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## Climate change and its mitigation strategies in pulses production

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### ABSTRACT

The productivity of rainfed pulses is often threatened by climate change due to unusually high temperature and drought especially during podding stage. Majority of the pulse-growing regions are vulnerable to climate change as maximum threshold temperature for tolerance of pulses has already been reached beyond 35°C. Pulses are unable to derive benefits of high CO<sub>2</sub> fluxes, because these crops are grown under climatologically stressed environment. Since both drought and heat are invariably recurrent phenomenon in pulse-growing regions, gene exploration from required germplasm for stress tolerance would remain the possible future hope for evolving newer varieties tolerant to multiple-abiotic stresses. Therefore, strategies have been made to develop climate-resilient varieties based upon screening of large number of germplasm. Early flowering, short duration, faster biomass accumulation, deep root-system, high water-use efficiency and high root proliferation before onset of terminal drought and heat have been found to be the desired strategies to escape the abiotic stresses. A number of genotypes have been identified which are tolerant to heat stress based on high fertility of pollen and pod formation at temperature beyond 40°C. Drought-specific genes such as *Dreb 1A*, *Dreb 1B* and *Osmotin* are being used for developing drought-tolerant chickpea (*Cicer arietinum* L.) and pigeonpea [*Cajanus cajan* (L.) Millsp.] varieties. Similarly, drought specific signal molecule ABA and its role in drought tolerance have been characterized. Identification of linked quantitative loci QTL's for root and high yield (MAS) and gene mining for abiotic stresses tolerance, have widen the scope towards developing drought tolerance in pulses. Improved agronomic strategies such as restructuring plant types, changing cropping pattern, efficient nutrient and water management, conservation agriculture, seed bank for alternate legume crops, watershed management, micro-irrigation etc. are some of the innovative options to address climate-change issues in pulses. Under changing climatic scenario, the soil organic carbon (SOC) is subjected to depletion and adoption of resource-conservation technologies and best of these management practices have tremendous potential in sequestering carbon in soils. Resource-conservation technologies, conservation-agriculture practices and improved farming practices can reduce emission of greenhouse gases (GHGs) and enhance carbon storage in soils. Moreover, organic system of pulse production increases soil organic matter and cultivation of cover crops and lessens the emissions of gases through production and transportation of synthetic fertilizers due to less demand for them. The inclusion of pulses in crop rotation reduces the need for fertilizer inputs and contributes nitrogen to succeeding crops. Lesser fertilizer requirements are also significantly lowering GHGs emissions.

**Key words** : Abiotic stress, Climate change, Drought, Pulses, Terminal heat

### INTRODUCTION

Climate change is primarily driven by rise in temperature due to excessive burning of fossil fuels leading to increase in the CO<sub>2</sub> and other greenhouse gases trapping the infrared radiation (heat) received from the Sun. This phenomenon is known as greenhouse effect, which leads to global warming. The rise in temperature is threatening the

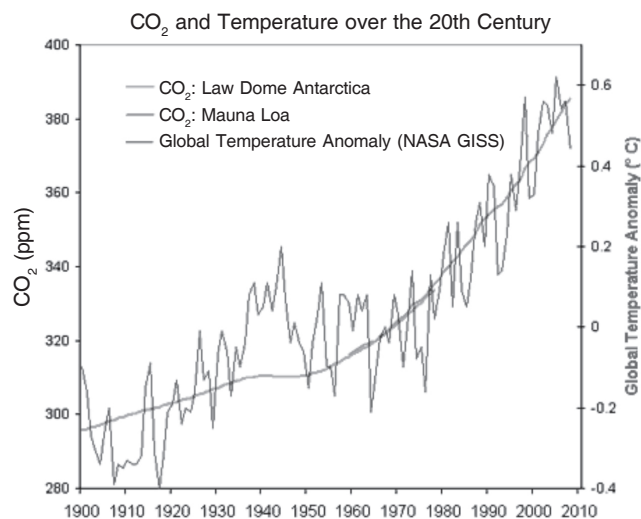
global food security, impacting productivity of pulses adversely in South East Asian countries, which contribute more than 50% of the world's total pulses production (FAO, 2016). Projections of climate change indicate that the agricultural productivity in these regions would decrease from 2020 onwards (Gornall *et al.*, 2010).

