Research Journal of Chemical and Environmental Sciences
Res J. Chem. Environ. Sci. Vol 11 [5] October 2023: 01-09
Online ISSN 2321-1040
CODEN: RJCEA2 [USA]
©Academy for Environment and Life Sciences, INDIA
Website: www.aelsindia.com/rjces.htm

REVIEW ARTICLE

Review on Climate Resilient Strategies to Mitigate Abiotic Stresses in Pulses

R.S. Choudhary[1], Ishwar Singh[2], Lekha[3] and N.L. Dangi[4]
[1]Associate Professor (Agronomy) &Senior Scientist & Head, KrishiVigyan Kendra, Sirohi
[2]Professor (Agronomy) &Director, Directorate of Extension Education, AU, Jodhpur
[3]Associate Professor (Entomology), Agriculture Research Sub Station, Sumerpur, Pali
[4]Associate Professor (Entomology), Agriculture Research Station, Sumerpur, Pali
(Agriculture University, Jodhpur, Rajasthan, India)
Corresponding author: agroudr2013@gmail.com

ABSTRACT
Climate change is evident worldwide due to exponential rise in atmospheric carbon-di-oxide (eCO_2) and temperature (eT). It leads to more complexity in achieving the sustainable food security. Grain legumes are the major sources of dietary proteins with multifaceted impact on ecosystem services. Being the C_3 crops, climate change (more specifically eCO_2) usually has positive impact on physiology and productivity of grain legumes as compared to C_4 cereal crops. Pulses, being rich in protein, minerals and vitamins, play a significant role in the nutritional security of Indian people, especially those below poverty line, who can ill-afford animal food products. However, per capita per day availability of pulses in India at present is about 45 g against the minimum recommended dose of 70 g/capita/day (Economic Survey, 2021-21). The productivity of pulses in India (~885 kg/ha) is very low as compared to other countries (2020-21). Biotic and abiotic stresses are the major barriers in realizing the yield potential, as about 87% of the area under pulses is rainfed and mainly confined to marginal and sub-marginal lands. Their cultivation in resource-scarce conditions exposes them to various abiotic and biotic stresses, leading to significant yield losses. Furthermore, climate change due to global warming has increased their vulnerability to emerging new insect pests and abiotic stresses that can become even more serious in the coming years.
Key words*: Abiotic stress, climate change, crop husbandry, pulses*

Received 10.06.2023 Revised 12.09.2023 Accepted 19.10.2023

INTRODUCTION

Only 9% of the world's agricultural area is conducive for crop production, while 91% is under stresses which widely occur in combinations. While losses to an extent of more than 50% of agricultural production occur due to abiotic stresses, their intensity and adverse impact are likely to amplify manifold with climate change and over exploitation of natural resources. Global food demand is predicted to grow by 70–85% as the population increases to over 9 billion people by 2050 [18]. A "next generation Green Revolution" is required to achieve future food security. India is the leading producer (25% of global production), consumer (27% of world consumption) and importer (14%) of pulses in the world. India has made remarkable progress in enhancing production of pulses during the past 15 years. During 2005-06, the total production of pulses in India was 13.38 million MT, which increased to 27.3 million MT during 2021-22. This shows an impressive growth of 91% or a compound annual growth rate (CAGR) of 4.42%. Grain legumes are nature's precious gift to mankind and often named 'poor man's meat' as these are rich in protein (16–50%), essential elements, dietary fibre (10–23%) and vitamins [43]. Apart from protein, grain legumes are store house of various nutritional components such as: carbohydrates, sugars, vitamins, more than 15 essential mineral elements and mono and polyunsaturated fatty acids [40]. Grain legumes play an important role in providing the ecosystem services. Biological nitrogen fixation (BNF) capacity, deep root systems, low input requirements, propensity to survive in problem soils and withstand abiotic stresses make grain legumes as a popular choice for farming community in the intensive cereal-based cropping systems [33].

During 2020-21, chickpea had a lion's share of 49.3% in the total pulses production. Chickpea (*Cicerarietinum* L.) is the 2ndmost important legume crop after common bean (*Phaseolus vulgaris* L.) [25, 67] and an economically beneficial protein-rich food legume. Among remaining pulses, pigeonpea contributed 16.2%, mungbean 10.3%, urdbean 9.3%, lentil 4.9% and other pulses 9.9%. During the past 15 years, the highest growth in production was observed for mungbean (178%), followed by chickpea (125%), urdbean (90%), pigeonpea (51%) and lentil (34%). Estimates indicate that India needs an annual growth rate of 4.2% in pulse production to ensure projected demand of 30 million tonnes by 2030. To meet this benchmark, constraints to production must be analysed and effective steps must be undertaken. The pulses have great potential to bear the vagaries of the changing climate, provided other crop management practices are strictly followed to harness achievable yields.

Presently, the impact of global warming can be seen worldwide. India has witnessed highly fluctuating weather conditions in the last decades [68]. It is evident that high temperatures have changed the rainfall pattern as well as distribution and have increased water scarcity. Data from last five decades (1967–2017) depicted an average rise of CO_2 concentration (ppm yr^{-1}) by 155% with the highest concentration during 2015 (3 ppm yr^{-1}) along with spike in global temperature by 0.85°C over the last century (IPCC, 2014). Surprisingly, the world witnessed a rise in global average temperature and atmospheric CO_2 concentration by 0.2 °C and 20% over the last five years (2015–19), respectively as compared to 2011–15 [70].

