Kirkhouse Trust

**Stress Tolerant Orphan Legumes**

**MONOGRAPH SERIES**

# Mothbean

## [*Vigna aconitifolia* (Jacq.) Marechal]

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**Stress Tolerant Orphan Legumes**

*Monograph Series*

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**The Kirkhouse Trust (KT)** is a UK-registered charity founded by Sir Edwin M. Southern to fund the improvement of legume crops that are important for food and nutrition security in African countries and India and to promote scientific education. The origins of KT are entwined with the development of Sir Ed's molecular biology company, Oxford Gene Technology (OGT). In 1997, Oxford University assigned Sir Ed's microarray patents to OGT in exchange for 10% of the equity. In 2000, OGT's income began to grow, and KT was registered as a charity and endowed with an initial donation from the company.

KT's funding model aims to address its twin objectives of improving legume crops, which are important for smallholder farming systems in target countries and raising national scientific capacity. KT has a hands-on strategy, with a team of international scientific consultants working closely with the Principal Investigators (PIs) and students they mentor, providing technological backup as needed, and hosting PIs and students for study visits in their laboratories.

The STOL consortium was established in 2018 under the Promoting India-Africa Framework for Strategic Cooperation Initiative in partnership with the Indian Council of Agricultural Research (ICAR), Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, New Delhi, India. The programme aims to facilitate the introduction and exchange of stress-tolerant orphan legume varieties among partnering Indian and African institutions and assess the relative response of selected species to the higher levels of abiotic stresses expected because of climate change. Crops have been identified as potentially having a crucial role in adapting to climate change in arid parts of Africa and India, and selected species are likely to become the focus of KT breeding programmes in the medium to longer term.

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**Credit:** N. K. Sharma, Professor (Agrostology) and Zonal Director Research, SKRAU- Agricultural Research Station, Sriganganagar (Rajasthan), India.

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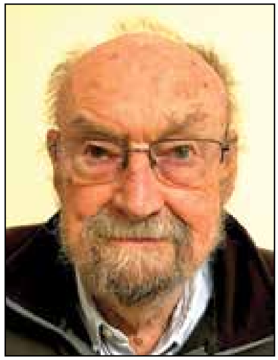
# FOREWORD



Roughly 2.5 billion people (30% of the world's population) live in semi-arid regions, and approximately a third of these people depend on agriculture for their food security and livelihood. Crop production in these regions has always faced challenges associated with excess heat, drought, a highly variable climate, land degradation, and a loss of biodiversity, which has been exacerbated in recent times by climate change, limited access to technology, poor market linkages, weak institutions, and lack of national and international partnerships. A possible strategy to cope with climate change is to switch from the cultivation of current crops to ones which are more drought-hardy. These include several minor legume crops, commonly known as orphan legumes, currently being grown to a limited extent in the drier regions of both Africa and Asia to provide food and nutritional security to households. These species have remained relatively neglected by both researchers and industry because of their limited economic importance in the global market.

To promote these orphan legumes, the Kirkhouse Trust initiated a consortium programme on "Stress Tolerant Orphan Legumes (STOL)" in partnership with several African countries and India. The STOL programme aims to facilitate the introduction and exchange of stress-tolerant orphan legume among partnering Indian and African institutions and assess the relative response of selected species and varieties to the higher levels of biotic and abiotic stresses expected because of climate change.

To facilitate the better understanding and cultivation of these new crops among Indian and African partners the STOL project is supporting the publication of a series of monographs for selected orphan legumes and Mothbean (*Vigna aconitifolia* (Jacq.) Marechal) is one of such crops.

I congratulate the authors of this monograph Dr N. K. Sharma, Professor, Swami Keshwanand Rajasthan Agricultural University, Bikaner and Dr. R. Sharma, Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur, India for compiling and synthesising information to bring out the mothbean monograph, which the Kirkhouse Trust is pleased to publish as part of the STOL monographs series. I am sure this publication will enlighten the policymakers, scientists, extension personnel, entrepreneurs and farmers for the improved production and consumption of mothbean across African countries as well as in India.

Edwin Southern

**Professor Sir Edwin M. Southern**
Founder & Trustee of the Kirkhouse Trust

# PREFACE

Mothbean is a short duration, deep rooted legume recognized for its twin benefits of tolerance for drought and heat. It has ability to grow under harsh climate, low rainfall and poor soil conditions and considered as most significant pulse crop for arid zone. Mothbean is a cover crop, able to shield the soil from the sun's heat, retain soil moisture, prevent the loss of organic matter and retard soil erosion. Its leguminous nature fixes atmospheric nitrogen and enhances soil productivity. It is cultivated on plain lands as well as sand dunes as a sole crop or mixed with other crops and pasture grasses and is also intercropped with woody perennials. This crop is basically grown under rainfed conditions, and its cultivation is almost organic due to the negligible input of agro-chemicals and synthetic fertilizers. The existence of mothbean is extremely important for maintaining crop diversity and the long-term sustainability of agriculture in the arid zone of India.

Mothbean is a potential reservoir of proteins, essential minerals and vitamins, providing nutritional security to vegetarians. Its mature seed is used to prepare *dhal,* sprouted seeds are included as a component of salads, and green pods are consumed as a vegetable. Mothbean is a principal ingredient of world-famous spicy snack called *Bikaneri Bhujiya*, the production of which consumes about 80% of the crop, and which has enormous potential as a generator of foreign exchange.

Mothbean is cultivated on about 1 Mha of land in the arid zone of the Indian state of Rajasthan, specifically in the districts of Bikaner, Churu, Barmer, Jodhpur, Nagaur and Hanumangarh. The production and productivity of mothbean is highly erratic, depending heavily on the amount and distribution of rainfall. The average productivity of mothbean in Rajasthan is 329 kg/ha, which is much lower than its potential. The poor productivity of mothbean is a matter of great concern. Technology demonstrations of mothbean conducted at farmer's fields under the National Food Security Mission (NFSM) project led by Swami Keshwanand Rajasthan Agricultural University (SKRAU) in Bikaner have revealed that about 70% yield enhancement could be realised with the use of improved seed and crop management practices.

Given the increasing pressure on both our agricultural systems and human nutrition, the potential of mothbean has never been more relevant. Through this monograph, we hope to encourage a renewed appreciation for this ancient crop and to stimulate further research into its potential benefits. The authors have sought to describe the key factors that influence consumer acceptance of orphan legumes in the diet, as well as the known functional properties of these legumes and legume-based food products. We have made an effort to gather information covering both genetic and non-genetic components, gathered from both public and private sources. While we cannot promise that its coverage is comprehensive, we are confident that it will serve as a helpful tool for researchers working on mothbean improvement.

This publication includes the research work mainly done at SKRAU, Bikaner and the Indian Council of Agricultural Research (ICAR)-Central Arid Zone Research Institute (CAZRI), Jodhpur and reported under different publications by various workers particularly by Dr. D. Kumar, former Project Coordinator, ICAR-AICRP on Arid Legumes, ICAR-CAZRI, Jodhpur; Dr. R.C. Sharma and Dr. M.M. Sharma, Mothbean Breeders, SKRAU, Bikaner; Ms. Savita Meena and Ms. Sangeeta Pal, ex-PG students SKRAU, Bikaner; and the authors themselves. The contribution of farmers associated with field experiments and demonstrations conducted under Rashtriya Krishi Vikas Yojna (RKVY) and NFSM projects by SKRAU, Bikaner is also acknowledged.

We wish to express our thanks to the Kirkhouse Trust (UK), headed by Prof. Sir Edwin Southern, for providing financial support, and to Drs Prem Mathur and Robert Koebner, acting as consultants to the Kirkhouse Trust, for their critical review and comments. We are confident that this publication will serve as a guideline for mothbean growers, entrepreneurs, industry, planners and researchers across the globe.

**N. K. Sharma**
**R. Sharma**

*December 2024*

# 1. INTRODUCTION

Mothbean [*Vigna aconitifolia* (Jacq.) Marechal] is a native of the hot, arid zone of northwest India, outside of which it is also cultivated in various parts of Asia, Africa, North America and Australia. Mothbean is known in India by various vernacular names, including *math, kheri, madike, bhioni, kunkuma*and *matki* (Kumar, 2002), while in other parts of the world, it goes by the names *Turkish gram, dew bean* and *haricot mat* (Yaqoob *et al*., 2015). Mothbean is a short duration, deep-rooted leguminous plant, recognized for its outstanding level of tolerance to drought and heat, as well as for its high water use efficiency. As the crop is adapted to low rainfall conditions and to poor soils, it is considered to be an important pulse crop for the inhabitants of the hot, arid regions of India. Its benefits when used as a cover crop are that it shields the soil from the sun's heat, helps to retain soil moisture, limits the loss of soil organic matter and retards soil erosion. Its ability to fix atmospheric nitrogen means that crop residues make a positive contribution to soil fertility.