India is the largest producer, consumer and importer of pulses in the world. Major pulses grown in India are chickpea, pigeonpea, greengram [*Vigna radiata* (L.) R. Wilczek], blackgram [*V. mungo* (L.) Hepper], lentil (*Lens culinaris* Medikus), and field pea (*Pisum sativum* L.), whereas cowpea [*Vigna unguiculata* (L.) Walp.], horsegram [*Macrotyloma uniflorum* (Lam.) Verdc.], faba bean (*Vicia faba* L.), kidney bean (*Phaseolus vulgaris* L.), ricebean [*Vigna umbellata* (Thunb.) Ohwi & H. Ohashi]

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and adzuki bean [*Vigna angularis* (Willd.) Ohwi & H. Ohashi] are minor pulses. Pulses are highly vulnerable to climate change as these crops are grown under rainfed conditions. The drought and high temperature both have been the recurrent events during the present scenario of climate change. Rainfed pulses suffer due to severe water crisis because of delayed monsoon and uneven distribution of rainfall or complete failure of rains. The productivity of pulses in Gujarat and Andhra Pradesh, though falling under arid and semi-arid regions, is often high owing to moderate temperature during pod filling, as these areas are closer to the coastal belt. A parallel increase in CO<sub>2</sub> and temperature has been observed during past 2 decades globally (Fig. 1). An average surface temperature may increase by 5°C with doubling of CO<sub>2</sub> concentration in the atmosphere. The rate of increase of CO<sub>2</sub> is approximately 2 µmol/mol/year and is expected to reach up to 670 µmol/mol by the end of this century. It is projected that if carbon emissions are not regulated globally, the atmospheric CO<sub>2</sub> level may become almost double (670 µmol/mol) from the present level of 380 µmol/mol by the end of this century, consequently, temperature is to rise between 3.5 and 5°C. Rise in the global temperature would influence the hydrological cycles due to change in the land and sea-surface temperature, deviation of monsoon, erratic, scanty or often heavy rainfall, changing the pattern of rainfall distribution and melting of polar ice (Sankaranarayanan *et al.*, 2010).



**Fig. 1.** CO<sub>2</sub> to global temperatures over the past century (Reproduced from Skeptical Science 18 June 2009 by John Cook)

Most of the agricultural crops have the maximum temperature tolerance limit up to 35°C beyond which anthesis and particularly reproduction process is affected adversely. The C<sub>3</sub> crops, especially pulses, have the narrow-temperature tolerance limit for optimum physiological function

and are mostly in the range of 30–35°C. Even *Vigna* groups of pulses (greengram and blackgram) grown during summer season are often exposed to high temperature beyond 40–42°C, resulting in drastic reduction in their grain yields.

## CONCEPT AND STRATEGIES FOR STRESS TOLERANCE

### *Gene diversity in temperature tolerance*

Gene diversity is being exploited for development of tolerant varieties of pulses to temperature extremities both for sub-optimal and supra-optimal temperatures. The (base) temperature below <5 °C for longer period often becomes lethal for pulses. Foliage growth usually ceases or reduces in most of the winter pulses (chickpea, lentil etc.), growing at low temperature range of 6–15°C. Majority of pulses varieties are well adapted to optimum temperature range falling between 15 and 35°C but can have ability to tolerate up to maximum limit to 45°C, though with significant reduction in photosynthesis, chlorophyll content, decreased foliage growth and enhanced pollen sterility with progressive increase in the temperature beyond 35°C. Temperature rise up to 42–45°C even for the shorter period may induce forced maturity, leaf senescence, pollen sterility and causes failure of anthesis. Grain-filling is adversely affected in young pods that recently set seeds exposed to high temperature above 42°C and as a result further seed development abruptly terminates and such impaired seeds never restore to their normal conditions even temperature becomes favourable afterwards. These immature seeds usually do not imbibe during water soaking and remain hardy. Most of the research efforts for improving heat tolerance in pulses are based on exploitation of genetic diversity of heat tolerance within the temperature range between 36 and 45°C. Temperature above 45°C is considered to be lethal for most of the pulses, as it causes irreversible physiological changes at cellular level, aggregation of macromolecules, massive destruction of photosynthesis process leading to complete inhibition, and no fertilization takes place at this extreme temperature.

