Gautam R., Kumar N., Yadavendra J. P., Neog S. B., Thakur S., Khanal A., Bhandari B. and Hollington P. A. 2007. Food security through ricebean research in India and Nepal (FOSRIN). Report 1. Distribution of ricebean in India and Nepal. Local Initiatives for Biodiversity, Research and Development, Pokhara, Nepal and CAZS Natural Resources, College of Natural Sciences, Bangor University, Wales, UK.

Ghani A. 2003. Medicinal plants of Bangladesh: chemical constituents and uses. Dhaka Asiatic Society of Bangladesh, pp. 5-16.

Gill R. and Eapen S. 1986. Plant regeneration from hypocotyle protoplasts of moth bean (*Vigna aconitifolia*). Curr. Sci., **55**: 100-102.

Gill R., Eapen S. and Roa P. S. 1986. Tissue culture studies in moth bean- Factors influencing plant regeneration from seedling explants of different cultivars. Proc. Indian Acad. Sci. (Pl. Sci.), **96**: 55-61.

Gill R., Mishra K. P. and Rao P. S. 1987. Stimulation of shoot regeneration of *Vigna aconitifolia* by electrical control. Ann. Bot., **60**: 399-403.

Godbole G., Kunachgi M. N., Potdar U. A., Krishnamurthy K. V. and Mascarenhas A. F. 1984. Studies on a drought resistant legume: The moth bean *Vigna aconitifolia* (Jacq) Marechal II morphogenetic studies. Pl. Cell Rep., **3**: 75-78.

Gurjar K., Sakshi R. Joshi U., Palit P., Bhatt K. V., Mohapatra T. and Sharma R. 2014. Identification of Heat-Related ESTs in Moth Bean through Suppression Subtraction Hybridization. Appl. Biochem. Biotechnol., **173**(8): 2116-2128. DOI: 10.1007/s12010-014-1011-2.

Hu C. A., Delauney A. J. and Verma O. P. 1992. A bifuctional enzyme (delta1-pyrroline-5-carboxylate synthetase) catalyzes the first two steps of proline biosynthesis in plants. Proc. Natl. Acad. Sci. USA., **89**: 9354-9358.

Isemura T., Kaga A., Tomooka N., Shimizu T. and Vaughan D. A. 2010. The genetics of domestication of rice bean *Vigna umbellata*. Ann. Bot., **106**(6): 927-944

Isemura T., Kaga A., Tomooka N. and Vaughan D. A. 2007a. QTL analysis for domestication related traits in rice bean (*Vigna umbellata*). Breeding Science Autumn Meeting. Sept 22-23, Tsuruoka City, Yamagata, Japan. P 189.

Isemura T., Kaga A., Tomooka N. and Vaughan D. A. 2007b. Construction of a rice bean linkage map using azukibean SSR markers. Breed. Res., **10**(2): 316.

Joshi K. D., Bhandari B., Gautam R., Bajracharya J. and Hollington P. A. 2006. Ricebean: a multipurpose underutilized legume. Paper presented at 5th International Symposium on New Crops and Uses: Their roles in a rapidly changing world. Organized by the Centre for Underutilized Crops, University of Southampton in partnership with National Non-food Crops Centre and the Tropical Agricultural Association.

Kadam S. S., Salunkhe D. K. and Maga J. A. 1985. Nutritional composition, processing and utilization of horse gram and moth bean. CRC Crit. Rev. Food. Sci. Nutr., **22**: 1-26.

Kaga A., Ishii T., Tsukimoto K., Tokoro E. and Kamijima O. 2000. Comparative molecular mapping in Ceratotropis species using an inter-specific cross between azuki bean (*Vigna angularis*) and rice bean (*V. umballata*). Theor. Appl. Genet., **100**: 207-213.

Kashiwaba K., Tomooka N., Kaga A., Han O. K. and Vaughan D. A. 2003. Characterization of resistance to three bruchid species (*Callosobruchus* Spp., Coleoptera, Bruchidae) in cultivated rice bean [*Vigna unbellata* (Thunb.) Ohwi & Ohashi]. J. Econ. Ento., **96**: 207-213.