The cultivation of mothbean is mainly confined to areas receiving annual rainfall between 250-450 mm with optimum temperature range of 25-37°C, but it can withstand daytime temperatures up to 45°C. The crop, which is seldom irrigated, is normally cultivated on poorly fertile and less productive soils, conditions often associated with sandy plains and sand dunes. It is intolerant to saline-alkaline soil and water logging. The existence of mothbean is extremely important for maintaining both crop diversity and the long-term sustainability of agriculture in the Indian hot arid zone. As a sole crop, it is typically grown with minimal inputs and minimal aftercare, but it is also cultivated in mixtures and intercropped with either crops such as pearl millet (*Pennisetum glaucum*), guar (*Cyamopsis tetragonoloba*) or sesame (*Sesamum indicum*); it is also grown in agro-forestry systems based on *khejri* (*Prosopis cineraria*) and wild jujube (*Zizyphus nummularia*), as well as in pasture lands along with Sewan grass (*Lasiurus sindicus*).

Within India, mothbean can be found from the northwest Himalayas (up to an altitude of 6,000 m asl) to Karnataka in the south, and from the foothills of the northeast Himalayas to Saurashtra in the west (Arora, 1985). It has been cultivated in the hot arid zone for many centuries, with its major sites of production lying in the Rajasthan districts of Bikaner, Churu, Barmer, Jodhpur, Nagaur and Hanumangarh, along with some smaller areas in the states of Gujarat, Maharashtra, Tamil Nadu and Punjab. Outside of India, it is cultivated in drier parts of Asia, Africa, North America and Australia. The crop's productivity is highly dependent on the amount and distribution of rainfall. Its average productivity across Rajasthan is 329 kg/ha. Technology demonstrations conducted in farmer's fields by SKRAU in Bikaner have revealed that a yield enhancement up to 70% is attainable through the use of improved quality seed and the adoption of modern crop management practices.

Mothbean provides a potential source of dietary protein, essential minerals and vitamins, thereby providing nutritional security to the many vegetarians who live in the arid zone. Mature seed is used to prepare *dhal*, sprouted seed is included as an ingredient in salad, and green pods are consumed as a vegetable. Mothbean is the principal ingredient of a world-famous spicy snack called *Bikaneri bhujiya*, the manufacture of which consumes about 80% of the grain produced. The export of *Bikaneri bhujiya* generates a significant volume of foreign exchange.

Traditional mothbean varieties are late maturing and have a spreading growth habit; as a result, they accumulate a high amount of biomass but set little seed. Such varieties are favoured by livestock farmers. Modern varieties have been bred for early maturity, an upright growth habit and a high harvest index.

## 2. TAXONOMY

Mothbean is a self-pollinated legume belonging to the family Fabaceae, sub-family Papilionaceae (Verdcourt, 1970). The species was originally classified as a member of the genus *Phaseolus* and was named *P. aconitifolia* (Jacq.). It was later reassigned to the genus *Vigna* (Verdcourt, 1970). Note that the genera *Vigna* and *Phaseolus* are taxonomically closely related to one another, but whereas the latter genus has been retained for species of American origin (Verdcourt, 1970, Marechal *et al.,* 1978), the former harbours species originating in Africa (cowpea group), Asia (adzuki bean group) and America. *V. aconitifolia* belongs to the sub-genus *Ceratotropis*, along with *V. radiata* (green gram or mungbean*), V. mungo* (black gram or urdbean), *V. angularis* (small redbean or adzuki bean), *V. umbellate* (ricebean or redbean), *V. reflexopiloxa*var. *glabr*a (Creole bean), *V. trilobata* (wild bean) and *V. trinervia* (Tooap´ee) (Tomooka *et al.,* 2002).

The plant has an annual life cycle; traditional varieties adopt a prostate creeping habit, while short duration modern varieties have been selected on the basis of their bushy, upright habit. The prostrate habit results from the tendency of the primary and secondary branches of the plant to stay close to the ground (Fig. 1). The length of the primary branches varies between 30 cm and 150 cm. The main shoot is angular with short internodes covered with hairs. The leaves are alternate and trifoliate, formed by deeply lobed leaflets. The plant has a

**Fig. 1: A mothbean variety with a prostate creeping habit.**

**Fig. 2: A mothbean inflorescence comprising small, bright yellow flowers borne on peduncles of variable length.**

well-developed taproot with nodules developing on the entire root system, either in clusters or strung out like beads. The inflorescence is an axillary, capitate raceme, bearing several small bright yellow flowers on peduncles of variable length (Fig. 2). Pollen is produced by a set of ten diadelphous anthers. The ovary is superior, sessile and minutely hirsute; it forms a twisted style and a flat stigma. The flowers open in the morning and wither by the evening. Their 5 mm wide cylindrical pods are brown or pale grey and vary in length from ca. 3-7 cm (Fig. 3). The pods are covered in short stiff bristles and form a short, curved beak; inside the pod, 4-9 cuboid to cylindrical brown seeds form, of size 3-5 mm by 1.5-2.5 mm. The 1,000 seed weight of cultivated varieties ranges from 32 to 38 gm. Germination is epigeal (Sharma, 1997).

**Fig. 3: Mothbean pods.**

# 3. CYTOLOGY AND GENETIC LINKAGE MAP

Obtaining a reliable karyotype of many *Vigna* species is hampered by the small size (1.6 -3.7 µm) of their chromosomes (She *et al.*, 2015). Mothbean is a diploid species with a somatic chromosome number of 22. According to Bhatnagar *et al.* (1974), its haploid set of 11 chromosomes comprises one long (2.7-3.5 µm) sub-median chromosome, five medium length chromosomes (1.96-2.6 µm) with a sub-median chromosome, one medium length median chromosome and four small (<1.95 µm) median chromosomes. On the other hand, She *et al.* (2015) have suggested the presence of only two types of chromosomes, giving a karyotype formula of 9m + 2sm, thereby fitting the fairly symmetrical karyotype represented by the category 2B proposed by Stebbins (1971). Sinha and Roy (1979) and Shamurailatpam *et al.* (2015) noted the presence of sub-telocentric chromosomes. The overall length of the complete haploid complement is reported to be 42.53 ± 3.93 µm, and the chromosomal arm ratio ranges from 1.08 to 1.60 (Shamurailatpam *et al.*, 2015; She *et al*., 2015). The length of the longest chromosome is > 2.1 fold greater than that of the shortest one. The sites of binding to the fluorochrome chromomycin A3, which serve as an indicator of GC-rich heterochromatin, are located in the terminal region of the short arms of the chromosome(s) (Shamurailatpam *et al*., 2015). The pericentromeric regions of each chromosome harbour sequences which stain following sequential treatment with propidium iodide and 4′,6-diamino-2-phenylindole dihydrochloride. Thus, both GC-and AT-rich repetitive sequences are present in the heterochromatic regions (She *et al.*, 2015). The 45S rDNA site occupies the entire short arm of one chromosome. Unlike other Asiatic *Vigna* spp., the single 5S rDNA locus in mothbean is located in the centromeric regions of chromosome 11.

Yundaeng *et al.* (2019) constructed a genetic linkage map for mothbean, based on a set of 172 microsatellites used to genotype 188 $F_2$ progeny bred from a cross between a wild accession (TN67) and the cultivar ICPMO056; the resulting 1,016.8 cM map, which delivered the expected number of linkage groups (eleven), was used to locate 50 quantitative trait loci (QTLs) and three major genes. A high degree of synteny was revealed between the genomes of mothbean and mungbean, adzuki bean, ricebean and yardlong bean (*V. unguiculata*). Some of the mapped QTLs were associated with one or more of 20 domestication-related traits. Most of them mapped to five of the linkage groups (1, 2, 4, 7 and 10). The key domestication traits seed dormancy and pod shattering were each under the control of a large effect QTL, along with a contribution of one or two minor QTLs; in contrast, the 18 other traits were all under polygenic control.

# 4. GEOGRAPHICAL ORIGIN AND CENTRES OF DIVERSITY

The domestication of mothbean probably took place in or around the Indian sub-continent (Purseglove, 1974; Marechal *et al*., 1978). Vavilov (1926) and de Candolle (1986) both mention India as the centre of origin for both wild and cultivated forms of mothbean, although Dana (1976) has indicated that wild forms can be found from the Sonarm desert in Mexico to Tapuchula in Guatemala. Arora and Nayar's (1984) claim that wild forms of mothbean can be found in India has been doubted by Goel *et al.* (2002). However, Takahashi *et al.* (2016) identified three wild ancestors of mothbean in a gene bank collection collected from southeast India. Their collection sites in Tamil Nadu (ID-5 and ID-6) and Andhra Pradesh (ID-4) have provided evidence to support the notion that mothbean originated and was domesticated in peninsular India. *V. trilobata*, a species distributed across southern India, has been considered by some authors to be the wild progenitor of the domesticate (Whyte *et al.*, 1953). However, attempts to form hybrids between this species and cultivated forms have met with only limited success (Chavan *et al.,* 1966; Biswas and Dana, 1976). Subsequent observations have suggested that the two species are distinct (Marechal *et al.*, 1978; Tateishi, 1996; Tomooka *et al.*, 1996). A comparison of chloroplast genome sequences was taken to imply that mothbean shares a common ancestor with mungbean (Javedi *et al.*, 2011), while genotyping, based on amplified fragment length polymorphism markers, was used by Tomooka *et al*. (2002) to suggest a close relationship between mothbean and two of its fellow *Ceratotropis* species (black gram and mungbean). Nuclear gene sequence comparisons have also supported the notion of a close relationship between black gram and mothbean (Wang *et al.*, 2008).