### *Winter dew precipitation*

The dew precipitation in fact is gradually vanishing during the winter as a result of high night temperature. Normal dew water during December and January may support crop growth substantially even if winter rain fails. The increase in average temperature is expected to hasten the maturity and shorten the crop duration. Cool-season legumes are more prominently subjected to severe atmospheric drought and may likely to require supplemental irrigation if present trend continues. Scanty rainfall in

some areas may lead to increased demand for irrigation water due to more evaporative loss, affecting rates of decomposition of organic matters and release of nutrients and decline of soil fertility. What is more pertinent is the fact that unavailability of irrigation water for pulses and more so at terminal stages hinders life-support system (in absence of life-saving irrigation) in pulses for higher productivity and farm income.

#### *Adverse effects of stresses on pulses*

As drought is a recurrent phenomenon, pulses may not likely to be benefitted by increased CO<sub>2</sub> level due to combined effects of terminal drought and heat stresses. Biological nitrogen fixation (BNF) in legumes is very sensitive to high temperature and almost ceases beyond 35°C (Kurdali, 1996). Nodule growth is adversely affected during podding stages if temperature is high, which results in poor or lack of nitrogen accumulation in the leaves and decreasing protein content, and tends to enhance starch content in the seeds. About 60% carbon and nitrogen reserve in leaf and stems in cool-season pulses support grain filling through post-anthesis remobilization under normal condition. As nodulation and nitrogen fixation almost terminate at high temperature, exogenous application could prove beneficial to improve yield under heat stress.

The drought and heat stresses combindly affect wide range of physiological processes and alter plant-water relationship and reduce yield by more than 40% in pulses. The heat stress above 35°C often causes irreversible damage to growth and development (Wahid *et al.*, 2007). The cool-season legumes optimally function between the temperature range 15 to 35°C and biomass growth and particularly reproduction are partially or completely arrested beyond 40°C, though duration of exposure to high temperature has profound effect on these physiological processes (Ali *et al.*, 2009; Basu, 2010). Grain legumes are categorized as per their thermo-tolerances in the following decreasing order:

Mungbean > pigeonpea > urdbean > chickpea > lentil > rajmash > field pea

Therefore, strategies are to be made to develop heat- and drought-tolerant varieties of pulses with improved yield for warmer climates based on specific physiological attributes such as early flowering, short duration, vigorous root-system and large-seed size with quick biomass accumulation. Accordingly, contingency measures could be taken up as a climate smart technologies for realizing higher-order sustainability (Sankaranarayanan *et al.*, 2010; Praharaj *et al.*, 2015).

#### *Crop response to climate change*

The reproductive parts and grain-filling process are

extremely sensitive to chilling and high temperature. The combined effect of heat and drought is more detrimental than effect of drought and heat alone, as a result productivity further goes down (Basu *et al.*, 2009). Pigeonpea, in particular, is highly sensitive to temperature fluctuations, causing massive flower drop, forced drying and bending of apical leaves when subjected to cold stress (< 5°C) (Basu *et al.*, 2009).

In greengram, temperature above 42°C during summer causes seed hardening due to incomplete sink development. Field pea is well adapted to low temperature than other winter pulses like lentil and chickpea showing retarded growth below 7°C. Day-time maximum air temperature beyond 40°C during reproductive phase in winter pulses results in complete failure of anthesis, pod setting and induces hardening of seeds. The failure of anthesis at high temperature is primarily caused by poor pollen germination, stigma receptivity, pollen load on stigma and ovule viability above 35°C (Basu *et al.*, 2009). Field pea is even more sensitive to high temperature than chickpea and lentil.