Katoch R. 2013. Nutritional potential of rice bean (*Vigna umbellata*): An underutilized legume. J. Food Sci., **78**(1): C8-16.

Kaur A., Kaur P., Singh N., Singh Virdib A., Singh P. and Chand Ranac J. 2013. Grains, starch and protein characteristics of rice bean (*Vigna umbellata*) grown in Indian Himalaya regions. Food Res. Int., **54**(1): 102-110.

Kaur D. and Kapoor A. C. 1990. Starch and protein digestibility of rice bean (*Vigna umbellata*): Effects of domestic processing and cooking methods. Food Chem., **38**(4): 263-272.

Khadka K. and Acharya B. D. 2009. Cultivation practices of ricebean. Local Initiatives for Biodiversity, Research and Development (LI-BIRD), Pokhara, Nepal.

Khanal A. R., Khadka K., Poudel I., Joshi K. D. and Hollington P. 2009. Report on farmers' local knowledge associated with the production, utilization and diversity of ricebean (*Vigna umbellata*) in Nepal. *In*: The Ricebean Network: Farmers indigenous knowledge of ricebean in Nepal (Report N°4), EC. 6th FP, Project no. 032055, FOSRIN (Food Security through Ricebean Research in India and Nepal).

Khokhar S. and Chouhan B. M. 1986. Nutrient composition, protein fractions and antinutritional factors of mothbean. Bull. Grain Technol., **24**(1): 3-10.

Kohler F., Golz C., Eapen S. and Schieder. 1987. Influence of Polant cultivar and plasmid DNA on transformation rates in tobacco and moth bean. Pl. Sci., **53**: 87-91.

Konarev A., Tomooka N. and Vaughan D. A. 2002. Proteinase inhibitor polymorphism in the genus Vigna subgenus Ceratotropis and its biosystematic implications. Euphytica, **123**: 165-177.

Krishnamurthy K. V., Godbole D. A. and Mascarenhas A. F. 1984. Studies on a drought resistant legume: The moth bean *Vigna aconitifolia* (Jacq) Marechal I. Protoplast culture and organogenesis. Kumar A. S., Gamborg O. L. and Nabors M. W. 1988. Plant regeneration from cell suspension cultures on *Vigna aconitifolia.* Pl. Cell Rep., **7**: 138-41.

Kumar S., Saxena S. N., Jat R. S. and Sharma R. 2008. Agrobacterium tumefaciens mediated genetic transformation of mothbean (*Vigna aconitifolia* (Jacq) Marechal). Indian J. Genet., **68**(3): 327-329.

Kumar S., Singh G., Jat R. S., Saxena S. N. and Sharma R. 2010. Transformation of mothbean (*Vigna aconotifolia*) cotyledonary nodes through vacuum infiltration of *Agrobacterium tumefaciens*. Green Farming, **1**(6): 551-554.

Laura Bravo, Perumal Siddhuraju, Fulgencio Saura-Calixto. 1999. Composition of underexploited Indian pulses. Comparison with common legumes. Food Chemistry, **64**: 185-192.

Lawn R.J. 1995. The Asiatic *Vigna* species. Chapter 65 *In*: J Smartt. and N.W. Simmonds (Eds.) Evolution of crop plants. Second edition. Longman Scientific and Technical, Harlow, UK. ISBN 0-582-08643-4, pp 321-326.

Marechal R., Mascherpa J. M. and Stainer F. 1978. Etude taxonomique d'un groupe complexe d'speces des genres *Phaseolus* et *Vigna* (Papilionaceae) sur la base de donnees morphologiques et polliniques, traitees par l'analyse informatique. Boissiera 28.

Mejia M. M. 1984. Scientific and common names of tropical forage species. Cali, Colombia, CIAT, 75 pp.

Mukherjee A. K., Roquib M. A. and Chatterjee B. N. 1980. Ricebean for the scarcity period. Indian Farming, **30**: 26-8.