Drought stress is a serious situation for agriculture in the context of climate change and the ever-increasing world population [23; 63]. Extreme drought conditions reduce crop yields through negative impacts on plant growth, physiology, and reproduction [72, 5]. In the future, the shortage of water will increase drought-affected regions. Moreover, it will negatively impact those regions that have higher precipitation rates [44]. As per a Food and Agriculture Organization [21, 22]], climate change has put global food security more at risk; heightened the dangers of under nutrition in resource-poor regions of the world due to heat, drought, salinity, and waterlogging; and increased the threat of newly emerging diseases and insect pests. While assessing the impact of drought on crop yields, Kuwayama et al. [39] reported 0.1–1.2% yield reduction for corn and soybeans for each additional week of drought. According to Ambachew et al. [1], drought stress can cause 20–90% yield reduction in common bean, which in the worst scenario could go up to 100%. In other pulses, yield losses have been measured to the extent of 6–86% and 15–100% due to different abiotic and biotic stresses, respectively [56].

Constraints for Productivity of Pulses

The poor productivity of pulses in India is attributed primarily to poor spread of improved varieties and technologies, untimely and inadequate availability of quality seed of improved varieties and other inputs, water-stress due to dependence on rainfall, low and high temperature stress, vulnerability to pests and diseases and cultivation on marginal and sub-marginal land. These crops being grown as rainfed (87%) on marginal and sub-marginal lands are frequently prone to biotic and abiotic stresses. Choudhary [12] and Pooniya et al. [51] reported that yield gaps in pulses at research farms and farmer's field varied to the extent of 368–492 kg/ha in urdbean, 220–417 kg/ha in kidney bean (*Phaseolus vulgaris* L.), 477– 563 kg/ha in pigeonpea, 372–494 kg/ha in cowpea, 225–601 kg/ha in chickpea and 253–510 kg/ha in lentil. Among the abiotic stresses, drought and heat stress may reduce seed yields by 50%, especially in arid and semiarid regions **(Table 1)**.

Table 1. Abiotic and biotic stresses limiting productivity of major pulse crops in India

Crop	Season	Stress	
		Biotic	**Abiotic**
Chickpea	Timelysown	Weeds, *Fusarium* wilt,root rot, chick pea stunt	Low temperature, nutrient stress
	Earlysown	*Fusarium* wilt, root rot,blight, stunt,pod-borer	Terminal drought, salt stress
	Latesown	Weeds, *Fusarium* wilt, pod-borer	Terminal drought, cold, nutrient stress
Pigeonpea	*Kharif*-early	Weeds, *Fusarium* wilt, blight, pod-borer	Waterlogging, nutrient stress
	Medium late	Weeds, *Fusarium* wilt,mosaic, pod-borer complex	Cold, terminal drought, waterlogging
	Pre-*rabi*	Weeds, wilt, leaf blight, pod-fly	Cold, terminal drought
Mungbean	*Kharif*	Weeds, mosaic virus, sucking insect-pests	Pre-harvest sprouting, terminal drought
	Zaid	Mosaic virus, root and stem rot, stem Agromyza, sucking insect-pests stress	Pre-harvest sprouting, temperature, drought stress
	Rabi	Weeds, powdery mildew, rust	Terminal drought
Urdbean	*Kharif*	Weeds, mosaic and leaf curl virus, anthracnose	Terminal drought

	Zaid	Mosaic virus, root and stem rot, stem Agromyza	Pre-harvest sprouting, temperature, drought
Lentil		*Fusarium wilt*, root rot, rust	Moisture, temperature
Clusterbean		Weeds	Moisture and nutrient stress

Source: Reddy [57]

Legumes can adapt either positively or negatively under climate change depending upon internal physiological adjustment and crop husbandry practices. Indeterminate nature of legumes makes the task more daunting for climate scientists to ascertain the adaptation strategies or phenological triggers that empower legumes under changing climate. These heterogeneous and complex aspects needs to be addressed by experts considering single or sometimes multiple stressors like eCO_2, temperature or biotic or abiotic hassles through agronomical, physiological and microbiological studies. Therefore, comprehending the grow response and adaptation of various grain legumes to climate change is important and requires multi-disciplinary interventions to meet global food and nutritional security. The objective of this paper is to undertake exhaustive review on challenges associated with global climate change and to find out the prospects of grain legumes to consider as climate smart crop towards abiotic stresses.

Abiotic Stresses and their Effects on Pulses

Abiotic stresses are primarily unavoidable and are the most harmful factor concerning the growth and productivity of crops, especially under un-irrigated areas. The ability to tolerate effectively by challenging these stresses is a complicated phenomenon stemming out from various plant interactions occurring in the specific environments. Abiotic stresses are occurring naturally and agronomists can only think of mitigation strategies for these stresses under varied climatic conditions. Losses caused by various abiotic stresses in major pulses are given in Table 2.

Table 2. Yield loss in major pulses due to abiotic stresses

Crop	Abiotic stress	Yield loss(%)
Chickpea	Terminal drought	30–60
	*p*Hlessthan6.0	22–50
	Salinity(ESP>10)	Upto50
Lentil	Terminal drought	6–54
	Salinity(ESP>15)	Upto50
	*p*Hlessthan6.0	30–86
Fababean	Terminal drought	Upto70
Fieldpea	Terminal drought	21–54

Source: Kumar et al. [34]

Adaptation of extreme temperature stress

Exposure to extreme temperatures (chilling, freezing, or HT) causes detrimental effects on plant productivity and crop yields. The semiarid regions of the world are particularly vulnerable to the weather variability associated with climate change [2]. A mechanistic understanding of plant responses to HT, particularly when the stress is imposed at flowering, is crucial for the development of stress tolerant genotypes because plant reproductive organs are very sensitive to HT stress, [23, 54]. HT reduce pollen viability and shorten the grain-filling period, temperature increases of 3–4 °C are likely to cause crop yields to fall by 15–35% in Africa and Asia and by 25–35% in the Middle East [48]. Like HT, LT stresses such as chilling and freezing also severely impair seedling survival and lower crop yields worldwide. Several studies have shown new insights into the mechanisms by which plants perceive cold stress and how they transduce the LT signal to activate adaptive responses [42].