Low biomass and forced maturity are the manifestation of high temperature in pulse crops. Biomass is decreased significantly under short and warm winters, less dew precipitation, and high night temperature. Specifically, late-flowering chickpea genotypes with low biomass are often encountered with sudden high temperature during anthesis, whereas short-duration varieties growing in central and south zones of India do not encounter such contrasting temperatures. Short-duration, bold-seeded chickpea genotypes, e.g. 'ICC 4958', 'Phule G 5', bred at warmer south zone of India have high biomass and deep root-system compared to medium- to late-maturing chickpea genotypes 'KWR 108', 'C 235' and 'Pant G 114' bred in the northern plains of India (Basu *et al.*, 2014). The deeper root-system of pulses supports water extraction from deep soils to meet out the water requirement of high evapotranspiration demand under warm climates of south India, whereas shallow-rooting genotypes of northern India are equipped with faster and efficient water absorption from top soil layers saturated with dew precipitation.

High temperature also reduces seed size. Majority of chickpea genotypes show reduced, shrivelled or deformed grains at high temperatures exceeding 35°C. Pollen germination in other crops has been reported to be highly vulnerable at high temperatures, and the degree of pollen tube growth is reduced significantly (Kakani *et al.*, 2005). In pulses, remobilization of pre-anthesis reserve carbohydrates and nitrogen in leaves and stems contribute significantly towards grain filling. Therefore, biomass is the main factor determining grain yield in majority of the pulses grown during winter season. In addition, cellular



membrane stability decreases at high temperature in cowpea. Exposure of chickpea and pigeonpea to 35°C for 24 h reduced the membrane stability, but genetic differences in membrane stability are evident. The heat-tolerant chickpea genotype ‘ICCV 92944’ showed the lowest membrane injury when subjected to high temperature and sensitive line ‘ICC 10685’ had the maximum injury (Fig. 2).

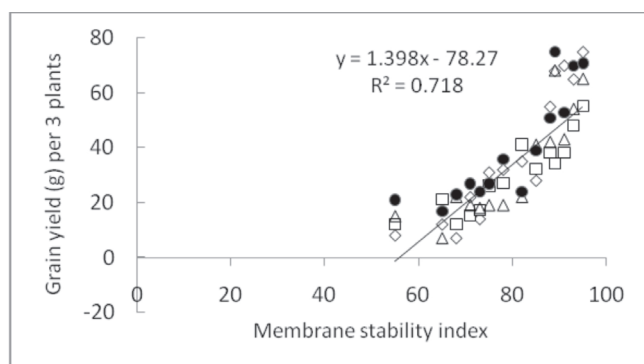


Fig. 2. Relationship of grain yield with membrane-stability index

Chickpea genotypes, viz. ‘ICCV 92944’, ‘ICC 1205’, ‘ICC 15614’, ‘ICC 8950’, ‘ICC 1356’, ‘ICC 10685’, ‘ICC 4567’ and ‘ICC 5912’, have membrane-stability index 87.5, 82.0, 81.2, 86.0, 81, 79.9, 83.4 and 83.8, respectively.

The pollen of heat-tolerant chickpea genotype (‘ICCV 92944’) is viable at 35/20°C (41% fertile) and at 40/25°C (13% fertile), whereas the pollen of heat-sensitive genotype (‘ICC 5912’) is completely sterile at 35/20°C with no *in-vitro* germination (Fig. 3). However, the stigma of the sensitive genotype (‘ICC 5912’) remains receptive at 35/20°C and non-stressed pollen (27/16 °C) germinated on it during reciprocal crossing. Both anthers and pollen show more structural abnormalities under stress such as changes in anther locule number, anther epidermis wall thickening and pollen sterility, rather than function (e.g. *in-vivo* pollen-tube growth). The critical temperature for pod set was  $\geq 37^\circ\text{C}$  in heat tolerant chickpea genotypes (‘ICC 1205’ and ‘ICC 15614’) and  $\geq 33^\circ\text{C}$  for heat-sensitive genotypes (‘ICC 4567’ and ‘ICC 10685’). In mungbean, high tem-

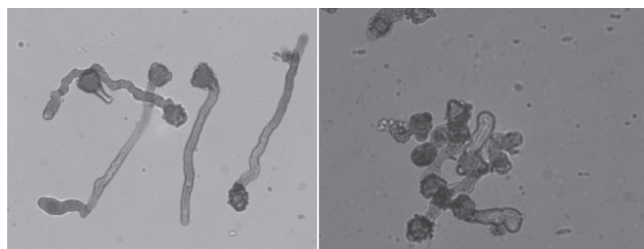


Fig. 3. Fertile germinating pollen-grains at 25°C with distinct pollen tubes (left) and sterile pollen (right) at 43°C in chickpea

perature increases flower shedding and pollen sterility. Dehiscence of anthers occurs at high temperature in cowpea. Similarly, heat stress also affects flower initiation, flowering, pollen formation, and fertilization and pod set/ development in common bean and pea. High night temperatures affect pod and seed set in common bean, lima bean (*Phaseolus lunatus* L.) and cowpea.

