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Stress tolerant crop varieties of

major arid zone crops to promote resilience to climatic stresses

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The western dry or hot arid regions of India is unique for its harsh climatic conditions; mainly high temperature, low rainfall and nutrient deficient soils which are affecting crop productivity. Crop productivity is apparently influenced by genetic potential, cultivation practices and climatic factors; of which genetic potential is very important with respect to crop and varietal adaptability under specific conditions. Arid region demands crops and varieties having high tolerance to moisture stress and high temperature stress under limited nutrient availability for climate resilience. The inherent potential of pearl millet, moong bean, moth bean and cluster bean to survive under hot arid conditions made them the principal crops of the region occupying maximum acreage. The seed purpose watermelon showed high adaptability for cultivation under hyper arid conditions. Earliness in crop varieties is an important trait to add climate resilience in arid environment. The popular varieties of the region showed tolerance to moisture stress and high temperature.

Key words: Arid region, Clusterbean, Mung bean, Moth bean, Matira, Pearl millet

IN western arid regions of India pearl millet, moong bean, moth bean and cluster bean are the predominant crops due to their inherent potential to tolerate extremes of temperature, intense radiations under limited water availability. These crops are grown on about 70% of total cultivated area (15 m ha) of Rajasthan during *kharif* mostly under rainfed conditions. To survive such limiting environments they are endowed with certain adaptive strategies both constitutive and responsive. They are equipped with morphological, structural and developmental constitutive traits like, deep roots, prostrate trailing growth, low yield (reduced respiration) and indeterminate growth. They also employ some contingent strategies for drought avoidance e.g. cessation of growth, short life-cycle, leaf shedding, leaf rolling mechanisms to reduce water loss and efficient translocation for improved water use efficiency. Most of the constitutive traits that impact drought resistance operate mainly through dehydration avoidance and efficient water use. The traits like reduced plant size, leaf area, leaf area index (LAI) and crop duration that are important for moderating water use and reducing injury under drought stress were efficiently used in modern cultivars released in a number of crops including pearl millet, moong bean, cluster bean and moth bean. The varieties of pearl millet, moong bean, moth bean, and cluster bean developed in recent past in hot arid climates are described below with important features.

Pearl millet

Millets previously classified as coarse grain are now called 'Nutri-Cereal'. Year 2018 will remain in record for redefining the nomenclature for millet crops comprising pearl millet, sorghum, finger millet and other millets grown in India. These nutri-cereals possess great potential to meet food and nutritional security mandate of the country because of high nutritive value than rice and wheat. Moreover their genetic potential to grow in resource limited and adverse conditions declared them climate resilient crops. Pearl millet (*Pennisetum glaucum*) is the most important nutri-cereal, as it is the third most widely cultivated food crop after rice and wheat. Pearl millet is the principal fodder and food crop of western hot arid region. The average area in the country is around 8.16 m ha, of which 56% acreage (4.62 m ha) area lies in Rajasthan of which 73% (3.8 m ha) acreage is in hot arid region. Though the productivity is low in arid parts (6.88 q ha^{-1}) than state (8.70 qha^{-1}) and national average (11.47 qha^{-1}). Besides climatic factors availability of quality seed is also crucial for getting higher yields. In the region seed replacement rate varies from 24.41 to 84.86% whereas hybrid seed needs to

be purchased every year to have better yields. Recently focus for genetic improvement is on biofortification i.e. increasing the iron (Fe) and zinc (Zn) levels in the seed for nutritional security.

Production technology: Pearl millet hybrids are generally sown in crop geometry of 45 cm row-to-row and 10 to 15 cm plant-to-plant distance.On an average 3.5 to 4.0 kg seed is required for sowing of 1 ha area. The crop is responsive to nitrogen (N) fertilizer dose varying from 40 to 80 kg ha^{-1}, farmyard manure application along with Phosphosus solubilizing bacteria and *Azospirillum* gave better yield in sandy and sandy-loam soils of arid regions. Being a short duration rainfed crop, effective weed control up to 30 days after sowing should be done for better yield. One hand weeding after 25 to 30 days after sowing should be done for controlling weeds effectively. All the varieties in seed chain are resistant to downy mildew and tolerant to blast, the two most menacing diseases. Foliar insects like shoot fly sometimes damage the crop, any broad spectrum insecticide like clothianidin as seed treatment followed by fipronil and imidacloprid spray at 35 to 40 days after sowing is effective.

