Indian Journal of Plant Sciences ISSN: 2319–3824(Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jps.htm
2015 Vol. 4 (4) October-December, pp.1-9/Manga et al.
Review Article

ADAPTATION AND SELECTION OF CROP VARIETIES FOR HOT ARID CLIMATE OF RAJASTHAN

***Manga V.K., Aravind K. Jukanti and Bhatt R.K.**
Central Arid Zone Research Institute, Jodhpur 342 003
**Author for Correspondence*

ABSTRACT
Arid region occupies nearly 3,17,090 sq km area in India, of which 2,46,790 sq km is hot arid region. About 80% of the hot arid area falls in the eleven districts of Rajasthan. These areas are characterized with low, erratic rainfall with high coefficient of variation and high mean maximum temperatures. Soils are mostly sandy with a low organic matter content (0.1 to 0.45 per cent) and with poor moisture holding capacity and high infiltration rate of 9 cm/hour. Crop plants suited to arid regions are those that survive and produce in spite of arid/dry conditions. Sorghum and pearl millet are traditionally grown as rainfed crops mostly in environments characterized by a combination of the above listed stress factors, which become too marginal and unproductive for maize. Sorghum is a drought tolerant species, and pearl millet is even more drought tolerant with higher water use efficiency than sorghum. Similarly, pearl millet is even more salt tolerant than sorghum and is the second most salinity tolerant major cereal after barley. Pearl millet is better adapted to dry nutrient deficient soils and is thus cultivated under extreme harsh conditions of high temperature, low erratic rainfall and on soils with poor water holding capacity. It also has strong deep root system and short life cycle and can grow rapidly when moisture is available. As a result, it can survive and reliably produce small quantity of grain where mean annual precipitation is as low as 250 mm as compared to minimum water requirement of 400 mm for sorghum and 500-600 mm for maize. India is the largest producer of pearl millet, both in terms of area (9.3 m ha) and production (7.97 m t). Though a large number of pearl millet hybrids and some open pollinated varieties have been released for cultivation in arid regions, genetic differences in maturity and drought tolerance make some cultivars more suitable for dry regions. Early maturing cultivars escape terminal drought, making these more suitable for regions having extreme arid conditions, like western Rajasthan, parts of Gujarat and Haryana. Besides pearl millet, legumes are also cultivated in the arid western Rajasthan. These are moth bean (*Vigna aconitifolius*), mung bean (*Vigna radiate*), cluster bean (*Cyamopsis tetragonoloba*), horse gram (*Macrotyloma uniflorum*) and cowpea (*Vigna unguiculata*). Of these moth bean, guar and horse gram are highly drought tolerant and a number of early maturing varieties for cultivation in the arid regions have been identified. Climate change is occurring due to global warming and it is estimated that average temperature of the air above earth's surface would rise by 1.4 to 5.8°C over the next 100 years. This will affect climate sensitive sectors like agriculture. For mitigating the effects of climate change**,** there is a need to develop heat tolerant, early maturing, drought tolerant, salt tolerant and disease, and insect pest resistant varieties. Pearl millet already has many of these traits that make it a well adapted crop for arid regions. Similarly, arid legumes which are adapted the harsh agroclimatic conditions of the arid region have several early maturing varieties. Further challenges of climate change can be tackled through development of varieties through biotechnology and genetic engineering approaches.

Keywords: *Arid Zone, Crop Varieties, Adaptation, Climate Change*

INTRODUCTION
Drought is the most yield limiting abiotic stress in hot arid region. Plants have evolved that are capable of living and reproducing in arid, semi-arid, and even desert regions. However, as aridity increases, fewer and fewer species are adapted, and the potential biomass is reduced. In such regions the potential evaporation of water from the land exceeds the rainfall and the availability of water to produce agricultural crops is restricted. Plants of arid regions are adapted to aridity by several mechanisms. There are plants with a short life cycle that can germinate, grow, and produce during a very short period of

available moisture, plants with deep or extensive root systems which have the ability to gather water over a wide area, plants which can store water in their tissues and release it very slowly, plants that are protected from water loss by wax or other impediments, plants with very small or narrow leaves, thus reducing water loss and plants in which the tissues themselves can withstand much desiccation without dying. Crop plants in arid regions may have any or a combination of such mechanisms. Another problem in the arid region is of high temperatures. Heat is principally received from the sun. High temperatures during germination cause seedling mortality leading to low plant population and at flowering causes abortion of flowers, resulting in direct reduction of seed number leading to reduced yield.