# 5. PLANT GENETIC RESOURCES

In India, ICAR-National Bureau of Plant Genetic Resources (NBPGR) is responsible for the collection of indigenous germplasm from various parts of the country, including from Rajasthan, Gujarat, Maharashtra, Tamil Nadu, Haryana, Madhya Pradesh, Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir, Andhra Pradesh, Delhi, Bihar, Manipur and Uttarakhand, together with its characterization, evaluation, multiplication, conservation, introduction and distribution to users. So far, a total of 3,422 accessions have been collected, of which 3,381 are indigenous and 41 are exotic. The base collection (stored under long-term (50 to 100 years), at about -20°C with 5% moisture content) is maintained at the NBPGR genebank (Kanishka *et al*., 2023). In addition, active collections (seed are stored at 0 to 4°C temperature and the seed moisture is between 5 to 8%), are maintained at NBPGR's regional station in Jodhpur (Rajasthan) and working collections (seeds are stored for 3-5 years at 10-20°C and usually contain about 8 to 10% moisture) at ICAR's Institute of Pulses Research (IIPR) in Kanpur and its coordinating centres for genetic improvement of mothbean (Asthana, 1998). Over 2,000 accessions have been characterized and evaluated by the research group in Jodhpur (Singh *et al*., 2001). Some other gene banks curate small collections. The worldwide availability of mothbean germplasm at various institutions is listed in Table 1.

**Table 1: Global holdings of mothbean germplasm (Source: Agrawal *et al*. (2019) and Zahoor (2007).**

| Country | Institutes/Centres | Accessions |
|---|---|---|
| India | National Bureau of Plant Genetic Resources, New Delhi | 3,422 |
| Pakistan | National Agricultural Research Centre, Islamabad | 66 |
| Japan | National Agriculture and Food Research Organization (NARO) | 43 |
| Kenya | Kenya National Gene Bank, Nairobi | 50 |
| Russian Federation | N.I. Vavilov Research Institute of Plant Industry Russian VIR, St. Petersburg | 64 |
| Taiwan | World Vegetable Centre, Taiwan | 26 |
| USA | Plant Genetic Resources Conservation Unit, Southern Regional Plant Introduction Station, USDA-ARS, Griffinn, GA | 58 |
| Australia | Australian Grains Genebank | 36 |
| Australia | Australian Pastures Genebank, Australia | 28 |
| Ukraine | Ustymivka Experimental Station of Plant Production, Ukraine | 35 |
| Belgium | Botanic Garden Meise, Belgium | 7 |
| Colombia | Centro Internacional de Agricultura Tropical, Colombia (CIAT) | 8 |
| Germany | Gene Bank, Leibniz Institute of Plant Genetics and Crop Plant Research, Germany | 7 |
| Brazil | Embrapa Recursos Geneticose Biotecnologia, Brazil | 7 |
| **Total** | | **3,857** |

# 6. BREEDING SYSTEM

Given the diversity represented in the gene pool, there is much scope for improving mothbean by combining agronomic traits present in different accessions *via* hybridization. However, crossing mothbean is a non-trivial task since its flowers are small and delicate. In the meantime, pure line selection and mutagenesis have served to deliver major advances in yield and other key agronomic traits. All of the late and medium maturing varieties developed in India were established *via* pure line selection from local collections, whereas the first early maturing variety (RMO-40) was developed *via* mutagenesis. RMO-40 laid the foundation for the development of a number of Indian short duration varieties. The major objective of current breeding programmes is to develop high yielding varieties able to be grown under rainfed conditions. The traits targeted to achieve this goal include early flowering, early maturity, synchronised maturity, stem branching, a rise in harvest index, a greater number of clusters/bunches per plant, a greater number of pods set per plant, a greater number of seeds set per pod, larger seed, an improved content of crude protein, resistance against yellow mosaic disease and an improved level of tolerance of heat and moisture deficiency.

Genetic variability studies conducted at SKRAU have revealed significant differences among accessions with respect to a range of agro-morphological, physio-biochemical, seed and seedling traits (Table 2). Based on genetic diversity studies undertaken at SKRAU (Fig. 4) it was possible to group the germplasm collections into 6-8 clusters (Pal, 2020; Meena, 2021). Positive correlations were observed between seed yield and a number of agronomic (number of pods set per plant, harvest index, number of seeds set per pod, 1,000 seed weight); physio-biochemical (leaf chlorophyll content, membrane stability index, leaf proline content and relative water content) and seed density (bulk and particle/true density) traits. Hence, selection based on one or more of these traits could be effective in advancing the yield potential of mothbean.

Although mothbean has been cultivated for centuries, crop improvement programmes were not put in place until the 1960s; these early efforts were directed to develop high yielding, disease resistant, early maturing varieties suitable for growing under rainfed conditions. The resulting varieties have been categorized into three groups, depending upon their time to reach maturity (Sharma, 1997; Kumar, 2002; Sharma, 2016).

**Table 2: Variability with respect to key morphological and biochemical traits.**

| S. No. | Characters | Range |
|---|---|---|
| | **1. Agro-morphological traits (Meena Savita, 2021)** | |
| 1. | Days to 50% flowering | 30-68 |
| 2. | Days to maturity | 59-89 |
| 3. | Plant height (cm) | 30.70-53.31 |
| 4. | Number of pods/plant | 15.82-61.62 |
| 5. | Number of seeds/pod | 4.72-6.51 |
| 6. | Pod length (cm) | 3.56-4.80 |
| 7. | 100-seed wt. (gm) | 2.61-3.96 |
| 8. | Biological yield/plant | 22.36-68.96 |
| 9. | Harvest Index (%) | 4.17-35.11 |
| 10. | Seed yield/plant (gm) | -7.95 |
| | **2. Physio-biochemical traits (Pal Sangeeta, 2020)** | |
| 1. | Chlorophyll-a content (mg/gm) | 0.73-2.14 |
| 2. | Chlorophyll-b content (mg/gm) | 0.30-1.09 |
| 3. | Total chlorophyll content (mg/gm) | 1.30-2.92 |
| 4. | Membrane stability index | 39.04-55.80 |
| 5. | Relative water content (%) | 68.63-92.72 |
| 6. | Proline content (mg/gm fresh wt.) | 1.12-4.96 |
| 7. | Protein content in grains (%) | 21.03-23.68 |
| | **3. Seed traits (Pal Sangeeta, 2020)** | |
| 1. | Seed volume | 20.00-30.00 |
| 2. | Particle/true density (gm/cm3) | 1.08-1.52 |
| 3. | Bulk density (gm/cm3) | 0.78-1.07 |
| 4. | Porosity (%) | 24.22-37.60 |
| 5. | Water absorption capacity (mg/seed) | 32.88-50.11 |
| 6. | Water absorption index | 1.01-2.43 |
| | **4. Seedling traits at 15 days after sowing at 30°C (Pal Sangeeta, 2020)** | |
| 1. | Germination (%) | 70.00-97.00 |
| 2. | Shoot length (cm) | 3.79-8.62 |
| 3. | Root length (cm) | 3.84-10.39 |
| 4. | Seedling length (cm) | 7.76-18.71 |
| 5. | Seedling fresh wt. (gm) | 0.62-1.36 |
| 6. | Seedling dry wt. (gm) | 0.16-0.34 |
| 7. | Seedling vigour index | 631.87-1,548.00 |

**Fig. 4: Genetic diversity studies being undertaken at SKRAU.**

**Late maturing traditional varieties (100-120 days):** Varieties in this group (Type-1, Type-3, Gujarat Moth-1, Baleshwar-12) were developed by evaluating landraces grown by farmers. Their salient characteristics are a spreading habit, a high production of biomass, poor seed yield and a low harvest Index (10-12%); their late maturity leaves them prone to damage by terminal drought; they are susceptible to yellow mosaic disease. Presently, these varieties are not recommended for cultivation.

**Medium maturing varieties (75-90 days):** These varieties (Jadia, Jawala, Maru Moth, IPCMO-880, IPCMO-912, CAZRI Moth-1) were developed under the ICAR-All India Coordinated Research Project on Arid Legumes using conventional breeding methods, with a focus on selection for earliness, grain yield and resistance to yellow mosaic disease. Their salient characteristics are a semi-spreading to full spreading habit and a moderate harvest index (15-25%); like the traditional varieties, they are prone to damage by terminal drought and are susceptible to yellow mosaic disease. Presently, these varieties are also not under national seed production programme due to poor economic traits. However, in this group, the varieties Jadia and Jawala remain popular in the hot arid zone.