Improved varieties: Hot arid regions of western India demands early maturing hybrid varieties capable of escaping drought conditions which are often experienced in arid regions due to low rainfall patterns with limited rain events. In the last fifteen years hybrids and composites were released for cultivation in hot arid regions (Table 1). The most popular variety of the region HHB-67 (released in 1990) was extra early maturing thus had highest acreage in India, later it became susceptible to downy mildew. Considering its popularity and acceptance, however, HHB-67 (Improved) was developed by marker assisted breeding for resistance to downy mildew in 2005. At present HHB-67 (I) and RHB-177 are the two most popular hybrids in the region and are in seed chain. Recently two new varieties (HHB-272 and MPMH-21) were notified that are gaining popularity in the region.

Plate 1. Promising varieties of moong bean grown in hot arid region

Moong bean

Moong bean crop was wider adoptability with nitrogen-fixing ability grown successfully in hot arid areas. It has its importance in human diet as it possesses easily digestible 25 to 28% protein in the seed. The cultivation area of moong bean was increased ten-fold from 1970-71 to 2016-17 in Rajasthan due to availability of short duration improved varieties having resistance to biotic and abiotic stresses making this crop a potential for arid region. The important varieties growing widely in arid region were IPM 02-03, IPM 02-14, IPM 205-07, IPM 410-03 and SML 668.

Production technologies: Moong bean was grown on well drained sandy soils and sowing was done from first week to third week of July on the onset of monsoon. Row- to-row spacing was kept 30 cm keeping intra-row spacing 10 cm. Seed rate of 15 to 20 kg/ha seed is sufficient. For getting better yield effective weed control was done, and crop was made free from weeds up to 30 days. A hand weeding and hoeing after 30 days of sowing is very effective for weed control and aeration to root zone. The crop was harvested when pods turned brown and defoliation of leaves start to avoid shattering in the field. To avoid storage pest seeds should be dried, properly packed and treated before keeping in storage.

Improved varieties: Traditional moong bean cultivars cultivated in India had long maturity period (90-110 days), indeterminate growth habit, and non-synchronous maturity need multiple harvesting. They were low yielding (400 kg/ha), small seed-sized, susceptible to MYMV and

Table 1. Downy mildew resistant early hybrids and composite varieties of pearl millet developed by public sector for western arid conditions of India

Varieties of pearl millet	Year of release	Yield (q ha^{-1})	Special characters
CZP-9802	2002	13.00	Composite variety flowers in 42-46 days and matures in 72-75 days; tolerant to high moisture stress, compact ear head, high tillering; grain grey with yellow base
HHB-67 (I)	2005	28.30	Hybrid variety flowers in 40-45 days and matures in 65 to 70 days, extra early maturity; highly resistant to moisture stress
GHB-538	2005	41.50	Hybrid variety flowers in 44-45 days and matures in 70 to 75 days; tolerant to lodging; light brownish grey grains
GHB-719	2007	22.00	Hybrid variety flowers in 43-45 days and matures in 70 to 74 days;fully exerted conical-shaped, compact and bristled earheads; globular, grey medium-sized grains
GHB-757	2008	23.00	Hybrid variety flowers in 44-46 days and matures in 70 to 74 days; tolerant to smut and ergot; salt-tolerant medium tall; compact cylindrical ear heads; grey brown grains
RHB-154	2009	26.00	Hybrid variety flowers in 46-50 days and matures in 75 to 80 days; tolerant to lodging, medium tall; cylindrical earheads
RHB-177	2011	19.50	Hybrid variety flowers in 45 days and matures in 72 to 74 days;tolerant to lodging, medium tall; cylindrical bristled, light yellow grains
HHB-226	2011	20.81	Hybrid variety flowers in 48 days and matures in 75 days;tolerant to drought and rust; long to go earheads with dark brown long bristles; medium seed size
MPMH-21	2016	20.00	Hybrid variety flowers in 47 days and matures in 73 to 77 days; resistant to smut, blast and tolerant to stress.