Arid Regions in India

Arid regions occupy nearly 3,17,090 sq km area, of which 2,46,790 sq km is hot arid region and 70300 sq km is classified as cold arid (Krishanan, 1968). The hot arid zone is spread over the states of Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka and Andhra Pradesh. About 80% of the hot arid area falls in the eleven districts of Rajasthan. These areas experience an annual rainfall between 100 mm in the north-western sector of the Jaisalmer district to 450 mm in the eastern boundary of the arid zone in Rajasthan. It varies from less than 300 mm to 500 mm in the arid zone of Gujarat and from 200 to 450 mm in the Haryana-Punjab region. The year to year variability, represented by the coefficient of variation is very high in the western part of the arid zone of Rajasthan and Gujarat states. It varies from less than 40 per cent in the Sikar and Jhunjhunu districts to more than 70 per cent in western Jaisalmer and in the Barmer district. The arid region also experiences extreme temperatures. The mean highest day time temperatures vary between 36ºC and 42.9ºC in the east to 38.8ºC and 45.5ºC in the western most part of the arid region (Rao and Singh, 1998). Maximum surface soil temperatures reach beyond 62 ºC during May and June. High solar incidence of 450 to 500 calories per cm^2 per day and wind velocity of 10 to 20 km per hour results in high PET (6 mm/day) and consequent high mean aridity index of 78 per cent. Low erratic rainfall combined with extreme temperatures results in frequent crop failures. This considerably affects the agricultural economy of the arid region. Soils of arid western Rajasthan are mostly sandy with a low organic matter content (0.1 to 0.45 per cent) and with poor moisture holding capacity and high infiltration rate of 9 cm/hour. Soil salinity and alkalinity to the extent of 45 per cent of the unirrigated area and surface crust formation after kharif sowing, following light showers, complicates the situation (Singh *et al.*, 1974).

Crop Variety Selection and Adaptation

Crop plants suited to arid regions are those that survive and produce in spite of arid/ dry conditions. These plants vary in ability to tolerate aridity and in yields under arid conditions. Selection the right crops for arid regions might involve considerable experimentation in a particular region. This is followed by the development of suitable production systems. Native systems, as crude as they may appear, usually represent the accumulated wisdom of centuries of experimentation. Improvement in these systems requires the introduction of species already adapted to these stresses, and their further genetic improvement is likely to play a significant role in enhancing the crop productivity and stability.

Table 1: Drought tolerance of food crops

S. No.	Scientific Name	Common Name	Degree Of tolerance*
1	*Zea mays*	Corn	1.0
2	*Sorghum bicolor*	Sorghum	1.5
3	*Pennesitum americanum*	Pearl Millet	2.5
4	*Vigna aconitifolius*	Moth Bean	2.5
5	*Vigna radiata*	Mung Bean	2

**Rated from 0 (no tolerance) to 3 (high tolerance). Adopted from "Dryland Farming: Crops and Techniques for Arid Regions" by Randy Creswell and Dr. Franklin W. Martin 1993(revised 1998) pp 23, published by ECHO Staff*

Varieties which have performed excellent in irrigated or high rainfall areas generally fail to perform well under dry land conditions. Many attempts at dry land farming have failed, largely due to lack of recognition of the requirements for the variety selection. To survive and produce under harsh environments of arid region a variety should have, Short life cycle; drought tolerance; high temperature tolerance; high water use efficiency, capacity to grow under low fertility conditions and salt tolerance. Drought tolerance of some of the food crops is given in table 1.