**Early maturing varieties (62-70 days)*:*** The leading early maturing varieties are RMO-2251, RMO-435, RMO-257, RMB-25, RMO-423, RMO-225, FMM 96, RMO-40, CAZRI Moth-2 and CAZRI Moth-3. The first of these, released in 1994, was RMO-40, which was derived by exposing Jawala seed to 400 Gy γ irradiation + 0.1% ethyl methane sulfonate (EMS). The variety's extreme earliness (62-65 days) helps the plant to escape drought. Its average seed yield ranges from 600 to 900 kg/ha. RMO 40 was the parent of a number of subsequently released early maturing varieties. Their salient characteristics are an erect to semi-erect habit (Fig. 5), synchronized

**Fig. 5: Erect to semi-erect synchronized growth habit with high number of pods/plant.**

**Table 3: Important early maturing varieties of mothbean developed in India.**

| S. No. | Varieties | Year of release | Maturity period | Developing Institution |
|---|---|---|---|---|
| 1. | RMO-40 | 1994 | 62-65 | SKRAU, Bikaner |
| 2. | FMM 96 | 1997 | 58-60 | SKRAU, Bikaner |
| 3. | RMO-225 | 1999 | 64-66 | SKRAU, Bikaner |
| 4. | RMO-435 | 2002 | 64-68 | SKRAU, Bikaner |
| 5. | CAZRI Moth-2 | 2003 | 65-67 | CAZRI, Jodhpur |
| 6. | RMO-423 | 2004 | 67-70 | SKRAU, Bikaner |
| 7. | RMO-257 | 2005 | 63-66 | SKRAU, Bikaner |
| 8. | CAZRI Moth-3 | 2005 | 62-64 | CAZRI, Jodhpur |
| 9. | RMB-25 | 2006 | 66-68 | SKRAU, Bikaner |
| 10. | RMO-2251 | 2018 | 62-67 | SKRAU, Bikaner |
| 11. | CAZRI Moth-4 | 2024 | 73-83 | CAZRI, Jodhpur |
| 12. | CAZRI Moth-5 | 2024 | 73-84 | CAZRI, Jodhpur |

growth and maturity, and a harvest index of >30%. They take 35-36 days to reach 50% flowering and 58-84 days to reach maturity (Table 3). Other features of this group of varieties include: a plant height of 15-20 cm, 6-7 branches/plant, 10-12 clusters/plant, 40-45 pods/plant, a pod length of 3.5-4.0 cm, 5-6 seeds/pod, a

1,000 seed weight of 32-38 g and a crude protein seed content of 22-24%. Early maturing varieties now dominate mothbean production in the hot arid zone. The average seed yield of mothbean in Rajasthan is 329 kg/ha, but with the adoption of improved package of practices, this yield level can be substantially increased to 500-700 kg/ha under rainfed conditions and to 1,000-1,200 kg/ha with some irrigation input. Biomass yields can reach 2,000-2,500 kg/ha under rainfed conditions and 3,000-3,500 kg/ha with irrigation.

Presently, only early maturing varieties are represented in the seed production chain and almost the whole cropping area of mothbean is given over to them, thanks to their adaptive features.

# 7. CROP PRODUCTION TECHNOLOGY

Mothbean is cultivated mostly as a rainfed crop, both on level and on undulating sandy soils, so the conservation of soil moisture is of special importance in order to ensure good germination and the initial establishment of the crop. Hence, with the onset of rain, the soil should immediately be prepared with disc-cultivation and harrow to develop a good tilth, and sowing should be completed quickly thereafter. Delayed sowing can lead to a drastic reduction in seed yield. Ensuring weed-free field conditions is needed to maintain an optimal plant population and to support the growth and development of the crop. The critical period of crop-weed competition is from 15 to 30 days after sowing. In Rajasthan, India sowing is typically completed during the first half of July after the first effective rains.

To combat soil-borne diseases, the seed can be pre-treated with either 8-10 g/kg *Trichoderma*, 2.5 g/kg thiram or 2.0 g/kg carbendazim. After this treatment, the addition of *Rhizobium* inoculum is recommended to stimulate nodule formation. The seed should be sown 4-5 cm below the surface at a rate of 12-15 kg/ha for a monoculture crop, and at about half this rate in the mixed/intercropping situation. The former rate should produce a population of about 300,000 plants per ha. The choice of a relatively low population density reflects the need to conserve moisture in a stress-prone environment; it also enhances soil aeration which results into better root nodulation and root development of the crop. A sowing rate of 8-10 kg/ha is practised by several farmers focused on sustainable crop production under moisture stress.

Synthetic fertilizers are not usually applied to rainfed mothbean crops, but yields can be enhanced by a basal dressing at sowing of 10 kg/ha N and 20 kg/ha P. Foliar fertilization has also been shown to augment the crop's yield, and in a drought-prone environment, likely represents a more effective use of fertilizer than basal application (Romheld and El-Fouly, 1999). A foliar application of K (0.2%), $ZnSO_4$ (0.2%), ascorbic acid (100 ppm), thiourea (500 ppm), salicylic acid (100 ppm), thioglycolic acid (100 ppm) and 1% soluble NPK (19:19:19) has been shown to be helpful in supporting the plants' tolerance of heat and moisture stress (Gething, 1990; Smirnoff, 1996). A foliar application of 1% soluble NPK (19:19:19) during the flowering to pod development stage has been found to be effective in achieving higher yields, as is a foliar spray of 500 ppm thiourea. Spraying 0.2% $ZnSO_4$ + 100 ppm ascorbic acid during the grain development stage acts as an effective mitigant against terminal stress. If some irrigation water is available, life-saving sprinkler irrigation can be used to rescue a severely stressed crop (Fig. 6).

**Fig. 6: Life-saving sprinkler irrigation in a mothbean crop.**

Shallow tillage in a standing crop creates dust mulch and minimizes evaporation and therefore enhances water use efficiency in a moisture deficient situation.

Upon physiological maturity, the crop is normally harvested manually (Fig. 7), and small heaps of harvested plants are left to dry in the sun for up to a week


**Fig. 7: Manually harvesting practices of mothbean: (a) Mothbean harvest stored at threshing floor, (b) – Manual threshing stage 1, (c) Manual threshing stage 2, and (d) Manual threshing stage 3.**

before threshing. The moisture content of the harvest seed should not be more than 9% before storage. Shor-term storage (i.e. one year) is usually carried out at room temperature, but an ambient temperature of 15°C and a relative humidity of 35% are considered more appropriate. Seed viability remains high for at least 3-4 years when stored at 4-8°C, 35% relative humidity.

## 7.1 Trialling modern mothbean varieties and crop technologies in farmers' fields in Rajasthan

As part of a Government of India strategic research project entitled "*Enhancing mothbean and mungbean productivity through high yielding varieties, nutrient management and IPM practices in western Rajasthan*", seven early maturing mothbean varieties were evaluated in farmers' fields, some of which relied only on rainfall, while others had access to limited sprinkler irrigation (Table 4). The seeding rate was 15 kg/ha of seed pre-treated with 2.5 g/kg carbandazim. The fertilizer regime comprised a basal application of 10 kg/ha N and 20 kg/ha P, a foliar spray of imidacloprid 17.80 SL @ 150 mL/ha at 35-40 days after sowing, and a foliar spray of 1% soluble NPK at 40-45 days after sowing. Most of trials were sown during the first week of July and harvesting took place in the first week of September. Under rainfed conditions, the average yield of the varieties ranged between 417 kg/ha and 515 kg/ha, but with the provision of restricted irrigation, the range rose to

**Table 4: Seed yield of mothbean varieties at farmer's fields in the arid zone.**

| Varieties | Seed yield (kg/ha) | | | | |
|---|---|---|---|---|---|
| | Rainfed situation (No. of trials-6) | | Irrigated situation (No. of trials-9) | | Overall performance (No. of trials-15) |
| | Average | Range | Average | Range | Average |
| CAZRI Moth-2 | 428 | 325-639 | 839 | 691-985 | 538 |
| RMB-25 | 486 | 351-727 | 841 | 787-975 | 581 |
| RMO-40 | 431 | 326-619 | 769 | 711-910 | 521 |
| RMO-225 | 417 | 301-572 | 754 | 655-870 | 507 |
| RMO-257 | 481 | 328-715 | 761 | 625-823 | 556 |
| RMO-423 | 469 | 350-723 | 764 | 630-845 | 547 |
| RMO-435 | 517 | 399-779 | 834 | 735-940 | 601 |
| Range | 417-517 | 325-779 | 754-841 | 625-985 | 507-601 |
| Mean | 461.28 | - | 794.57 | - | 550.00 |

754-841 kg/ha. The highest yielder was RMO-435 (601 kg/ha), followed by RMB-25 (581 kg/ha) and RMO-257 (556 kg/ha). These three varieties have therefore been promoted for use by farmers in western Rajasthan.

The project also aimed to demonstrate the utility of the above-mentioned package of crop management practices. The two varieties chosen for this purpose were RMO-435 and RMB-25. In all, 90 demonstrations (83 of which were successful) were conducted, some under rainfed conditions and others providing limited irrigation. In the 70 rainfed only trials, the average seed yield ranged from 225-750 kg/ha (overall average 434 kg/ha), while in the 13 trials where some irrigation was given the range in seed yield was 582-1,040 kg/ha (mean 878 kg/ha). The wide range observed was likely a result of the erratic rainfall pattern and site variation in soil quality. The overall productivity of the demonstrations was 504 kg/ha, a level which is >70% higher than the state-wide average yield achieved across Rajasthan (Table 5). The yield enhancement observed under technology demonstrations was mainly attributed due to the use of improved varieties sown with the recommended seed rate, along with the provision of basal and foliar applied fertilizer, and plant protection measures.