Table 2. Improved varieties of moong bean suitable for arid areas

Varieties of moong bean	Year of release	Yield (q ha^{-1})	Special characters
IPM-205-7 (Virat)	2017	12-14	Matures in 50 to 55 days,resistance to yellow mosaic virus disease, suitable for summer cultivation with irrigation facility
IPM-410-3 (Shikha)	2016	12-14	Matures in 60 days,highly resistant to moong bean yellow mosaic virus and powdery mildew diseases, suitable for spring season with irrigation facility
IPM-02-03	2003	12-15	Matures in 62 days,highly resistant to moong bean yellow mosaic virus, suitable for *kharif* cultivation
IPM-02-14	2009	10-11	Matures in 62-65 days, resistant to moong bean yellow mosaic virus and leaf crinkle virus, suitable for *kharif* cultivation
SML-668	2002	10-12	Matures in 60 days,resistant to moong bean yellow mosaic virus, suitable for *kharif* cultivation and also summer cultivation
GM-4	2002	13-14	Matures in 61-68 days,partially resistant to yellow mosaic virus, bold-seeded variety suitable for *kharif* and summer cultivation
MH-2-15	2008	7-8	Matures in 60 days,moderately resistant to moong bean yellow mosaic virus, suitable for *kharif* cultivation
RMG-344	2002	8-10	Matures in 65-70 days,resistant to web blight and leaf spot disease, suitable for *kharif* cultivation
RMG-268	1998	10-12	Matures in 65-70 days,resistant to web blight and leaf spot disease, suitable for *kharif* cultivation

insects. Further old improved moong bean varieties were of medium maturity duration (70 to 80 days to maturity) and non-synchronizing in maturity. The new moong bean varieties developed by different centres are resistant to moong bean yellow mosaic virus, compact plant type, high harvest index, early (55 to 60 days) and synchronous maturity, bear pods in bunches, with shiny seeds, and determinate growth habits. Most suitable varieties for moong bean cultivation in arid areas were given in Table 2, Plate 1.

Moth bean

Moth bean (*Vigna acounitifolia*) is a drought-resistant legume popular in hot arid regions, commonly called mat bean, moth bean, *matki*, Turkish gram or dew bean. It is a rich source of protein (22 to 24%) and occupies 1.09 m ha area in the country with production of 0.36 MT and average yield of 3.30 q ha^{-1}. Rajasthan ranks first in area and production contributing 85.51% in area (0.93 mha) and 80.33% in production (0.291 MT) at the country level.

Seed is used either whole or split as pulse and is important component of several snacks *viz*., *papar, bhujia, mangori, mogar, namkins*. Plants being highly palatable and rich in protein serve the purpose of fodder for cattle. Being a leguminous crop it also adds atmospheric nitrogen (N) to the soil.

Production technology: Moth can be easily grown on well drained sandy soils and sowing was done from first week of July to second fortnight of August depending on the onset of monsoon, but optimum time is mid-July. Row-to-row spacing of 30 cm should be maintained keeping intra-row spacing of 10 cm. Seed rate of 10 to 12 kg ha^{-1}is sufficient in arid regions. For good plant stand seed should be treated with fungicides and *Rhizobium* cultures before sowing. One hand weeding 25 to 30 days after sowing was done for controlling weeds effectively. Except Yellow Mosaic Virus(YMV) disease no serious diseases and insect pests affect the crop under normal rainfall conditions but prolong rainfall during vegetative stage, diseases and pests can affect the crop adversely. YMV is most devastating disease under congenial environmental conditions, it is transmitted through white flies. Growing tolerant varieties is desirable and spray of Dimethoate for controlling white fly population should be done for good crop harvest.