Major Cereal Crops

Sorghum and pearl millet are grown in the arid and semi-arid tropical regions, where soil surface temperatures can rise above 60ºC, adversely affecting germination and seedling survival, leading to poor crop stand. Seedlings of some sorghum genotypes surviving at soil surface temperatures as high as 55 ºC have been reported (Peacock, 1982). Pearl millet has been found to be even more heat tolerant than sorghum with several genotypes surviving at as high as 62ºC of soil surface temperature (Peacock *et al.*, 1993). Pearl millet is gaining popularity as a summer crop (because of high yield in summer season) in parts of Gujarat, Rajasthan, Maharashtra, Tamil Nadu and Uttar Pradesh. During summer season, this crop experiences high air temperatures exceeding 42ºC in parts of Gujarat and Rajasthan. High temperatures during flowering can lead to poor seed setting, resulting in poor grain yield. This has prompted the development of pearl millet varieties tolerant to high temperatures during flowering. Thus conditions under which sorghum and pearl millet are traditionally grown as rainfed crops, mostly in environments characterized by a combination of the above listed stress factors, become too marginal and unproductive for maize.

Table 2: Adaptive features of sorghum and pearl millet

Adaptation trait	Sorghum	Pearl millet
Drought tolerance	Higher than maize	Higher than sorghum
Water-Use-efficiency	Better than maize	Better than sorghum
Seedling heat tolerance	Higher than maize	Higher than sorghum
Reproductive heat tolerance	Higher than maize	Higher than sorghum
Crop maturity	90-130 days	62-95 days

Sorghum is a drought tolerant species, and pearl millet is even more drought tolerant with higher water use efficiency than sorghum (table 2). When frequently irrigated, water use efficiency of sorghum and pearl millet was comparable to maize, but as number of irrigations reduced and severe stress situations emerged, pearl millet becomes most water use efficient crop (table 3).

Table 3: Water use efficiency of Sorghum, pearl millet and maize

Crop	Dry matter (kg/ha/mm water)		
	Seven irrigations	Four irrigations	Two irrigations
Sorghum	15.4	16.4	14.0
Pearl millet	14.6	13.8	17.9
Maize	15.0	12.8	11.0

Source: Singh and Singh (1995)

Sorghum is moderately tolerant to soil salinity and even more salt tolerant than maize (Mass, 1985). Pearl millet is more salt tolerant than sorghum and is the second most salinity tolerant major cereal after barley. Also much larger genetic variability for whole plant response to soil salinity has been reported in pearl millet (Ashraf and McNeilly, 1987; Krishnamurthy *et al.*, 2007). Large variability for salinity tolerance has been detected and salinity tolerant germplasm and improved populations and breeding lines have been identified (Ramesh *et al.*, 2005; Kulkarni *et al.*, 2006). Further pearl millet is better adapted to dry nutrient deficient soils and is thus cultivated under extreme harsh conditions of high temperature, low erratic rainfall and on soils with poor water holding capacity. It also has strong deep root system and short life cycle and can grow rapidly when moisture is available. As a result it can survive and reliably produce small quantity of grain where mean annual precipitation is as low as 250 mm as compared to minimum water requirement of 400 mm for sorghum and 500-600 mm for maize.

India is the largest producer of pearl millet, both in terms of area (9.3 m ha) and production (7.97 m t), with an average productivity of 856 kg ha $^{-1}$. Rajasthan constitutes about 50% area and 42% of production of pearl millet in the country. More than 75 per cent of area under pearl millet occurs in western Rajasthan. Since the release of first hybrid in pearl millet HB-1 in 1965, more than 125 hybrids and varieties have been developed.

Most of the hybrids developed performed better and increased productivity in areas with reliable good rainfall but had little impact on the productivity in poor environments. This is because most of these hybrids were developed elsewhere and did not possess the adaptation and desired characteristics required for arid areas consequently could not make significant impact.

Though a large number of pearl millet hybrids and some open pollinated varieties have been released for cultivation in arid regions, genetic differences in maturity and drought tolerance make some cultivars more suitable for dry regions.

Early maturing cultivars escape terminal drought, making these more suitable for regions having extreme arid conditions, like western Rajasthan, parts of Gujarat and Haryana. A list of hybrids and open pollinated varieties recommended (Manga and Kumar, 2011) for cultivation in arid areas is given in table 4.