A Government of Rajasthan strategic research project entitled "*Action research for refinement of package of practices for productivity enhancement of crops in different agro-ecological situations*" compared three different nutrient management practices (Table 6) with conventional farmers' practice; the intention was to demonstrate the benefit of fertilizer application (Fig. 8). The chosen variety was RMO-435, sown at 15 kg/ha. All the trials conducted across three districts of Rajasthan (Jalore, Pali, Jodhpur) relied only on rainfall. The highest yield improvement (>27%) over farmers' practice was achieved by applying 75% of the recommended dose of fertilizers (7.5 kg N, 15 kg/ha P), the provision of bio-fertilizer (Azotobacter and PSB culture), and a 1% foliar spray of soluble NPK (19:19:19) given at flowering.

**Table 5: Seed yield of mothbean as affected by improved cultivation practices at farmer's fields.**

| Agro-ecological situation | Total demonstrations | Successful demonstrations | Average seed yield (kg/ha) | State average (kg/ha) | % increase over state average |
|---|---|---|---|---|---|
| Rainfed | 77 | 70 | 434 (225-750) | - | 46.6% |
| Irrigated | 13 | 13 | 878 (582-1040) | - | 196.6% |
| Overall | 90 | 83 | 504 | 296 | 70.2% |

**Table 6: Seed yield of mothbean as affected by alternative nutrient management practices in farmer's fields.**

| Nutrient Management Practices | Seed yield (kg/ha) | Percent increase over farmer's practice |
|---|---|---|
| 125% Recommended dose of fertilizers (Nitrogen 12.5 kg & Phosphorus 25 kg/ha) | 500.4 | 19.8 |
| 100% Recommended dose of fertilizers (Nitrogen 10 kg & Phosphorus 20 kg/ha) + Bio-fertilizers (Azotobactor & PSB culture) | 500.2 | 17.15 |
| 75% Recommended dose of fertilizers (Nitrogen 7.5 kg and Phosphorus 15 kg/ha) + Bio-fertilizer (Azotobactor & PSB culture) + 1% foliar spray of soluble NPK (19:19:19) at flowering stage | 500.9 | 27.4 |
| Farmer's practice | 400.3 | - |

**Fig. 8: Field demonstration plot showing the benefit of fertilizer application.**

# 8. SEED PRODUCTION

Field standards prescribed by Government of India for mothbean seed production are as follows: a minimum of two field inspections, one before flowering and the second during the flowering to pod development stage. The field needs to be free of volunteer plants. The isolation distance is set at 10 m for foundation seed and 5 m for certified seed. A maximum of 0.1% off-types is allowed for foundation seed and of 0.2% for certified seed. Samples of the seed are routinely analysed for physical purity, genetic purity and germination ability. As with other crop species, farmer participatory seed production has proven to be a very effective method for rapid seed multiplication, validation, dissemination and adoption of high yielding mothbean varieties. Details of seed standards prescribed by Government of India for mothbean are given in Table 7 and a field view of seed production is as shown in Fig. 9.

**Table 7: Seed standards of mothbean prescribed by Government of India.**

| Seed lot components and attributes | Standards for each class | |
|---|---|---|
| | Foundation | Certified |
| Pure seed (minimum) | 98.0% | 98.0% |
| Inert matter (maximum) | 2.0% | 2.0% |
| Other crop seed (maximum) | 5/kg | 10/kg |
| Weed seeds (maximum) | 5/kg | 10/kg |
| Other distinguishable varieties (maximum) | 10/kg | 20/kg |
| Germination including hard seeds (minimum) | 75% | 75% |
| Moisture (maximum) | 9.0% | 9.0% |
| Moisture for vapour proof containers (maximum) | 8.0% | 8.0% |

**Fig. 9: Field demonstration plot of mothbean breeders seed production.**

# 9. USES

Mothbean is a multipurpose crop and offers a variety of edible products such as whole dried seeds (Fig. 10), decorticated seed (*mogar*), green pods (consumed as a vegetable), sprouts as a salad ingredient; leaves, pod shells and branches as fodder for animals, and flour to prepare various snacks. About 80% of the production of mothbean is taken up by the food processing industry; much of their product is exported, generating a significant level of local employment (Kumar, 2002). Mothbean products have anti-inflammatory properties, help regulate blood pressure and diabetes and prevent constipation.

**Fig. 10: Whole dried seeds of mothbean.**

## 9.1 Food preparations

Some important food preparations of mothbean are shown in Table 8.

## 9.2 Fodder

Mothbean is a multipurpose legume. In addition to the value of its grain, its straw serves as nutritious and palatable fodder. This is especially the case for traditional varieties which develop a substantial volume of above-ground biomass. Farmers intending the crop to be used for fodder maximize fodder yield and quality (palatability, nutritive value and digestibility) by harvesting the crop while at the pod formation stage.

**Table 8: The various culinary uses of mothbean.**

| Products | Description |
|---|---|
| <br>***Bhujiya***<br><br>***Doka*** | **Bikaneri *bhujiya* and *doka*:** Bikaneri *bhujiya* is a world-famous spicy snack. Its principal ingredient is mothbean flour, mixed in a 4:1 ratio with chickpea flour, along with water, oil, spices and salt. The dough is fried at 175-180°C. The ingredients and their ratio used to prepare *doka* are similar to those used to prepare Bikaneri *bhujiya*, but the final product's thickness is different. It has been registered as Geographical Indication for Bikaner by Government of India. |
|  | **Mothbean *Papad*:** *Papads* are very thin (~1mm) discs of unleavened dough formed from a mixture of mothbean, black gram and green gram flour, together with some spices. When dried to a moisture content of 14-15%, the *papads* are packed in polythene sheets and can be stored for months. *Papads* are generally eaten at the end of a meal in India. |
| <br>**Mothbean vadi/ nuggets**<br><br>**Mothbean sticks** | **Mothbean *vadi*/nuggets and mothbean sticks:** *Vadi* are prepared by wet grinding decorticated mothbean seeds (*mogar*) into a thick paste which is mixed with spices, ginger, green chilli and coriander. The paste is usually formed into nuggets of size 1-3 gm but is also prepared in the form of sticks. Both nuggets and sticks are dried in the sun; after drying, they can be stored for months at room temperature and included as an ingredient in various vegetarian dishes. |

| Products | Description |
| --- | --- |
| <br>**Split seeds**<br><br>**Cooked dal** | **Mothbean split and cooked *dal*:** *Dhal* is prepared by boiling split seeds in water containing salt and turmeric. After boiling, the seed is fried in *ghee* or butter along with cumin, asafoetida, chilli powder and coriander powder. A paste of garlic, onion, ginger and tomato is commonly added to make the *dhal* tastier and more digestible. *Dhal* is consumed along with either bread (chapati) or rice. |
|  | **Mothbean green pods use for vegetables:** Green pods are used to prepare a tasty and nutritious vegetable dish. The pods are cut into pieces and steam cooked in oil. Cumin, asafoetida, chilli, coriander, turmeric and salt are added, along with a paste made from garlic, onion, ginger and tomato. |
|  | **Mothbean sprouts:** Mothbean sprouts are consumed as snacks and also as a salad ingredient. Clean seeds are soaked overnight in water at room temperature, and after removing excess water, the seed is left to germinate at room temperature during the winter and in a refrigerator during the summer. |
|  | **Mothbean *vade*:** Moth *vade* is prepared by wet grinding mothbean seeds into a thick paste which is mixed with spices, ginger, green chilli and green coriander. The paste is formed into 5-10 g nuggets which are deep fried in oil. It is a popular spicy snack in the Indian arid zone. |

| Products | Description |
|---|---|
|  | **Mothbean *Chapati*:** Mothbean is one of the ingredients of multi-grain flours used in the arid zone. The flat bread made using this flour has several health benefits and is therefore consumed by many health-conscious people. A few people even prepare *chapati* from mothbean flour alone. |

## 9.3 Suitability of the crop as a mitigant of climate change

Mothbean has a promising future as an element for ensuring the sustainability of crop production in the arid zone if current predictions of future climate change prove to be accurate. Its leguminous nature, its rapid maturity, its deep root system, its tolerance of moisture stress along with its low water requirement and high water use efficiency, its tolerance of heat, its short stature and its synchronized flowering all serve to allow the crop to adapt to a future climate characterized by lower rainfall and higher ambient temperatures. As a cover crop able to shield soil from direct sunlight, the cultivation of mothbean can help to retain soil moisture, reduce the loss of soil organic matter and retard soil erosion. Its ability to fix atmospheric nitrogen enhances soil fertility. Its agronomic traits and adaptive features make the crop very suitable as a means of restoring degraded lands in the hot arid zone.