The crop should be harvested when pods turn brown and defoliation of leaves start to avoid shattering and bird losses in the field. To avoid storage pests, seeds should be dried, properly packed and treated before storage.

Improved varieties: Varietal improvement of moth bean initiated in late 1960 or early 1970s in India,

Table 3. High-yielding varieties of moth bean released for cultivation in arid regions

Varieties of moth bean	Year of release	Yield (q ha^{-1})	Special characters
RMO-40	1994	5.5-6.5	Early maturing (62-65 days) variety, erect growth, short stature, suited to low rainfall, escapes drought at later stage of crop growth, tolerant to yellow mosaic virus (YMV) under field conditions
RMO-225	1999	5.0-8.0	Leaves are broad and shallow lobed with 2-3 pod clusters per leaf axil, erect plant type and matures in 65 to 67 days. It escapes drought and YMV
CZM-1	1999	5.0-6.0	It is a semi-spreading dual purpose variety matures in 72 to 75 days and shows field resistance to YMV
RMO-435	2002	5.5-6.0	Erect, short duration variety matures in 64 to 68 days, high protein (27%) content
CAZRI Moth-2	2003	10.0-12.0	Only variety produced through hybridization (RMO-40 × Jadia). Erect growth habit with good podding
RMO-423	2004	5.5-6.0	Short duration high-yielding variety maturing in 67 to 70 days, resistant to YMV, has good fodder value
RMB-25	2004	6.0-7.0	Early maturing (67 days), multi-clustered, semi-spreading, field resistance against YMV, root rot, leaf crinkle virus and bacterial lead spot as well as distinct resistance against jassids and white flies
RMO-257	2005	5.0-5.5	Early maturing (62 to 67 days), moderately tolerant to YMV, leaves are shallow lobed with 2 to 3 pod clusters per leaf axil
CAZRI Moth-3	2005	5.5-7.5	Erect, bears pods heavily and early maturing (62 to 64 days), drought tolerant and escapes YMV
RMB-2251	2016	5.0-6.0	Erect with 3 to 5 branches, suitable for mixed cropping, fodder remains green upto maturity, early maturity (63 to 67 days), escapes terminal drought

Plate 2. Moth bean varieties popular in the arid regions

at that time long duration spreading type varieties suitable for fodder and grain were released viz., Type 1, Type 2 and Baleshwar 12 having maturity of 100 to 120 days. These varieties were spreading types covering ground as mat and were selections from natural habitat. Further sincere and deliberate efforts on genetic improvement of this crop led to development of varieties of 80 to 90 days maturity like Jadia, Jwala and IPCMO-912, which performed well under normal rainfall distribution ranging from 250 to 400 mm in 4-5 rain events.

In the recent years, changing climate scenario offers fewer rain events with longer dry spells affecting crop growth and production of released varieties adversely. Fortunately, number of early maturing dwarf mutants were recovered and released as varieties 1990 onwards. A number of varieties were developed through mutation (RMO-40, FMM-96, RMO-225, RMO-257, RMO 423, RMO-435, CZM-1, CZM-3 and RMO-2251); these mutant varieties having 60 to 70 days maturity and other improved varieties were developed mainly at CAZRI, Jodhpur and SK Rajasthan Agricultural University, Bikaner (Table 3; Plate 2). The variety CZM-2 developed by CAZRI is gaining popularity and in recent years covered more than 30,000 ha area in the arid regions. Regular indents were received from national or state agencies for production of breeder seed of CZM-2.

Cluster bean

Cluster bean (*Cyamopsis tetragonoloba*) commonly called *guar* is another important crop that has evolved and adapted to hot arid and semi-arid conditions and is recognized as a cash crop for industrially valuable gum present in seed. India is the major producer of cluster bean accounting for about 80% of the total world production. In India it is grown in 4.65 m ha area with production of 2.7 MT. Rajasthan is major *guar* producing state contributing 87% in acreage and 81.5% in production; of which arid region of the state contributes high to national (82.6% acreage; 74.4% to production) and state (95.5% acreage; 91.2% to production) share.