Table 4: Hybrids and open pollinated varieties of pearl millet for arid areas of Rajasthan, Gujarat and Haryana

S. No.	Cultivar	Year Released	Days to 50% flowering	Remarks
1	HHB 60	1988	44	Early maturing, tolerant to high temperature, salinity, and drought
2	HHB 67	1990	44	Earliest maturing hybrid, drought escape, suitable for multiple and intercropping system
3	HHB 68	1993	45	Early maturing, suitable for multiple and intercropping system
4	ICMH 356	1993	48	Early maturing, drought escape as well as drought tolerant, downy mildew resistant and stable yield across environments
5	RHB 121	2001	47	Early maturing, downy mildew resistant, drought tolerant, bristled panicle, tolerant to lodging
6	PB 106	2001	47	Early maturing, drought tolerant, stay green stover till harvest
7	GHB 538	2005	47	Early maturing, escapes drought, drought tolerant and downy mildew resistant
8	HHB 67-2	2006	42	Very early maturing, escapes terminal drought, downy mildew resistant. Higher grain yield, and better fodder quality as compared to HHB 67
9	RHB 177	2011	44	Early maturing, medium tall, cylindrical bristled earheads, resistant to downy mildew.
10	RAJ 171	1992	53	Medium maturity, downy mildew resistant and drought tolerant, good quality fodder
11	PUSA 383	2001	48	Medium early, resistant to lodging, tolerant to moisture stress, suitable for rainfed and irrigated conditions
12	CZP 9802	2002	48	Early maturity, drought tolerant, better quality fodder
13	PUSA 443	2009	44	early maturing and fast growing pearl millet composite variety, highly resistant to downy mildew disease and suitable for moisture stress condition

Review Article

Legumes

Moth bean (*Vigna aconitifolius*), mung bean (*Vigna radiate*), cluster bean (*Cyamopsis tetragonoloba*), horse gram (*Macrotyloma uniflorum*) and cowpea (*Vigna unguiculata*) are the major leguminous crops grown in the hot arid climate of western Rajasthan. Mung bean and moth bean are drought tolerant, the former showing escape mechanism due to short growth and the latter showing resistance right from germination to maturity. Moth bean is highly drought and heat tolerant. It is characterized with trailing and spreading prostrate growth habit, which may help prevent early depletion of soil moisture and its fertility. This legume is the ultimate choice of the marginal and sub-marginal farmers for realization of sustained production under extreme hostile and harsh agro-climatic situations. The crop is grown on plain lands and on sand dunes and also in different combinations with crops, trees, fruit crops and grasses. It is used for different purposes including food, fodder and also as a green manure crop. Selection and evaluation of germplasm has yielded in identifying better performing lines, but most of these were spreading types with medium-late maturity, not suitable to arid regions. Later, mutation breeding efforts resulted in development of Maru Moth-1 and RMO-40. RMO-40 was a short duration variety (60 days), also formed the future source for breeding erect and early maturing types. Erect varieties with upright branching behavior are the most desirous attributes for realizing high yields. Mutation breeding also identified other early maturing lines that showed lesser incidence of YMV than the traditional varieties. CZM-32 and CZM-18 are mutant lines that flower in 28 days and mature in about 63 days with good yield potential (780 kg/ha; Kumar, 2002). Similarly CAZRI Moth-1, a semi-erect type has in built resistance to YMV (Kumar, 2001). CAZRI Moth-3, CAZRI Moth-2, RMO-45, RMO-40, and RMO-225 are other high yielding varieties. Improved moth bean varieties suited for arid regions are presented in Table 5.