Response Mechanism to Abiotic Stresses in Plants

Plants are often exposed to different situations of abiotic stresses. In evolutionary terms, adapted organisms are those that have managed to modulate several response mechanisms in favor of their defence in order to overcome such stresses and return to normal basal metabolism. Importantly, these environmental factors severely limit agricultural growth and productivity. As an example, the increase in atmospheric CO_2 can trigger changes in the photosynthetic rate of plants, causing changes in the growth rate, which usually impacts positively overall biomass, but decreasing nutritional quality [65, 52]. Plants respond to stimuli caused by stress with distinct changes related to their development and physiology. In this context, many mechanisms like photosynthesis and gas exchange [9], cell death, changes in cell wall composition [64], nutrient translocation [17], transcriptional activity of genes, transposable elements [41], lipid signalling [34], metabolites, proteins [47], and antioxidant profile [13] can be changed during stresses. The physiological response mechanism for abiotic stresses occurs from a complex pathway of responses, starting with the perception of stress, which triggers a cascade of molecular events, ending at various levels of physiological, metabolic, and developmental responses [7].

Abiotic stress tolerance

Of the multitude of diverse abiotic and biotic stresses faced by plants in the field, water availability is widely accepted to be one of the most important constraints to crop yields. Drought stress alone is expected to limit the productivity of more than half of the earth's arable land in the next 50 years, competition for water between urban and agricultural areas compounding the problem. A number of papers describe the mechanisms that enable plants to withstand extremes of temperature [8, 10, 16-20, 29]. Taken together, the new information provided in these manuscripts increases current understanding of the biochemical and molecular basis of crop adaptation to abiotic stresses, highlighting promising candidate genes/enzymes that are targets for manipulation to improve the ability of plants to produce better yields under changing climate conditions.

Adaptive Traits in Pulses

Climate change can result in a wide range of abiotic stresses, such as drought, heat, cold, salinity, flood, and submergence, and biotic stresses, including increased attacks of pathogens and pests [32]. Therefore, breeding of adaptive traits is required for increasing the resilience of crops to current climate change conditions to help sustain productivity. Adaptive traits show their adaptive plasticity in changing environmental conditions and help crop plants survive and/or reproduce under biotic and abiotic stress conditions [14]. These adaptive traits can be agromorphological [28, 36], physiological, and biochemical [60, 4]. The reproductive stage substantially influences seed yield in crop plants. It has been reported that drought stress during the pod-filling stage leads to pod abortion and thus reduces the number of seeds per plant, whereas terminal drought at the early podding stage resulted in an 85% decline in seed yield of chickpea [49]. Thus, pod-filling ability can be targeted as an agromorphological trait under moisture-deficient conditions for developing drought-resilient cultivars. A number of physiological traits including leaf parameters, seed set, pod abscisic acid concentrations, and root traits have been shown to impart tolerance to drought in chickpea [11]. The role of sucrose infusion has recently been identified in the salt tolerance of chickpea [31]. Prince et al. [55] performed an innovative analysis to decipher the mechanisms that underpin drought tolerance in legumes and established the role of root xylem plasticity in improving water-use efficiency in soybean plants subjected to water stress.

Crop Husbandry Strategies

Most of the standard climate models predict rise in temperature across the regions where pulses are grown. To meet out these emerging challenges of climate change, there is a dire need for developing policy framework and strong institutional support to strengthen existing research system to combat adverse impacts of climate change, especially on dryland areas which account for 40% of the total food production of the country [3]. Pulses are climate smart since they simultaneously adapt to climate change and contribute towards mitigating its effects [21]. There are technologies available for stepping up the productivity and production levels of pulses under changing climatic scenario in the rainfed regions. The role of various management practices/measures vis-a-vis climate change and pulse production from mitigation point of view is given here:

Adopting diversification in practice

Under dryland conditions to reduce risk, diversification of cropping is especially important. Crops may differ in their response to a given environment and this difference can be used to reduce the risk associated with growing pulse crops. Mixed cropping or intercropping is an example of a successful approach to crop diversification with best possible configurations. Therefore, efficient utilization of resources are needed by increasing cropping intensities following inter- and multiple-cropping systems. Multiple-cropping systems, such as intercropping or crop rotations with pulses, have a higher soil carbon sequestration potential [21]. Therefore, alternate land-use systems such as alley cropping, agri-horticultural and silvi-pastoral systems are better way in stabilizing pulse production. This system withstands climate extremes as pulses are hardier than most crops and help to nourish the soil [22]. The different field conditions allow to achieve a better fit between the crop and the environment and to reduce the general probability of stress affecting the crop. Varietal diversification of a crop offers a better probability for reducing loss due to environmental stress as compared to growing a single variety only. For environmental stress conditions, varietal diversification is based mainly on differential phenology, primarily flowering date. A typical example is a transient frost or heat wave that is likely to occur around flowering time of the specific crop. Damage reduction can be achieved when the crop is sown to several varieties of different flowering dates. In temporal diversification, the purpose of setting a distinct planting date is to optimize crop development with respect to rainfall in rainfed agriculture. Similarly, higher rainfall intensities forecast during cropping season may prohibit planting in situ (under field condition) where certain contingency planning could help to compensate the productivity loss [53, 58].