## 9.4 Nutritional profile and health benefits

Mothbean provides a good source of dietary carbohydrates and proteins for the largely vegetarian population of the arid and semi-arid zones of India. Its seed protein content ranges from 22 to 24%, and its amino acid profile complements that of cereal grain, especially regarding its content of lysine (5.8%) and tryptophan (3.2%) (Sathe and Venkatachalam, 2007). The proportion of non-digestible carbohydrate present in the seed (37.1%) is lower than in most pulses, so its digestibility is considered to be good. On the other hand, the seed contains appreciable amounts of undesirable anti-nutritional oligosaccharides, although these can generally be degraded by soaking and/or cooking. The chemical composition of mothbean, according to USDA National Nutrient Database for Standard Reference, is given in Table 9.

**Table 9: Nutritional composition of mothbean (value per 100 g).**

| Nutrient proximate | Quantity | Vitamins | Quantity | Lipids | Quantity |
|---|---|---|---|---|---|
| Water | 9.68 gm | Vitamin C, total ascorbic acid | 4 mg | Fatty acids, total saturated | 0.364 gm |
| Energy | 343 kcal | Thiamin | 0.562 mg | 16:00 | 0.313 gm |
| Energy | 1435 kJ | Riboflavin | 0.091 mg | 18:00 | 0.051 gm |
| Protein | 22.94 gm | Niacin | 2.8 mg | Fatty acids, total monounsaturated | 0.129 gm |
| Total lipid (fat) | 1.61 gm | Pantothenic acid | 1.535 mg | 18:1 undifferentiated | 0.129 gm |
| Ash | 4.26 gm | Vitamin B-6 | 0.366 mg | Fatty acids, total polyunsaturated | 0.75 gm |
| Carbohydrate, by difference | 61.52 gm | Folate, total | 649 µg | 18:2 undifferentiated | 0.485 gm |
| Minerals | Quantity | Folic acid | 0 µg | 18:3 undifferentiated | 0.265 gm |
| Calcium, Ca | 150 mg | Folate, food | 649 µg | Fatty acids, total trans | - |
| Iron, Fe | 10.85 mg | Folate, DFE | 649 µg | Cholesterol | - |
| Magnesium, Mg | 381 mg | Vitamin B-12 | 0 µg | Amino Acids | - |
| Phosphorus, P | 489 mg | Vitamin A, RAE | 2 µg | Tryptophan | 0.147 gm |
| Potassium, K | 1191 mg | Retinol | 0 µg | Isoleucine | 1.138 gm |
| Sodium, Na | 30 mg | Vitamin A, IU | 32 IU | Leucine | 1.541 gm |
| Zinc, Zn | 1.92 mg | Vitamin D (D2+D3) | 0 µg | Lysine | 1.248 gm |
| Copper, Cu | 0.688 mg | Vitamin D | 0 IU | Methionine | 0.22 gm |
| Manganese, Mn | 1.82 mg | | | Cystine | 0.117 gm |
| Selenium, Se | 8.2 µg | | | Phenylalanine | 1.028 gm |
| | | | | Valine | 0.734 gm |
| | | | | Histidine | 0.771 gm |

Source: USDA National Nutrient Database for Standard Reference, Release 28 slightly revised May 2016 Software v.3.5.3 2016-10-05; The National Agricultural Library.

## 9.5 Suitability for mixed farming systems

Mothbean is cultivated on plain lands as well as sand dunes as sole crop or mixed with other crops such as pearl millet (Fig. 11), clusterbean or sesame, or with pasture grasses (particularly *L. sindicus*). It is also intercropped with certain woody perennials. Its leguminous nature, deep root system, short duration, moisture

**Fig. 11: Mothbean co-cultivation with pearl millet.**

stress tolerance, erect to semi-erect plant type, short stature and synchronized growth habit are some of the adaptive features which make the crop suitable for mixed/intercropping with seasonal crops, pasture grasses and also as a component of agro-forestry systems.

# 10. CROP IMPROVEMENT CONSTRAINTS

Despite the many adaptive features of mothbean for cultivation in the hot arid zone, its production and productivity are highly erratic and generally low. Across Rajasthan, the state responsible for ~90% of the national acreage planted to the crop, the average grain yield is just 329 kg/ha. However, with the use of improved seed and crop management practices, a yield level of 500-700 kg/ha under rainfed conditions, and 1,000-1,200 kg/ha if irrigated should be attainable. Raising the yield potential of the crop is hampered by a variety of factors. Chief among these is a paucity of investment into research, which reflects the fact that the cultivation of the crop is largely confined to the country's hot arid zone. Genetic progress is inhibited by the difficulty to perform hybridizations due to the small size of the species' flowers.

Since the cultivation is confined to hot arid zone, limited numbers of research institutions with small group of researchers are involved in mothbean improvement programme as compared to other field crops. To date, varietal development has relied on pure line selection and mutation breeding.

## 10.1 Abiotic stressors

Most mothbean crops in the hot arid zone are not irrigated, because of a lack of suitable water. The crop is typically grown on soils with a poor capacity to hold water, a problem which is exacerbated by the unpredictable nature of the local climate, where precipitation is low and erratic, resulting in a high frequency of episodes of moisture stress. This stress is compounded by high ambient temperatures and strong winds, which drive up the crop's loss of moisture through evapo-transpiration.

## 10.2 Biotic stressors

The crop is susceptible to a variety of both fungal and viral pathogens and several insect pests all the way from the seedling stage to physiological maturity. The plants' short stature leaves it prone to competition by weeds, which not only limit the crop's access to space, moisture and nutrients, but also act as an attractant of several pest insects. The seed is particularly favoured by a number of bird species. Once seed has been harvested, it is very liable to damage by storage pests.

## 10.3 Major diseases and insect pests

Of the causative micro-organisms responsible for the major diseases affecting the plant, two are viral (yellow mosaic virus and crinkle virus), three are fungal (*Cercospora* leaf spot, *Macrophomina* blight and root rot, and powdery mildew) and one is bacterial (bacterial leaf spot). Its major insect pests are whiteflies, thrips, jassids, black weevils and pulse beetles, along with a number of minor pests (termites, white grubs, mites, pod bugs, grey weevils, galerucid beetles and grasshoppers). These, along with recommended prevention and control measures, are described in Table 10.

**Table 10: Major pest and diseases of mothbean.**

| Disease/pests symptoms | Prevention and control |
|---|---|
|   | **Yellow Mosaic Virus (YMV):**<br>This group of viruses is responsible for the most destructive of the diseases affecting mothbean. The viruses are transmitted by whitefly (*Bemisia tabaci* Genn). Initially, tender leaves develop yellow spots, which increase in area over time until the entire leaf area becomes chlorotic and the leaf begins to curl. The growth of the whole plant becomes stunted, and the pods which form are deformed and contain shrivelled and undersized seed. The disease can result in a loss of up to 80% of the seed yield. The causative viruses have several alternate hosts, which act as the primary source of inoculum.<br>***Prevention and control*:** The incidence of the disease can be minimized by the use of improved seed of recommended varieties bred for resistance. Infected plants should be removed as soon as symptoms are observed. Timely weed management helps to reduce the population of alternate hosts. Chemical treatment of the seed before sowing with 2 mL/ kg of seed of imidacloprid 17.80 SL can control the disease. Because the viruses are spread by whiteflies, foliar spraying with a systemic insecticide (100 g/ha acetamprid 20 WS, 100-150 mL/ha imidacloprid 17.80 SL, 100 g/ha thiomethoxam 25 WG, 400-500 g/ha acephate 75 SP or 500 mL/ha dimethoate 30 EC) should control the population of the vector. An additional spray after 12-15 days can be given if required. |

| Disease/pests symptoms | Prevention and control |
|---|---|
|   | **Crinkle virus:** The initial symptoms of a crinkle virus infection appear 3-4 weeks after sowing. The virus causes crinkling and curling of the leaves, stunts the growth of the plants and induces malformation of the floral organs with negative consequences for reproductive development. The extent of the resultant yield loss depends upon the time of occurrence and intensity of the disease. ***Prevention and control*:** The same measures taken to prevent and control this viral disease are recommended as those listed above for YMV. Infected plants should be rogued at an early stage to minimize the spread of the disease. |
|    | **Cercospora leaf spot (*Cercospora dolichi*):** This fungal disease can induce severe losses of yield under warm and humid weather conditions. Its characteristic symptom is the appearance on the leaves of spots with a brown to greyish centre and a reddish-brown border: these develop 4-6 weeks after sowing. Petioles, stems and pods can also be affected. During favourable conditions, the spots increase in area, and by the time the plant has reached flowering and the pods have begun to form, the leaves have necrosed and have dropped to the ground. The fungus survives on infected seed and crop debris. ***Prevention and control*:** Proper field sanitation, the use of crop rotation, the destruction of diseased crop debris and ensuring the absence of alternate hosts in the vicinity of the crop all help to reduce the disease's incidence. Chemical control can be implemented by treating the seed before sowing with either 2.5 g/kg seed of thiram or captan. Upon the appearance of symptoms, a foliar spray of 2.0 g/L carbendazim (12%) + mancozeb (63%) should be given. A follow-up spray of the same formulation can be given after 10 to 15 days, if required. |
|  | **Macrophomina blight and root rot (*Macrophomina phaseolina*):** This fungus attacks the whole of the plant. Pre-emergence, it rots the germinating seed and kills the young seedling. It damages secondary roots and shreds the cortex region of the tap root. Post-emergence, the fungus attacks the stem at ground level, forming localized dark brown patches which coalesce and encircle the stem. Black dot-like sclerotia are formed on the surface and below the epidermis of the stem and root. The disease develops rapidly under conditions of high temperature and moisture stress. The pathogen is both seed- and soil-borne. |