Table 5: Improved varieties of moth bean and cowpea*

S. No	Average Rainfall (mm)	Varieties	Maturity (days)	Important Characters
Moth bean				
1	170-200	FMO-96	58-59	Released for Rajasthan and suitable for intercropping
		CAZRI Moth-3	60-62	Suitable for extreme drought
2	200-250	RMO-40	61-62	Suitable for extreme drought
		RMO-225	64-65	Suitable for low rainfall and field tolerance to YMV
3	250-300	CAZRI Moth-3, RMO-435, FMO - 96, RMO-40	60-65	Suitable for Rajasthan (RMO-435)
4	300-350	CAZRI Moth-2	66-68	First variety from hybridization, suitable for high inputs and better soils
		RMO-435	64-65	-
		RMO-257	63-65	Suitable for intercropping and dual purpose
5	350-450	CAZRI Moth-1	73-75	Good source of fodder

** Adapted from Kumar and Rodge (2013)*

Mung bean though not an arid legume but due to short growth period 65-70 days, characterised with drought escape mechanism, as a result it is a potential arid pulse having yield potential higher than moth bean. Promising varieties of mung bean suitable for arid western Rajasthan are S-8, K 851, RMG 62 and RMG 268, SML 666, RMG 344 and Gangotri.

Another important legume crop of high commercial importance is cluster bean. It is a high value crop due to the growing importance of 'guar gum' obtained from the endosperm. Guar is a drought hardy crop and suitable to regions with limited availability of water throughout its growing period and is characterized with high capacity to recover once stress is relieved. It is an important legume of arid and semi-arid regions suitable for different kinds of cropping systems. Improved high yielding varieties of guar like RGC 1002, RGC 1071, RGC 1084, HGS 365, and HG 884 have higher yields (1000-1400 kg/ha) compared to traditional varieties (800-900 kg/ha). Improved short duration varieties are: HG 365, HG 563 and HG 884.

Table 6: Suitable cluster bean varieties for different regions*

S. No	Average Rainfall (mm)	Varieties	Maturity (days)	Important Characters
Rajasthan				
1	170-200	RGC-936	85-90	Drought hardy variety
		HG-365	80-85	High viscosity (3500 cP)
2	200-250	RGC-563	85-90	Suitable to low rainfall areas; improved gum content
3	250-300	RGC-1066	100-105	Suitable for Rajasthan and also suited to mechanical harvesting
4	300-350	HG-884	95-100	High gum content (30-31%)
5	375-400	RGC-1002, RGC-1017	95-105	Moderately resistant to BLB and PM (RGC-1017)
6	400-450	RGC-1038	95-100	Suitable for summer cultivation
		RGC-1031	105-108	Field tolerant to BLB and ALB
Haryana				
1	200-250	HG-365, HG-563	80-85	-
2	250-350	HG-884, HG-2-20	95-112	-
Gujarat				
1	-	HG-563	80-85	-
		GG-2	95-100	Moderately resistant to BLB
2	-	HG-365, RGC-936	80-90	-

** Adapted from Kumar and Rodge (2013)*

Significant improvement in gum content has not been made due to certain genetic constraints, but some varieties having relatively high viscosity (HG 365, 3000-4000 cP) and gum content (HG 884, 31.41%) have been developed (Kumar and Rodge, 2012).

Cowpea is another legume suitable for the arid regions due to its early maturity, moderate salt tolerance and multipurpose usage. It is the only arid legume which is spread wide across the continents and growing well in arid and semi-arid regions. It is characterized for initial fast growth, with drooping leaves, hence can even suppress weeds growth initially. Early germplasm evaluation efforts have resulted in development of several promising varieties. But efforts to develop drought tolerant varieties with high yield potential have been limited. In cowpea compact growth with erect stem are important traits for breeding. Improved short (RC 101; 60-62 days) and medium duration (GC-3, 90-95 days and GC-5; 75-80days) varieties have been developed that are suitable for arid regions of Rajasthan and Gujarat. Similarly high protein varieties have also been developed for cultivation (Co [CP 7], 28.1% and PGCP, 28.0%). Improved cowpea varieties suited for arid regions are presented in Table 7.

Table 7: Improved varieties of cowpea*

Cowpea				
1	-	RC-101	60-62	Synchronized growth and suited for mechanical harvesting; escapes CYMV; suited for Rajasthan
2	-	V-240	90-95	Dual purpose; suited for Rajasthan
3	-	GC-5	75-80	Large seeds; suited to kharif and summer; suited for Rajasthan
4	-	GC-3	90-95	For Gujarat
5	-	GC-5	75-80	For Gujarat

** Adapted from Kumar and Rodge (2013)*

Horse gram is probably the toughest annual legume that can be grown on poor soils, encountered with much adverse conditions, which may not allow other crops to grow. It is cultivated on wide range (200 – 700 mm) of rainfalls on a variety of soils. Under harsher environmental situations and resource constraints horse gram is known as the immediate and ultimate choice of poor farmers of arid regions. Improved varieties of horse gram for arid regions are given in table 8.