Nagaraja N., Nehru S. D. and Manjunatha A. 1999. Plant type for yield in horse gram as evidenced by path coefficient and selection indices. Karnataka J. Agric. Sci., **12**: 33-37.

NAS. National Academy of Sciences. 1979 Ricebean. *In*: Tropical Legumes, Resources for the Future, pp. 80-85.

Ohashi H., Tateishi Y., Nemoto T. and Endo Y. 1988. Taxonomic studies on the Leguminosae of Taiwan III. Sci. Rep. Tohoku Univ. 4th Ser. (Biology), **39**: 191-248. p. 245-246.

Oommen S. K. Oommen and Sumabai D. L. 2002. Rice bean — potential fodder crop. The Hindu. Sci. Tech., online ed. India's Nat. Newspaper.

Parameshwarappa S. G., Kumar D. and Lamani. 2002. Performance of horsegram cultivars on medium black soils of Northern transitional zone of Karnataka. Karnataka J. Agric. Sci., **15**: 627-629.

Prakash B. G,, Guled M. B. and Bhosale M. 2008. Identification of suitable horse gram varieties for northern dry zone of Karnataka. J. Agric. Sci., **21**(3): 343-345.

Prakash B. G. and Khanure S. K. 2000, Genetic parameters, correlation and path coefficient analysis in horsegram. Karnataka J. Agric. Sci., **13**: 312-314.

Prakash B. G., Nayakar N. Y. and Guled M. B. 2002. KBHG-1; A promising horse gram variety for Northern dry zone of Karnataka. Karnataka J. Agric. Sci., 1**5**: 362-363.

Rajerison R. 2006. *Vigna umbellata* (Thunb.) Ohwi & H. Ohashi. *In*: M. Brink and G. Belay (Eds.). PROTA 1: Cereals and pulses/Céréales et légumes secs. [CD-Rom]. PROTA, Wageningen, Pays Bas.

Reddy P. C. O., Sairanganayakulu G., Thippeswamy M., Reddy P. S., Reddy M. K. and Sudhakar C. 2008. Identification of stress-induced genes from the drought tolerant semi-arid legume crop horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.) through analysis of subtracted expressed sequence tags. Plant Sci., **175**: 372-384.

Rodriguez M. S. and Mendoza E. M. T. 1991. Nutritional assessment of seed proteins in ricebean. Plant-Foods for Human Nutrition, **41**: 1-9.

Sakshi R., Joshi U., Palit P., Amit A., Deokar R., Meghwal R., Mohapatra T., Srinivasan R., Bhatt K. V. and Sharma R. 2012. Construction and analysis of an SSH cDNA library of early heat-induced genes of *Vigna aconitifolia* variety RMO-40. Genome, **55**: 783-796.

Salini K., Maruthi V., Maheswari M. and Sarkar B. 2014. Genetic improvement of horse gram through mutation breeding. 3rd International Conference on Agriculture & Horticulture, October 27-29, 2014 Hyderabad International Convention Centre, India. DOI: 10.4172/2168-9881.S1.011.

Sastrapradja S. and Sutarno H. 1977. *Vigna umbellata* (L.) DC in Indonesia. Ann. Bugor., **6**: 155-167.

Sathe S. K. and Venkatachalam M. 2007. Fraction and biochemical characterization of moth bean (*Vigna aconitifolia* L.) proteins. LWT, **40**: 600-610.

Sharma R. C. and Mathur J. R. 1984. Correlation and path analysis studies in mothbean (*Vigna aconitifolia* (Jacq.) Marechal). National seminar on New dimension in Pulse Research and Development. May, 21-23, 1984. JNKVV, Jabalpur.

Sharma R. C. and Mathur J. R. 1982. Studies of shedding behaviour in mothbean (*Vigna aconitifolia* (Jacq.) Marechal). Sci. Cult., **48**(2): 64-65.