| Disease/pests symptoms | Prevention and control |
|---|---|
| <br> | ***Prevention and control***: A basal application of one of 25 kg/ha zinc sulphate, 250 kg/ha neem (*Azadirachta indica*) cake or 5.0 kg/ha Trichoderma viride along with 100 kg/ha vermicompost at the time of sowing helps to suppress the pathogen. Alternatively, seed can be treated with 8-10 g/kg Trichoderma or 2.5 g/kg seed of carbandazim before sowing. Any diseased plants should be uprooted and destroyed at the earliest possible stage. On the appearance of disease, a foliar spray of 2.0 g/L carbendazim (12%) + mancozeb (63%) should be given. The same formulation can be given again after 12 to 15 days, if required. A foliar spray of 0.3% azadirachtin is also effective. |
|  | **Bacterial leaf spot (*Xanthomonas campestris*):**<br>Plants infected by this pathogen develop brown, circular to irregular raised spots on their leaves. Later, the spots become corky. In a severe infection, dark brown longitudinal slits or cankers develop on the stem from the soil surface up to the growing tip. The disease is seed-borne.<br>**Prevention and control:** Seed can be dressed with 0.01% streptocycline + 2.0 g/kg seed of captan before sowing. Any diseased plants should be uprooted and destroyed at the earliest possible stage. A foliar spray of 0.01% streptocycline +0.2% blitox controls the disease if given soon after the disease's first appearance. |
| <br><br>**Coried bug (*Riptortus pedestris*)**<br><br><br>**Pantatomid bug (*Nezara viridula*):** | **Pod bugs: Coried bug (*Riptortus pedestris*) and Pantatomid bug (*Nezara viridula*):**<br>The adults and nymphs of these bugs use their piercing mouthparts to penetrate the pod wall and suck the sap from developing seeds. As a result, damaged seeds become shrivelled and develop dark patches. In the case of a severe infestation, the tender parts of pods shrivel and dessicate. The bugs typically cluster on the leaves and pods. Seeds damaged by bugs neither germinate nor are acceptable as human food.<br>***Prevention and control***: Timely hoeing and weeding to keep the crop clean and weed free is recommended. At the initial stage of a pod bug infestation, a foliar spray of a systemic insecticide (e.g., 100 g/ha acetamprid 20 WS, 100-150 mL/ha imidacloprid 17.80 SL, 100 g/ha thiomethoxam 25 WG, 400-500 g/ha acephate 75 SP or 500 mL/ha dimethoate 3 EC can be used for control. A follow-up foliar spray of one of these systemic insecticides can be given 12-15 days after fist spray, if required. |

| Disease/pests symptoms | Prevention and control |
|---|---|
|  | **White grub (*Holotrichia serrata*):**<br>White grub is a polyphagous soil pest, which feeds on the plants' roots. It is emerging as a serious threat, particularly for farmers growing groundnut. The beetles emerge from the soil after the start of the rainy season and feed on tree foliage (particularly neem and *khejri*). During this period, the beetles mate, after which they return to the soil to lay their eggs.<br>***Prevention and control*:** The eggs/larvae of the white grub can be disrupted by deep ploughing during the summer, while the adults can be trapped by setting up light traps near the trees where they feed. Chemical control of the adults is possible using a foliar spray of the trees with an insecticide such as 25 mL/15 L of monocrotophos 36 SL or 36 mL/15 L of quinalphos 25 EC. Addition to the soil of 200 kg farmyard manure containing 8-10 kg/ha of a bio-agent (*Beauveria bassiana* or *Metarhizium anisopliae*) has been shown to be effective against white grubs (and also termites). An alternative soil additive is neem cake, castor cake, karanj cake (*Pongamia pinnata*) or Tumba cake (*Citrullus colocynthis*), applied at a rate of 500 kg/ha: these work as repellents and anti-feedants. After onset of rain, pesticides such as chloropyriphos 20 EC (@ 4 L/ha) or omidacloprid 17.80 SL (@ 300 mL/ha) can be delivered to the crop either via a sprinkler irrigation system or be mixed with the sand and uniformly spread in the field before irrigation. At the initial stage of white grub infestation, infected plants can be drenched with either 2.0 mL/L chloropyriphos 20 EC, 0.5 mL/L imidacloprid or 2 mL/L quinalphos. |
| | **Powdery mildew (*Erysiphe polygoni*):**<br>The fungus forms a powdery mass on the leaves which later turns a dirty white colour and eventually causes the leaves to drop.<br>***Prevention and control*:** The incidence of the disease can be minimized by the use of improved seed of recommended varieties bred for resistance. Seed can be dressed with 2.5 g/kg seed of thiram or captan. A foliar spray of 0.2% karathane will suppress the disease if given soon after the disease's first appearance. |
| | **Whitefly (*Bemisia tabaci*):**<br>Both the nymphs and adults of this pest damage the crop by sucking cell sap, thereby incurring a loss of chlorophyll, as evidenced by the formation of chlorotic patches on the leaves, which later curl. Whitefly infestation can occur at any stage of the crop's growth, but it typically peaks at time of pod formation. Whitefly also acts as a vector for the viruses responsible for YMV. |

| Disease/pests symptoms | Prevention and control |
|---|---|
| | ***Prevention and control*: The incidence of whitefly can be minimized by intercropping mothbean with pearl millet, the latter acting as a barrier to the movement of the pest. The use of recommended varieties bred for resistance is encouraged. Timely sowing of the crop (in Rajasthan by July 10$^{th}$) and regular hoeing and weeding to keep the crop clean and weed-free all help reduce the incidence of whitefly. Chemical control is possible by dressing the seed with 2 mL/kg of seed of imidacloprid 17.80 SL. At the initial stage of whitefly infestation, control is possible by foliar spraying with a systemic insecticide, such as 100 g/ha acetamprid 20 WS, 100-150 mL/ha imidacloprid 17.80 SL, 100 g/ha thiomethoxam 25 WG, 400-500 g/ha acephate 75 SP or 500 mL/ha dimethoate 30 EC. A follow-up foliar spray of one of these systemic insecticides can be given 12-15 days after fist spray, if required. |
| | **Thrips (*Caliothrips indicus*):**<br>Both the nymphs and adults of this pest cause damage by sucking cell sap from flower buds and therefore cause flower shed. The extent of flower drop and the extent of the yield loss depend upon the time of occurrence and intensity of the infestation.<br>***Prevention and control*:** As described for whitefly. |
| | **Jassids/leafhoppers (*Empoasca kerri*):**<br>Jassid nymphs and adults both cause crop damage by sucking cell sap from leaves and therefore deplete the plants' chlorophyll, leading to the formation of chlorotic patches on the leaves, which later curl. Jassids can cause problems throughout the vegetative and reproductive stages of the crop. The extent of yield loss depends upon the time of occurrence and intensity of the infestation.<br>***Prevention and control*:** As described for whitefly. |
| | **Pod borer (*Maruca vitrata*):**<br>Pod borer is a polyphagous pest which attacks many pulse crops, including mothbean. Its caterpillars feed on young leaves, flowers and pods. Small pods may be totally consumed by the caterpillars, but their favoured target is immature seeds.<br>***Prevention and control:*** At the initial stage of infestation, a foliar spray of one of 150 g/ha emametin benzoate 5% SG, 1.25-1.50 L/ha monocrotophos 36 WSC, 1 L/ha quinalphos 25 EC, 250 mL/ha indoxacarb 15.8 EC, 400-500 g/ha acephate 75 SP, 250 mL/ha cypermethrin 25 EC or 500 mL/ha profenophos 50 EC can control the pest. A follow-up foliar spray of one of these insecticides can be given 12-15 days after fist spray, if required. |

| Disease/pests symptoms | Prevention and control |
|---|---|
| | **Pulse beetle/bruchid (*Callosobruchus chinensis*):**<br>One pair of bruchids can compromise 100 g of stored seed within 30 days, reducing the seed lot's germination percentage below the minimum seed certification standards and rendering the seed unfit for human consumption.<br>***Prevention and control*:** To minimize damage caused by bruchids, seed should be dried to a moisture level of <9%, then stored under optimal conditions. For short-term storage (<12 months), it is sufficient to maintain the ambient temperature below 15°C and the relative humidity below 35%. Precious germplasm and breeding material can be safely stored for 3-4 years if the temperature remains in the range 4-8°C, and the relative humidity lies below 35%. Seed should be stored in clean containers and the storage area should be fumigated in a timely manner. |

# 11. CURRENT RESEARCH PRIORITIES

Mothbean is an essential component of the sustainable cropping system in the hot arid zone of India. It enjoys a substantial demand from the food processing industry, which has successfully marketed Bikaneri *bhujiya* both domestically and abroad. Given the economic significance of the crop to farmers in the hot arid zone, the priority of researchers, as well as that of developmental agencies and policy planners, is to focus on enhancing the crop's productivity. This goal is being pursued in a number of ways. Firstly, there is an intensification of the breeding effort to develop high yielding, short duration and disease resistant varieties which exhibit synchronized growth and maturity and a high harvest index, and which are adapted to rainfed conditions. The breeding programmes need to also encourage the participation of farmers to help validate and popularize improved varieties and crop management technologies. It will be of importance to support the production of seed of improved varieties, so that quality seed is made available to farmers both in a timely manner and at a reasonable price. Finally, the benefit has been recognized of establishing a seed bank to ensure seed availability to farmers even after crop failure caused by drought or some other reason.