Table 8: Horse gram varieties suitable for arid areas

S. No	Varieties	Maturity (days)	Yield Kg/ha	Important Characteristics
1	Maru Kulthi	90-95	700-800	Released in 1989 for all India. Selected from local material, and is semi-spreading type with light brown seeds
2	AK 21	85-90	650-750	Early maturing variety, high yield potential, compact, synchronized growth habit
3	AK 42	90-95	600-850	Medium late in maturity, high yield, suited to moderate rainfall areas. Brick red grain colour, straight plant growth

Adapted from Kumar (2007)

Agriculture in India is a source of livelihood for 65 per cent of the population and contributes to 27 per cent of the GDP, adverse impact on agriculture could have serious effect on the economy of the country besides an impact on food security and health. It is estimated that average temperature of the air above earth's surface would rise by 1.4 to 5.8°C over the next 100 years. Increased temperatures resulting from global warming would cause quick moisture loss resulting to shortage of moisture availability period and increase in dry/saline areas. It is estimated that a rise of one degree Celsius could reduce yields of major food crops by three to seven per cent in India, with higher losses in rabi season crops. The growing period for crops in rain-fed areas, which account for two-thirds of India's cropland, could also reduce. Changes in temperature and relative humidity will also have effect on the geographical distribution of insect pests and diseases, besides affecting the equilibrium of the host pathogen interactions and the rate of development of pathogens.

Future Trust Areas to Develop Climate Resilient Crop Varieties

Climate change is projected to have significant impact on agriculture. Agriculture is very much dependent on various facets of climate including temperature, rainfall, carbon dioxide content and their interactions. Therefore, it is necessary to develop crop varieties that are adapted to this scenario otherwise the farmers will suffer. The advancements in biotechnology and genomics should be efficiently utilized in developing improved cultivars. Genomics (including marker technology) has been making rapid progress even among often neglected cereal and legume crops. Linkage maps have been developed in several cereal and legume crops that could be effectively utilized in related crops if no data is available. Additionally, several QTLs have been identified for important traits including yield, disease tolerance, and drought tolerance. QTLs for these said traits have also been identified in arid region crop like pearl millet. The identified QTLs could be utilized in backcross breeding program to transfer the desired traits into an adapted cultivar through marker assisted selection (MAS) and breeding (MABC). MAS and MABC is being utilized in several crops including pearl millet, mung bean, chickpea and other legumes that are being grown in arid regions. In addition to these the modern breeding strategies for developing climate-resilient crop varieties, includes high-density genotyping, whole genome resequencing, high-throughput and precise phenotyping, doubled haploids (DH), genomics-assisted breeding (e.g., genome-wide association studies, breeder-ready marker development, rapid-cycle genomic selection, marker-assisted recurrent selection), and crop modeling are particularly important.

Another important area of crop improvement is genetic engineering. This is particularly important for the improvement of those traits that are not amenable for conventional breeding (Jauhar, 2006). Model species like *Arabidopsis thaliana* could be a good source of alleles for improving crops in stressful environment, ex. DREB1, DREB2 and HARDY (HRD) genes (Ortiz *et al.,* 2007; Karaba *et al.,* 2007). These have been utilized in improvement of response to drought and water use efficiency in rice. Another area of particular importance is the raising CO2 levels and therefore breeding crops that maximize the advantages of rising crops is required. Ainsworth *et al.,* (2008) has suggested the use of Rubisco from non-green algae that could dramatically increase C gain at the current and elevated levels of CO2. Identification of a gene, transfer and development of an improved cultivar is a tedious process and it requires proper management and careful planning. The development includes several steps including proof of concept, development phase and a regulatory phase. But definitely genetic engineering is a potential answer to deal with the changing climate for better agriculture.