Technology based on partial replacement of missing hills/ gaps through transplanting seedling to the minimum extent possible could serve as an alternative for realization of higher productivity and farm income in Indo-Gangetic Plains [53]. Similarly, furrow-irrigated raised bed (60 cm width FIRBs accommodating 2 rows) could be an effective land-configuration measure in conserving both soil moisture and enhancing productivity of chickpea and field pea. In case of terminal moisture stress, single irrigation at branching could be advocated for realizing higher yield and input use-efficiency [45].

Fallow and conservation tillage

The fallow system is designed to conserve soil moisture and improved availability of soil nutrients and the eradication of certain soil-borne pests. The benefit of fallow and conservation tillage in terms of increasing available soil moisture to the crop depends on soil water holding capacity, climate, and topography and management practices. Conservation tillage is the usual practice under dryland systems. Conservation tillage is basically meant to minimize tillage operations to conserve soil structure and to maintain ground cover by stubble mulch. These practices reduce water runoff and increase soil infiltration. Similarly, the conservation practices like zero/ minimum tillage practices with mulching have definite positive impact on pulses (chickpea) productivity in the Middle Indo-Gangetic Plains, especially in the seasons having low postrainy season precipitation [46].

In the existing agro-ecosystem of Indo-Gangetic Plains (IGP) where visible effects of extreme weather events (especially rainfall) were more evident, raised bed planting could provide a viable alternative to other land configurations for a remunerative pigeonpea–wheat system [61]. Similarly, in certain soils deep tillage was found very useful in improving soil-moisture storage, especially when hard soils or hardpans are a problem.

Maintaining adequate soil organic matter

Under changing climatic scenario, the soil organic carbon (SOC) is becoming a serious concern. The advanced agricultural practices have tremendous potential in sequestering carbon in crop land soils. In other words, several farming practices and technologies can reduce GHGs emission and prevent climate change by enhancing carbon storage in soils, thereby preserving both the existing soil carbon as well as reducing emission of all the greenhouse gases.

Important benefits of SOC in the low input agro ecosystems are the retention and storage of nutrients, increased buffering capacity, better soil aggregation, improved moisture retention, and increased cation-exchange capacity. Overall, optimum organic matter level in soils retain water and nutrients, which in turn are highly beneficial from pulse production point of view, which are usually grown in rainfed regions [22]. Study revealed that inclusion of pulses in the maize-based system and the organic nutrient-management system sequestered more organic carbon and maintained better soil health in Inceptisols of the Indo-Gangetic plains of India [68].

Reducing greenhouse gas emissions

Several reports have highlighted the potential of organic agriculture in reducing greenhouse gases (GHGs) emission. Organic system of pulse production increases soil organic matter levels through the incorporation of composted organic manures and cultivation of cover crops [62]. The inclusion of pulses in crop rotation reduces the need for fertilizer inputs. Pulses supply their own nitrogen and contribute nitrogen to succeeding crops [40]. Pulses helps in lowering emissions of GHGs due to lower fertilizer requirements [68]. Interestingly, legume rich feeds can curtail CH4 emission from livestock industries as it contains less fibre, faster rate of passage and contains condensed tannins and saponins which reduces cell wall digestion and modifies rumen methanogenesis [20]. Nitrous oxide emission also found to be lower from legumes (1.02 kg N_2O–N ha^{-1} $year^{-1}$) as compared to N fertilized cereals (2.71 kg N_2O–N ha^{-1} $year^{-1}$) [29]. Positive impact of reduced GHGs emission by grain legumes has been documented by Schwenke et al. [59]. However, exceptions do exist stating more N_2O emission in legumes than cereals [30, 50]. The possible reasons behind higher N_2O emission by legumes are faster decomposition rate of N-rich residues and denitrification of symbiotically fixed N within the nodule but, more extensive multi-location research must be conducted to get concrete evidences as it is highly influenced by management practices and local climatic conditions [6, 26].

Improved crop-specific practices

Agronomic practices such as tillage, sowing time, planting method, ridge-planting of kharif/ rainy-season pulses, crop geometry, plant population, nutrient and water management, seed treatment, weed management and plant protection have major impact on pulse productivity. Crop-specific agronomic practices hold tremendous scope to raise pulse productivity potential in water-stress region under changing climatic conditions. Further, judicious use of organic and inorganic fertilizers inputs improves moisture-holding capacity of soil and increase drought tolerance.

On other hand, conservation-agriculture system holds great potential to address the issues raised due to adverse impact of climate change. A study on rabi crops, viz. lentil, field pea, faba bean, Lathyrus and chickpea, sown under zero as well as conventional tillage after rice harvesting revealed that all pulses performed equally well following both tillage practices. Likewise, performance of chickpea sown after rice in zero-tillage system was statistically at par with conventional tillage practice; however, retention of rice residue on surface showed advantage over no-residue in zero tillage [35].

Water harvesting and supplemental irrigation

Pulse crops are usually grown in rainfed regions, leading to sub-optimal productivity levels. Hence scientific scheduling of irrigation, an estimate of quantity of water to be applied and deployment of water-saving irrigation methods can lead to enhanced yield, higher water and nutrient-use efficiency and larger area coverage under irrigation [14]. Similarly, adoption of sprinkler irrigation has tremendous potential in saving irrigation water and expanding area under irrigation. Further, drip irrigation holds huge potential for widely spaced crops like pigeonpea. Above irrigation technology, can expand irrigation area by 30–50%. Overall, micro-irrigation ensures higher water-use efficiency and in turn water economy [36].Micro-irrigation at critical stages generally considered at flowering through sprinkler or drip may prove beneficial for increasing productivity of pulses.