It is grown for feed, fodder, vegetable, green manuring and for gum extraction from seeds. Boiled clusterbean seed is a traditionally preferred animal feed. In recent times cluster bean gum has become a source of novel food additive fiber for food stabilization. It has emerged as the most important agro-chemical, which is non-toxic, eco-friendly and generally recognized as safe (GRAS) by FDA. It has several diversified uses in textile and paper industry, food processing, cosmetics, mining, pharmaceutical, explosives, petroleum, well drilling, oil industries, photography, refining etc.

Production technology: Cluster bean grows well under a wide range of soil types, however, it performs best on well drained sandy loam to loam soils. First fortnight of July is the optimum period for cluster bean sowing. Unbranched and early maturing varieties were sown at 30 cm row spacing, whereas branched medium duration varieties were sown at 45 cm row spacing. A seed rate of

Table 4. High-yielding varieties of cluster bean released for cultivation in arid regions

Varieties of cluster bean	Year of release	Yield (q/ha)	Special characters
RGC-936	1991	9.0-11.5	Branched, pubescent, bushy with serrated leaf margins, bears white flowers, early maturing (85 to 90 days), seeds are pinkish in colour, small seeded (2.9 to 3.1 g/100 seeds), tolerant to bacterial blight
HG-365	1998	18.0-20.0	Pubescent, branched, short stature, medium and serrated leaves, suitable for early as well as late sown conditions, matures in 90 to 95 days
HG-563	2001	18.0-20.0	Pubescent with smooth leaf margin, mature in 85 to 100 days, flowers light pink in colour, brisk podding behavior
RGC-1066	2006	10.0-14.0	Unbranched single stem, high yielding, suitable for intercropping and mixed cropping, pink flowers, flowering takes 35 to 37 days, leaves are broad, pubescent with smooth leaf margins, seeds light pink, round and bold (3.38 to 3.65 g/100 seeds), matures in 97 to 105 days with synchronized maturity,resistant to bacterial blight and root rot
RGC-1055	2006	15.0-20.0	Profusely branched, leaves deeply serrated, pubescent and surface covered with whitish pubescent hairs, light pink flowers, medium maturity (96 to 106 days) and exhibits synchronized maturity, seeds light grey, round and medium bold (3.17 g/100 seed), tolerant to bacterial blight and root rot diseases
RGC-1038	2009	12.0-15.0	Branched, medium tall (60 to 75 cm), pubescent with serrated leaf margins bearing pink flowers, seeds dark gray colour, round and medium bold (2.95 to 3.6 g/100 seed), flowers in 30 to 42 days and maturing in 95 to 105 days, with synchronized maturity
HG-2-20	2010	15.0-20.0	Pubescent leaves with serrated leaf margins, early flowering maturity and bold-seeded, moderately resistant to blight and root rot
RGC-1033	2011	15.0-20.0	Branched, leaves hairy, dark shiny and non-serrated, pink flowers, seeds round and whitish, medium bold (3.07 g/100 seeds), resistance to major diseases and insect pests.

Plate 3. Cluster bean varieties popular in the arid regions

15 to 20 kg ha^{-1} is appropriate depending upon the plant type, sowing time, seed size and soil type. Being a leguminous crop, it requires a starter dose of 15 to 20 kg nitrogen (N) and 30 to 40 kg phosphorus (P) for better growth. One hoeing-cum-weeding operation 25-30 days after sowing is highly recommended to keep the crop weed free. Post-emergence application of weedicide Imazethypr @ 50 g active ingredient (a.i.) per hectare is effective in controlling weeds in cluster bean.

Cluster bean can be affected by bacterial leaf blight, *Alternaria* leaf spot, root rot and wilt depending on weather conditions. Bacterial leaf blight is an important disease, intra-veinal spots which are round, water soaked or oily in appearance and enlarge to cover whole leaf surface are observed. Seed treatment with 100 ppm streptocycline followed by foliar application of streptocycline (150 ppm) and Blitox (0.2%) can control the disease effectively. Root rot is another serious disease causing seedling mortality at early as well as later stages. To prevent root rot crop rotation with non-legume crops and seed treatment with systemic fungicide is the most effective measure.