REFERENCES

Ainsworth E, Rogers A and Leakey ADB (2008). Targets for crop biotechnology in a future high-CO2 and high-O3 world. *Plant Physiology* **147** 13-19.

Ashraf M and McNeilly T (1987). Salinity effects on five cultivars/lines of pearl millet [*Pennisetum americanum* (L) Leeke]. *Plant Soil* **103** 13-19.

Jauhar PP (2006). Modern biotechnology as an integral supplement to conventional plant breeding: The prospects and challenges. *Crop Science* **46** 1841-1859.

Karaba A, Dixit S, Greco R, Aharoni A, Trijatmiko KR, Marsch-Martinez N, Krishnan A, Nataraja KN, Udayakumar M and Pereira A (2007). Improvement of water use efficiency in rice by expression of HARDY, an Arabidopsis drought and salt tolerance gene. *Proceedings of the National Academy of Sciences (USA)* **104** 15270–15275.

Krishanan A (1968). Distribution of arid areas in India. *Proceedings of International Geographical Congress Symposium on Arid Zone,* Central Arid Zone Research Institute, Jodhpur 11-19.

Krishnamurthy L, Serraj R, Rai KN, Hash CT and Dakheel AJ (2007). Identification of pearl millet [*Pennisetum glaucum* (L.) R.Br.] lines tolerant to soil salinity. *Euphytica* **158** 179-88.

Kulkarni VN, Rai KN, Dakheel AJ, Ibrahim M, Hebbara M and Vadez V (2006). Pearl millet germplasm adapted to saline conditions. *International. Sorghum Millets Newsletter* **47** 103-6.

Kumar D (2001). CAZRI Moth-1: a new variety of moth bean for arid and semi-arid areas. *Indian Farming* **11** 15-16.

Kumar D (2002). New concepts of moth bean improvement. In: *Moth bean in India,* edited by Kumar D and Singh NB (Scientific Publishers) Jodhpur, Rajasthan, India 31-48.

Kumar D (2007). *Production Technology for Horse Gram in India* (Evergreen Printers) Jodhpur, Rajasthan, India 20.

Kumar D and Rodge AB (2012). Status, scope and strategies of arid legumes research in India- A review. *Journal of Food Legumes* **25** 255-272.

Manga VK and Kumar Arun (2011). Cultivar options for increasing pearl millet productivity in arid regions. *Indian Journal of Fundamental and Applied Life Sciences* **1**(2) 200-208.

Review Article

Mass EV (1985). Crop tolerance to saline sprinkling water. *Plant Soil* **89** 273-84.
Ortiz R, Sayre KD, Govaerts B, Gupta R, Subbarao GV, Ban T, Hodson, D, Dixon JM, Ortiz-Monasterio JI and Reynolds M (2008). Climate change: Can wheat beat the heat? *Agriculture, Ecosystems & Environment* **126** 45-58.
Peacock JM (1982). Response and tolerance of sorghum to temperature stress. In: *Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum,* Patancheru, Andhra Pradesh, India; ICRISAT 143-59.
Peacock JM, Soman P, Jayachandran R, Rain AU, Howarth CJ and Thomas A (1993). Effects of high soil surface temperature on seedling survival in pearl millet. *Experimental Agriculture* **29** 215-225.
Ramesh S, Reddy BVS, Sanjana Reddy P, Hebber N and Ibrahim M (2005). Response of selected sorghum lines to salinity-stress under field conditions. *International Sorghum Millets Newsletter* **46** 14-17.
Rao AS and Singh RS (1998). Climatic features and crop production. In: *Fifty Years of Arid Zone Research in India,* edited by Faroda AS and Manjit Singh, Central Arid Zone Research Institute, Jodhpur 17-38.
Singh BR and Singh DP (1995). Agronomic and physiological response of sorghum, maize and pearl millet to irrigations. *Field Crops Research* **42** 57-67.
Singh RP, Daulay HS, Prasad MVR and Singh HP (1974). Hungary drylands of western Rajasthan need a new technology. *Indian Farming* **23**(12) 5-6.