Use of biofertilizers

The use of certain biofertilizers, such as *Arbuscular mycorrhiza* (AM) fungi enhances water-use efficiency (11–24%) in rainfed pea [38]. Apart from enhancing overall nutrient-use efficiencies particularly of phosphorus, biofertilizers is rather simple, very convenient, inexpensive and eco-friendly. The AM fungi do so by extending root-system into the soil through ramifying hyphae, thereby increasing its exploratory area for harnessing water from deeper layers.

Balanced nutrient management

Biological N_2 fixation enables pulse crops to meet 80–90% of their nitrogen requirements; hence a small dose of 15–25 kg N/ha is sufficient to meet the requirement of most of the pulse crops. However, rotation of pulses with cereal crop requires slightly higher dose of N (30–40 kg N/ha). Besides this, pulse crops respond well to 20–60 kg P_2O_5/ha. Sulphur application @ 20–40 kg/ha at sowing and zinc sulphate @ 25–50 kg/ha once in 2 years effectively overcome the deficiency of concerned nutrient, further enhancing pulse productivity. Ridge planting of kharif/ rainy-season pulses in states having black and heavy soils addresses the problem of water stagnation and improves pulse productivity and sustainability. Above practice ensure drainage of the root zone during heavy rains, further facilitating in-situ moisture conservation to be used by succeeding crop [15]. Further, boron and placement of phosphatic fertilizers and use of biofertilizers enhance efficiency of applied as well as native P. Hence balanced nutrition have higher nutrient-use efficiency and reduces dependence on synthetic fertilizers, which ultimately helps in reduced GHGs emissions.

CONCLUSION AND WAY FORWARD

Climate change due to increase in the frequencies of extreme events and climatic variability, causing serious concerns for enhancing pulse production and productivity in the country. Current trends of unpredictable global climate change have resulted in periodic spells of drought stress and frequent episodes of extreme temperature, thus challenging plant growth and yield in several crops. Induction of climate resilient (CR) varieties into seed chain is important to mitigate the adverse climate change effects vis-à-vis to increase yield as these crops grown predominantly as rain-fed. Pulses are largely drought-tolerant crop species, and are well adapted to rainfed situation, requiring little conserved soil moisture to sustain and produce reasonable good yield. However, inadequate rainfall under water-limited rainfed areas is often posing threat to pulses which leads to substantial loss of grain yield. To improve pulse productivity in the present scenario, gene mining for tolerance to abiotic stresses, restructuring plant types for climatically vulnerable regions, changing cropping pattern, efficient nutrient and water management, seed bank for alternate legume crops, watershed management, and micro-irrigation facilities are some of the better options to address climate change-related issues.

For food and nutritional security, it is essential to adopt mitigation and adaptation strategies for sustaining the production and productivity of pulses under changing climate conditions. However, pulse farmers, especially in South Asia and Africa, are poor in resources; hence, they have a limited capacity to adopt mitigation strategies. Consequently, we shall have to resolve the issues of climate change primarily through adaptation strategies. This calls for developing cultivars that can sustain food production in the future. By the adoption of recommended management practices, agriculture contributes not only to soil and water conservation, but also for enhancing the amount of soil organic carbon in soil and mitigating CO_2 emission effects on climate change. Therefore, improved agronomic practices hold tremendous potential to combat adverse impact of climate change on pulse production.