Sharma R., Jain M. and Kumar S. 2014. Evaluation of differences among *Vigna aconitifolia* varieties for acquired thermo-tolerance. Agric. Res., **3**: 104-112.

Shekhawat N. S. and Galston A. W. 1983. Isolation, culture and regeneration of moth bean *Vigna aconotifolia* leaf protoplasts. Plant Sci. Lett., **32**: 43-51.

Singh I., Bisht and Mohar Singh. 2013. Asian Vigna. 237-268. *In*: Mohar Singh, H.D.,Upadhyaya and I. S. Bisht (Eds.). 2013. Genetic and genomic resources of grain legume improvement. Elsevier. 32 James Town Road, London. p305.

Somta P., Kaga A., Tomooka N., Kashiwaba K., Isemura T., Chaitieng B., Srinivas P. and Vaughan D. A. 2006. Development of interspecific Vigna linkage map between *Vigna umbellata* (Thumb) Ohwi & Ohashi and *V. nakashimae* (Ohwi) & Ohashi and its use in analysis of bruchid resistance and comparative genomics. Plant Breed., 125: 77-84.

Soni P., Rizwan M., Bhatt K. V., Mohapatra T. and Singh G. 2011. *In-vitro* response of Vigna aconitifolia to drought stress induced by PEG-6000. J. Stress Physiol. Biochem., **7**(3): 109-121.

Soni P., Mohapatra T., Bhatt K. V. Singh G., Rizwan M. and Sharma R. 2013. Cloning of drought related genes in *Vigna aconitifolia* through modified differential display. J. Cell Tissue Res., **13**(2): p 3701.

Tikka S. B. S. and Kumar S. 1976. Association Analysis in *Vigna aconitifolia* (Jacq.) Marechal. Sci. Cult., 182-183.

Tikka S. B. S., Asawa B. M. and Kumar S. 1977. Correlated response to selection in mothbean. Gujarat Agric. Univ. Res. J., **3**: 1-4.

Tomooka N. et al. 2000. The effectiveness of evaluating wild species; searching for sources of resis beetles in the genus *Vigna* subgenus Ceratotropis. Euphytica, **115**: 27.

Tomooka N. et al. 2002a. AFLP analysis of diploid species in the genus Vigna subgenus Ceratotropis. Genet. Res. Crop Evol., **49**: 521.

Tomooka N. et al. 2002b. The Asian *Vigna*: genus Vigna subgenus Ceratotropis, Genetic Resources. Kluwer Academic Publishers, Dordrecht, The Netherlands, 270, 2002.

Tomooka N., Isemura T., Naito K., Kaga A. and Vaughan D. A. 2014. *Vigna* species. (Eds. M. Singh, I.S. Bisht and M. Dutta), Broadening the genetic base of grain legumes. Springer New Delhi Heidelberg New York Dordrecht London. DOI: 10.1007/978-81-322-2023-7.

Tomooka N., Kaga A., Vaughan D. A. and Jayasuriya A. H. M. 2003. Advances in understanding the genus Vigna subgenus Ceratotropis. *In*: Conservation and use of crop wild relatives. Proceedings of the joint Department of Agriculture, Jayasuriya A. H. M. and Vaughan D. A. (Eds.). Sri Lanka and National Institute of Agrobiological Science, Japan Workshop held on 3 February 2003.

Tomooka N., Lairungreang C., Nakeeraks P., Egawa Y. and Thavarasook C. 1991. Mung bean and the genetic resources. TARC, Japan.

van Oers C. C. C. M. 1989. *Vigna umbellata* (Thunb.) Ohwi & Ohashi. [Internet] Record from Proseabase. van der Maesen, L.J.G. and Somaatmadja, S. (Eds). PROSEA (Plant Resources of South-East Asia) Foundation, Bogor, Indonesia.

Zaman Q. and Malik M. A. 1999. Growth, seed yield and protein contents of ricebean (*Vigna umbellata*) in relation to nitrogen and phosphorus nutrition. Int. J. Agri. Biol., **1**(4): 290-292.