Improved varieties: Systematic efforts for cluster bean improvement were initiated in 1960s and more than 40 varieties were developed and released by various research organizations for fodder, seed, vegetable and dual purposes. Characteristics of promising varieties in seed chain are given in Table 4; Plate 3.

Seed purpose watermelon

Watermelon (*Citrullus lanatus*) is mostly grown as a cash crop during summer under assured irrigation or on conserved moisture in Indo-gangetic plains for its edible fresh fruit. While in western parts of Indian Thar Desert it is grown for its highly priced nutritious seeds as a mixed crop under rainfed conditions with pearl millet and cluster bean to minimize the risk of crop failure. Watermelon seed price ranges from ₹ 50.00 to 80.00 kg^{-1} in local market and hence provides extra income to the farmers. The seeds of watermelon after removal of hull are in great demand for culinary purpose besides household use. Watermelon seed contains approximately 18 to 20% protein, and 25 to 30% oil with 30 to 40% saturated fatty acids and 60 to 70% unsaturated fatty acids. Keeping in view the high quality oil content, genetic improvement work for seed yield of *matira* was initiated to provide economic support to farmers. Recently two varieties exclusively meant for seed purpose were identified (Table 5, Plate 4).

The performance of improved genotypes was evaluated at selected farmers' field under mixed cropping with cluster bean which gave 135 kg ha^{-1} seed yield than local genotypes (50 kg ha^{-1}) besides 185 kg seed yield from main crop (cluster bean) and provided extra income of ₹ 3,750.00 ha^{-1}from watermelon seed.

Table 5. Characteristics of improved varieties of seed purpose watermelon

Variety of water melon	Year of release	Yield (q ha^{-1})	Characteristics
SKNK-1102 (Gujarat Kalingada 2)	2016	3.0-4.0	Fruit yield ranges from 90 to 100 q ha^{-1} with 4 to 5 fruits per vine,round fruit
CAZJK-13-2 (CAZRI Kalingada 1)	2018	4.0- 6.0	Produces 5-6 elliptical fruits per vine, yield ranges from 100 to 120 q ha^{-1}, white flesh and black seeds

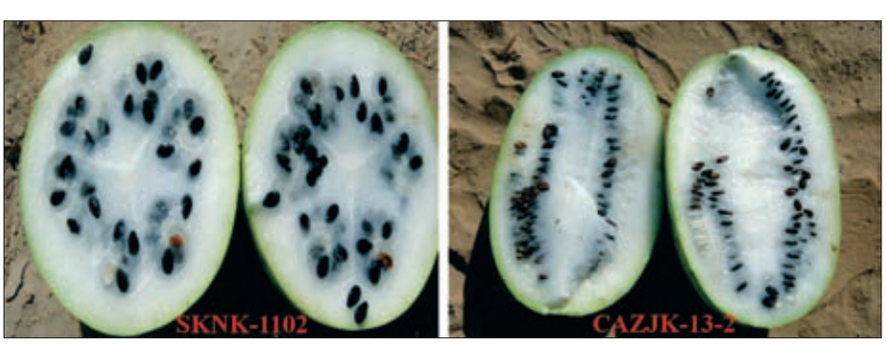

Plate 4. Improved genotypes of seed purpose watermelon

SUMMARY

Crops like pearl millet, moong bean, moth bean and cluster bean are integral part of the arid agricultural system. Pearl millet being the key fodder and grain crop has high acreage; early hybrid varieties are available which suits well under limited moisture and high temperature stress. Moong bean and moth bean are essential for sustainability and nutrient replenishment in nutrient poor soils of the region, though the crop acreage of moth bean is decreasing over the years which seem replaced by moong bean. Cluster bean occupied the place of an industrial cash crop for its valuable gum present in seed. India being the leader in cluster bean gum production, supports the sustainable demand from arid region. Varieties contributed significantly in increasing the yield and productivity of these crops in the region.

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