REFERENCES

1. Ambachew, D.; Mekbib, F.; Asfaw, A.; Beebe, S.E.; Blair, M.W. (2015). Trait associations in common bean genotypes grown under drought stress and field infestation by BSM bean fly. Crop J., 3, 305–316.
2. Arab Water Council (2009). Vulnerability of arid and semi-arid regions to climate change—Impacts and adaptive strategies. Perspectives on Water and Climate Change Adaptation, 9, 1–16.
3. Bahl, P.N. (2015). Climate change and pulses: Approaches to combat its impact. Agricultural Research 4(2): 103–108.
4. Bargaz, A.; Zaman-Allah, M.; Farissi, M.; Lazali, M.; Drevon, J.J.; Maougal, R.T.; Georg, C. (2015). Physiological and molecular aspects of tolerance to environmental constraints in grain and forage legumes. Int. J. Mol. Sci., 16, 18976–19008.
5. Barnabas, B., Jager, K., and Feher, A. (2008). The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ. 31, 11–38. doi: 10.1111/j.1365-3040.2007.01727.x
6. Bayer, C., Gomes, J., Zanatta, J.A., Vieira, F.C.B., Dieckow, J. (2016). Mitigating greenhouse gas emissions from a subtropical Ultisol by using long-term notillage in combination with legume cover crops. Soil Till. Res. 161, 86–94. doi:10.1016/j.still.2016.03.011.
7. Bhargava, S.; Sawant, K. (2013). Drought stress adaptation: Metabolic adjustment and regulation of gene expression. Plant Breed., 132, 21–32.
8. Bredow, M., Tomalty, H. E., Smith, L., & Walker, V. K. (2017). Ice and anti- nucleating activities of an ice-binding protein from the annual grass, Brachypodiumdistachyon. Plant, Cell & Environment, 41. 983–992.
9. Bryant, C.; Fuenzalida, T.I.; Brothers, N.; Mencuccini, M.; Sack, L.; Binks, O.; Ball, M.C. (2021). Shifting access to pools of shoot water sustains gas exchange and increases stem hydraulic safety during seasonal atmospheric drought. Plant Cell Environ., 44, 2898–2911.
10. Charrier, G., Chuine, I., Bonhomme, M. &Améglio, T. (2017). Assessing frost damages using dynamic models in walnut trees: Exposure rather than vulnerability controls frost risks. Plant, Cell & Environment, 41, 1008–1021.
11. Chen, Y.; Ghanem, M.E.; Siddique, K.H.M. (2017). Characterising root trait variability in chickpea (Cicerarietinum L.) germplasm. J. Exp. Bot., 68, 1987–1999.
12. Choudhary, A.K. (2013). Technological and extension yield gaps in pulses in Mandi district of Himachal Pradesh. Indian Journal of Soil Conservation 41(1): 88–97.
13. Choudhury, F.K.; Rivero, R.M.; Blumwald, E.; Mittler, R. (2017). Reactive Oxygen species, abiotic stress and stress combination. Plant J., 90, 856–867.
14. Cullis, C.; Kunert, K.J. (2017). Unlocking the potential of orphan legumes. J. Exper. Bot., 68, 1895–1903.
15. DAC, GoI. (2012). Report of expert group on pulses. Department of Agriculture and Cooperation, Government of India, Ministry of Agriculture, New Delhi, pp. 1–148.
16. D'Amelia, V., Aversano, R., Ruggiero, A., Batelli, G., Appelhagen, I., Dinacci, C., Carputo, D. (2017). Subfunctionalization of duplicate MYB genes in Solanumcommersonii generated the cold-induced ScAN2 and the anthocyanin regulator ScAN1. Plant, Cell & Environment, 41. 1038–1051.
17. Demidchik, V. (2015). Mechanisms of oxidative stress in plants: From classical chemistry to cell biology. Environ. Exp. Bot., 109, 212–228.
18. Djanaguiraman, M., Perumal, R., Ciampitti, I. A., Gupta, S. K., & Prasad, P. V. V. (2017). Quantifying pearl millet response to high temperature stress: thresholds, sensitive stages, genetic variability and relative sensitivity of pollen and pistil. Plant, Cell & Environment, 41. 993–1007.
19. Djanaguiraman, M., Perumal, R., Jagadish, S. V. K., Ciampitti, I. A., Welti, R., & Prasad, P. V. V. (2017). Sensitivity of sorghum pollen and pistil to high-temperature stress. Plant, Cell & Environment, 41. 1065–1082.
20. Eckerd, R.J., Grainger, C., De Klein, C.A.M., (2010). Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest. Sci. 130, 47–56. doi:10.1016/j.livsci.2010.02.010.
21. FAO. (2016). Pulses and Climate Change. Food and Agriculture Organization of the United Nations. Online: http:// 4.
22. FAOSTAT (2018). Food and Agriculture Organization of the United Nations, Statistics database. http://www.fao.org/faostat/en/#data, (Accessed 01.05.2019).
23. Farooq, M., Bramley, H., Palta, J. A., & Siddique, K. H. M. (2011). Heat stress in wheat during reproductive and grain-filling phases. Critical Reviews in Plant Sciences, 30, 1–17.
24. Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., and Basra, S. M. A. (2009). "Plant drought stress: effects, mechanisms and management," in Sustainable agriculture (Dordrecht: Springer), 153–188.
25. Gaur, P. M., Krishnamurthy, L., and Kashiwagi, J. (2008). Improving droughtavoidance root traits in chickpea (Cicerarietinum L.)-current status of research at ICRISAT. Plant Prod. Sci. 11, 3–11. doi: 10.1626/pps.11.3.
26. Hauggaard-Nielsen, H., Lachouani, P., Knudsen, M.T., Ambus, P., Boelt, B., Gislum, R., (2016). Productivity and carbon footprint of perennial grass–forage legume intercropping strategies with high or low nitrogen fertilizer input. Sci. Total Environ. 541, 1339–1347. doi:10.1016/j.scitotenv.2015.10.013.
27. Hou, Q.; Ufer, G.; Bartels, D. (2016). Lipid signalling in plant responses to abiotic stress. Plant Cell Environ., 39, 1029–1048.