Of equal importance is the popularization of crop management technologies and plant protection measures among farmers. For example, the application of basal and foliar fertilizers (including those containing micro-nutrients) is being promoted, as is the implementation of plant protection measures to reduce losses caused by pests (particularly whitefly) and disease (particularly yellow mosaic disease). Farmers need to be encouraged as strongly as possible to replace seed and adopt new varieties, and to use irrigation where this is available. Finally, attention needs to be given to improving the way in which mothbean seed is stored, so that post-harvest losses can be minimized.

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## Annexure I

# PACKAGE OF PRACTICES FOR MOTHBEAN CULTIVATION RECOMMENDED IN INDIA

| Particulars | Details |
|---|---|
| **Significant varieties** | RMO-2551, RMO-435, RMO-257, RMB-25, RMO-423, RMO-225, RMO-40, CAZRI Moth-2, CAZRI Moth-3, CAZRI Moth-4, CAZRI Moth-5 |
| **Sowing time** | July after effective rains |
| **Seed rate** | 12-15 kg/ha |
| **Plant geometry** | 30cm x 10-15cm<br>Optimum plant population about 300000 plant/ha |
| **Fertilizers** | ❖ Basal application of Nitrogen 10 kg and Phosphorus 20 kg/ha at the time of sowing<br>❖ Foliar spray of 1% soluble NPK at flowering to pod development stage<br>**Use of agro-chemicals**<br>❖ Foliar spray of 0.2% $K_2SO_4$ + 100 ppm ascorbic acid at grain development stage for terminal stress mitigation<br>❖ Foliar spray of 500 ppm thiourea at flowering stage is also beneficial in yield enhancement and stress mitigation |
| **Plant protection** | ❖ Seed treatment with Carbandazim @ 2.0-2.5 gm/kg seed<br>❖ Foliar spray of Azadirachtin 0.3% at 30 days after sowing followed by second spray of systemic pesticide like Thiomethoxam 25 WG 100 gm/ha or Imidacloprid 150 ml/ha, etc. at 40-45 days after sowing with the consultation of plant protection scientist |
| **Other impact points** | ❖ Crop should be sown in well prepared field<br>❖ Timely hoeing and weeding should be carried out for weed control and moisture management<br>❖ One or two lifesaving irrigations may be applied under moisture stress conditions, if good quality of irrigation water is available. |

## Annexure II

# CROP DESCRIPTORS FOR CHARACTERIZATION AND EVALUATION

Seed yield is a complex trait which is directly and indirectly affected by several morphological and physio-biochemical traits. Ancillary traits largely targeted during field evaluation for desired plant type are as under:

**Seedling observations**

1. Germination
2. Seedling length
3. Seedling fresh weight
4. Seedling dry weight
5. Seedling vigour index

**Agro-morphological observations**

1. Days to flowering
2. Days to maturity
3. Plant height
4. Number of branches per plant
5. Leaf size/ area
6. Number of clusters/bunches per plant
7. Number of pods per plant
8. Pod length
9. Pod thickness
10. Biological yield
11. Seed yield
12. Harvest index

**Seed observations**

1. 100 seed weight
2. Seed length
3. Seed thickness
4. Seed volume
5. Bulk density
6. True density
7. Porosity percentage
8. Water absorption capacity
9. Water absorption index

**Physio-biochemical observations**

1. Chlorophyll content
2. Membrane stability index
3. Relative water content
4. Crude protein content
5. Proline content

**Other observations**

1. Multiple disease resistance particularly the Yellow Mosaic Virus
2. Stress tolerance particularly the heat and moisture stresses

## Annexure III

# COMMONLY AVAILABLE PESTICIDES, FUNGICIDES AND BIO-AGENTS IN INDIAN MARKETS, BEING USED TO CONTROL PEST AND DISEASES IN MOTHBEAN

| | Name | Optimum dose | Mode of action | Effectiveness against pests |
|---|---|---|---|---|
| | | **Synthetic pesticides:** | | |
| 1. | Imidacloprid 17.80 SL | 100-150 ml/ha | Systemic | Sucking pests |
| 2. | Thiomethoxam 25 WG | 100 gm/ha | Systemic | Sucking pests |
| 3. | Acetamprid 20 WS | 100 gm/ha | Systemic | Sucking pests |
| 4. | Monocrotophos 36 WSC | 1.25-1.50 lit./ha | Contact cum systemic | Sucking pests, borer and defoliator |
| 5. | Quinalphos 25 EC | 1.0 lit./ha | Contact | Borer and defoliator |
| 6. | Indoxacarb 15.8 EC | 250 ml/ha | Contact | Borer and defoliator |
| 7. | Dimethoate 30 EC | 500 ml/ha | Systemic | Sucking pests |
| 8. | Chloropyriphos | 1.25-1.50 lit./ha | Contact | Soil pests like termite and white grub |
| 9. | Trizophos 40 EC | 1.0 lit./ha | Systemic | Sucking pests |
| 10. | Acephate 75 SP | 400-500 g/ha | Systemic | Sucking pests, Borer and defoliator |
| 11. | Metasystox 25 EC | 500 ml/ha | Systemic | Sucking pests |
| 12. | Cypermethrin 25 EC | 250 ml/ha | Contact | Borer and defoliator |
| 13. | Profenophos 50 EC | 500 ml/ha | Systemic | Borer and defoliator |
| 14. | Emametin Benzoate 5% SG | 150 gm/ha | Systemic | Borer and defoliator |

| | Name | Optimum dose | Mode of action | Effectiveness against pests |
|---|---|---|---|---|
| | | **Bio-pesticides:** | | |
| 1. | Azadirachtin | 1.25-1.50 lit./ ha | Repellant and Antifeedant | Sucking pests, borer and defoliator; and foliar diseases |
| 2. | Neem oil | 1.25-1.50 lit./ ha | Repellant and Antifeedant | Sucking pests, borer and defoliator; and foliar diseases |
| 3. | Neem cake/Castor cake/ Karanj cake/ Tumba cake | 500 kg/ha Soil application | Repellant and Antifeedant | Soil pests and soil borne diseases |
| | | **Fungicides:** | | |
| 1. | Carbendazim 50 WP | Seed treatment 2.0 gm/kg 400 gm/ha in standing crop | Systemic | Seed and soil borne as well as foliar diseases |
| 2. | Mancozeb 75 WP | 800 gm/ha | Contact | Foliar diseases |
| 3. | Thiram 75 WP | ST 3.0 gm/kg seed | Contact | Seed and soil borne diseases |
| 4. | Difenoconazole 25 EC | 500 gm/ha | Systemic | Foliar diseases |
| 5. | Copper oxychloride 50 WP | 1.0 kg/ha | Contact | Foliar diseases |
| 6. | Ridomil MZ 68 WG | 1.0 kg/ha | Systemic & contact | Foliar diseases |
| 7. | Captan 50 WP | Seed treatment 2-2.5 gm/kg seed | Contact | Seed and soil borne diseases |

| | Name | Optimum dose | Mode of action | Effectiveness against pests |
|---|---|---|---|---|
| 8. | Vitavax power | Seed treatment 2.0 gm/kg seed | Systemic & contact | Seed and soil borne diseases |
| | | **Bactericides:** | | |
| 1. | Streptocycline | Seed treatment with 200 ppm & 100 ppm in crop | Systemic | Bacterial diseases |
| | | **Bio-agents:** | | |
| 1. | *Trichoderma harzianum* | Seed treatment 8-10 gm/kg seed & soil application 5 kg/ha with 100 kg FYM | Bio-agent | Seed and soil borne diseases |
| 2. | *Trichoderma viride* | Seed treatment 8-10 gm/kg seed & soil application 5 kg/ha with 100 kg FYM | Bio-agent | Seed and soil borne diseases |
| 3. | *Beauveria bassiana* | Soil application 8-10 kg/ha with 200 kg FYM | Bio-agent | Soil pests like termite and white grub |
| 4. | *Metarhizium anisopliae* | Soil application 8-10 kg/ha with 200 kg FYM Bio-agent | Soil pests like termite and white grub | |


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