28. Huang, S.; Gali, K.K.; Tar'an, B.; Warkentin, T.D.; Bueckert, R.A. (2017). Pea phenology: Crop potential in a warming environment. Crop Sci., 57, 1540–1551.
29. Izydorczyk, C., Nguyen, T. N., Jo, S. H., Son, S. H. T., Anh, P., &Ayele, B. (2017). Spatiotemporal modulation of abscisic acid and gibberellin metabolism and signalling mediates the effect of suboptimal and supraoptimal temperatures on seed germination in wheat (Triticum aestivum L.). Plant, Cell & Environment, 41, 1022–1037.
30. Jeuffroy, M.H., Baranger, E., Carrouée, B., Chezelles, E.D., Gosme, M., Hénault, C., Schneider, A., Cellier, P., (2013). Nitrous oxide emissions from crop rotations including wheat, oilseed rape and dry peas. Biogeosciences 10, 1787–1797. doi:10.5194/bg-10-1787-2013.
31. Khan, H.A.; Siddique, K.H.M.; Colmer, T.D. (2017). Vegetative and reproductive growth of salt-stressed chickpea are carbon-limited: Sucrose infusion at the reproductive stage improves salt tolerance. J. Exp. Bot., 68, 2001–2011.
32. Kole, C.; Muthamilarasan, M.; Henry, R.; Edwards, D.; Sharma, R.; Abberton, M.; Batley, J.; Bentley, A.; Blakeney, M.; Bryant, J. (2015). Application of genomics-assisted breeding for generation of climate resilient crops: Progress and prospects. Front. Plant Sci., 6, 563.
33. Kumar, A., Choudhary, A.K and Suri, V.K. (2016). Influence of AM fungi, inorganic phosphorus and irrigation regimes on plant water relations and soil physical properties in okra (*Abelmoschusesculentus* l.) – pea (*Pisumsativum* L.) cropping system in Himalayan acid Alfisol. Journal of Plant Nutrition 39(5): 666–682. doi: 10.1080/ 01904167.2015.1087030.
34. Kumar, A., Choudhary, A.K., Suri, V.K., Bana, R.S., Pooniya, V. and Singh, U. (2014b). Site specific water management for sustainable agriculture. (In) Water Management in Agriculture, pp. 327–336. Meena, M.S., Singh, K.M. and Bhatt, B.P. (Eds). Jaya Publishing House, Delhi.
35. Kumar, J.; Solanki, R.K. (2014). Evaluation of germplasm accessions for agro-morphological traits in lentil. J. Food Leg., 27, 275.
36. Kumar, K., Solanki, S., Singh, S.N. and Khan, M.A. (2016). Abiotic constraints of pulse production in India. (In) Disease of Pulse Crops and their Sustainable Management, pp. 23–39, Biswas, S.K., Kumar, S. and Chand, G. (Eds). Biotech Books, New Delhi, India.
37. Kumar, N., Hazra, K.K., Nath, C.P., Praharaj, C.S., Singh, U., (2018). Grain legumes for resource conservation and agricultural sustainability in South Asia. In: Legumes For Soil Health and Sustainable Management. Springer, Singapore, pp. 77–107.
38. Kumar, N., Singh, M.K., Ghosh, M.K., Venkatesh, M.S, Hazra, K.K. and Nadarajan, N. (2012). Resource conservation technology in pulse based cropping systems. Indian Institute of Pulses Research, Kanpur, Uttar Pradesh, India, pp. 1–32.
39. Kuwayama, Y.; Thompson, A.; Bernknopf, R.; Zaitchik, B.; Vail, P. (2018). Estimating the Impact of Drought on Agriculture Using the US Drought Monitor. Am. J. Agric. Econ., 101, 193–210.
40. Lemke, R.L., Zhong, Z., Campbell, C.A. and Zentner, R. (2007). Can pulse crops play a role in mitigating greenhouse gases from North American agriculture? Journal of Agronomy 99: 1719–1725.
41. Makarevitch, I.; Waters, A.J.; West, P.T.; Stitzer, M.; Hirsch, C.N.; Ross-Ibarra, J.; Springer, N.M. 2015. Transposable elements contribute to activation of maize genes in response to abiotic stress. PLoS Genet., 11, e1004915.
42. Mantri, N., Patade, V., Penna, S., Ford, R., & Pang, E. (2012). Abiotic stress responses in plants: Present and future. In P. Ahmad, & M. N. V. Prasad (Eds.), Abiotic stress responses in plants: Metabolism, productivity and sustainability (pp. 1–19). New York, NY: Springer New York.
43. Maphosa, Y., Jideani, V.A., (2017). The role of legumes in human nutrition in. In: Hueda, M.C. (Ed.), Functional Food-Improve Health through Adequate Food. Intech open publishing, Croatia, p. 13.
44. McKersie, B. (2015). Planning for food security in a changing climate. J. Exp. Bot., 66, 3435–3450.
45. Mishra, J.P., Praharaj, C.S. and Singh K.K. (2012a). Enhancing water use efficiency and production potential of chickpea and fieldpea through seed bed configurations and irrigation regimes in North Indian Plains. Journal of Food Legumes 25 (4): 310–313.
46. Mishra, J.P., Praharaj, C.S., Singh K.K. and Kumar, N. (2012b). Impact of conservation practices on crop water use and productivity in chickpea under middle Indo-Gangetic plains. Journal of Food Legumes 25 (1): 41–44.
47. Nakabayashi, R.; Saito, K. (2015). Integrated metabolomics for abiotic stress responses in plants. Curr. Opin. Plant Biol., 24, 10–16.
48. Ortiz, R., Braun, H. J., Crossa, J., Crouch, J. H., Davenport, G., Dixon, J., Iwanaga, M. (2008). Wheat genetic resources enhancement by the International Maize and Wheat Improvement Center (CIMMYT). Genetic Resources and Crop Evolution, 55, 1095–1140.
49. Pang, J.; Turner, N.C.; Khan, T.; Du, Y.L.; Xiong, J.L.; Colmer, T.D.; Devilla, R.; Stefanova, K.; Siddique, K.H.M. (2017). Response of chickpea (Cicerarietinum L.) to terminal drought: Leaf stomatal conductance, pod abscisic acid concentration, and seed set. J. Exp. Bot., 68, 1973–1985.
50. Peyrard, C., Mary, B., Perrin, P., Véricel, G., Gréhan, E., Justes, E., Léonard, J., (2016). N_2O emissions of low input cropping systems as affected by legume and cover crops use. Agric. Ecosys. Environ. 224, 145–156. doi:10.1016/j.agee.2016.03.028.
51. Pooniya, V., Choudhary, A.K., Dass, A., Bana, R.S., Rana, K.S., Rana, D.S., Tyagi, V.K. and Puniya, M.M. (2015). Improved crop management practices for sustainable pulse production: An Indian perspective. Indian Journal of Agricultural Sciences 85(6): 747–758.
52. Poorter, H.; Knopf, O.; Wright, I.J.; Temme, A.A.; Hogewoning, S.W.; Graf, A.; Cernusak, L.A.; Pons, T.L. (2021). A meta-analysis of responses of C_3 plants to atmospheric CO_2: Dose–response curves for 85 traits ranging from the molecular to the whole-plant level. New Phytol., 233, 1560–1596.

53. Praharaj, C.S., Kumar, N., Singh, U., Singh, S.S. and Singh, J. (2015). Transplanting in pigeonpea – A contingency measure for realizing higher productivity in Eastern Plains. Journal of Food Legumes 28(1): 34–39.
54. Prasad, P. V. V., Bheemanahalli, R., &Jagadish, S. V. K. (2017). Field crops and the fear of heat stress- Opportunities, challenges and future directions. Field Crops Research, 200, 114–121.
55. Prince, S.J.; Murphy, M.; Mutava, R.N.; Durnell, L.A.; Valliyodan, B.; Shannon, J.G.; Nguyen, H.T. (2017). Root xylem plasticity to improve water use and yield in water-stressed soybean. J. Exp. Bot., 68, 2027–2036.
56. Rana, D.S.; Dass, A.; Rajanna, G.A.; Kaur, R. (2016). Biotic and abiotic stress management in pulses. Indian J. Agron., 61, 238–248.
57. Reddy, A.A. (2006). Impact assessment of pulses production technology, Research Report No 3, Indian Institute of Pulses Research, Kanpur, Uttar Pradesh, India.
58. Sankaranarayanan, K., Praharaj, C.S., Nalayini, P., Bandyopadhyay K.K. and Gopalakrishnan, N. (2010). Climate change and its impact on cotton (*Gossypium sp*.). Indian Journal of Agricultural Sciences 80(7): 561–575.
59. Schwenke, G.D., Herridge, D.F., Scheer, C., Rowlings, D.W., Haigh, B.M., McMullen, K.G., (2015). Soil N2O emissions under N2-fixing legumes and N-fertilised canola: a reappraisal of emissions factor calculations. Agric. Ecosys. Environ. 202, 232–242. doi:10.1016/j.agee.2015.01.017.
60. Shunmugam, A.; Kannan, U.; Jiang, Y.; Daba, K.; Gorim, L. (2018). Physiology based approaches for breeding of next-generation food legumes. Plants, 7, 72.
61. Singh, U., Praharaj, C.S., Singh, S.S. and Kumar, N. (2015). Influence of crop establishment practices and genotypes in pigeonpea– wheat system under IGP of India. Journal of Food Legumes 28(4): 315–319.
62. Suri, V.K., Kumar, A. and Choudhary, A.K. (2012). Soil health management through carbon sequestration under changing climatic scenario. Lead paper, ICLDBT International Symposium published during September 2012 in Progressive Agriculture 11(Conf. issue): 29–42.
63. Tardieu, F., Simonneau, T., and Muller, B. (2018). The physiological basis of drought tolerance in crop plants: a scenario-dependent probabilistic approach. Annu. Rev. Plant Biol. 69, 733–759. doi: 10.1146/annurev-arplant-042817-040218.
64. Tenhaken, R. (2014). Cell wall remodeling under abiotic stress. Front. Plant Sci., 5, 771.
65. Uddling, J.; Broberg, M.C.; Feng, Z.; Pleijel, H. (2018). Crop Quality under Rising Atmospheric CO_2. Curr. Opin. Plant Biol., 45, 262–267.
66. Van Oldenborgh, G.J., Philip, S., Kew, S., Van Weele, M., Uhe, P., Otto, F., Singh, R., Pai, I., Cullen, H., Achuta Rao, K. (2018). Extreme heat in India and anthropogenic climate change. Nat. Hazards Earth Syst. Sci., 18, 365.
67. Varshney, R. K., Song, C., Saxena, R. K., Azam, S., Yu, S., Sharpe, A. G., et al. (2013b). Draft genome sequence of chickpea (Cicerarietinum L.) provides a resource for trait improvement. Nat. Biotechnol. 31, 240–246. doi: 10.1038/nbt.2491.
68. Venkatesh, M.S., Hazra, K.K., Ghosh, P.K., Praharaj, C.S. and Kumar, N. (2013). Long-term effect of pulses and nutrient management on soil carbon sequestration in Indo-Gangetic plains of India. Canadian Journal of Soil Science 93: 127– 136.
69. Wang, N., Hatcher, D.W., Toews, R., Gawalko, E.J., (2009). Influence of cooking and dehulling on nutritional composition of several varieties of lentils (Lens culinaris). LWT Food Sci. Technol. 42, 842–848. doi:10.1016/j.lwt.2008.10.007.
70. WMO. (2019). WMO Statement on the State of the Global Climate in 2018 (https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate) (Accessed on: 01.05.2019).
71. Xia, X. J., Fang, P. P., Guo, X., Qian, X. J., Zhou, J., Shi, K., Yu, J. Q. (2017). Brassinosteroid-mediated apoplastic H_2O_2-glutaredoxin 12/14 cascade regulates antioxidant capacity in response to chilling in tomato. Plant, Cell & Environment, 41, 1052–1064.
72. Yordanov, I., Velikova, V., and Tsonev, T. (2000). Plant responses to drought, acclimation, and stress tolerance. Photosynthetica 38, 171–186. doi: 10.1023/ A:100720141

CITE THIS ARTICLE
R.S. Choudhary, Ishwar S, Lekha and N.L. Dangi. Review on Climate Resilient Strategies to Mitigate Abiotic Stresses in Pulses. Res. J. Chem. Env. Sci. Vol 11 [5] October 2023. 01-09