## CLIMATE CHANGE MITIGATION VIA CROP-IMPROVEMENT STRATEGIES

### Developing climate-resilient varieties

Pigeonpea germplasm have wide variability in osmotic adjustment (OA) ranging from 0.2 to 1.6 MPa or even higher in case of wild pigeonpea (5.0 MPa). A number of pigeonpea varieties have been identified which have high osmotic adjustment under drought. Some of these are: ‘VKS11/24-1’, ‘TGT 501’, ‘Bennur Local’, ‘JKM 7’, ‘BDN 2008-12’, ‘VKS11/24-2’, ‘RVK 275’, ‘AL 1855’, ‘ICP 13673’, ‘AL 201’, ‘GRG 2009-1’, ‘ICP 84031’, ‘MAL 13’, ‘BSMR 853’, ‘Bahar’, ‘GRG 815’, ‘BDN 708’. These genotypes are well adapted to drought condition. A large number of genotypes from diverse genetic resources of pulses have been identified as tolerant to multiple stresses. Among these, wild progenitors of diverse pulses have very high tolerance level for drought and heat or to both. Combined tolerance to heat and drought has been identified in wild accessions of pigeonpea, viz. *Cajanus scarabaeoides* (L.) Thouars. Wild accession ‘ICP 15671’ has a very high osmotic adjustment with pod-setting ability at 40°C.

Majority of the blackgram and greengram genotypes are lacking osmotic adjustment and thus remain sensitive to drought. On-going research at the ICAR-Indian Institute of Pulses Research, Kanpur, showed that some blackgram and greengram lines having osmotic adjustment to the maximum extent up to 0.4 MPa. These genotypes are: ‘PKG-U 03’, ‘STY 280-1’, ‘GP 15’, ‘PGRU 95016’, ‘IPU 90-32’, ‘IPU 06-12’, ‘UH 85-5’, ‘UH 85-13’ and ‘PLU 110’ of blackgram, and ‘Ganga 8’, ‘HUM 1’ and ‘ML 5’ of greengram. Very little or lack of osmotic-adjustment ability causes less tolerance to drought in blackgram and greengram and hence requires irrigation. The wild relatives of pulses are the potential sources of gene mining for heat and drought tolerance. The probable reasons could be one or a combination of the followings.

- Wild and extant varieties could have traits tolerant to high temperature/ elevated CO<sub>2</sub>
- Might have discarded in the past due to low yield potential
- Can be made use as parents for breeding of tolerant varieties to climate change

- Need for revisiting gene banks with a view to search for unique traits required for climate change
- Indigenous knowledge and farmers wisdom has immense value.

#### *Reducing crop duration*

- Developing cultivars tolerant to heat, salinity, flood and drought stress
- Modifying crop-, water- and pest-management practices
- Adopting resource-conserving technologies
- Crop diversification
- Better weather forecasting.

#### *Managing heat stress*

Screening for heat tolerance and identification and development of heat-tolerant genotypes will play vital role in genetic advancements of pulses for mitigation of climate change in the future. For example, delayed-sowing synchronization with the reproductive phase of the crop and occurrence of higher temperatures ( $\geq 35^{\circ}\text{C}$ ) was proposed strategy for heat-tolerance screening in chickpea (Gaur *et al.*, 2007). A screening of 180 genotypes at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, and ICAR-IIPR, Kanpur, India during 2007–08 revealed large genotypic variation with significant variations for heat-tolerance index (HTI) in chickpea (Krishnamurthy *et al.*, 2011). The genotypes which have high heat tolerance over best known heat-tolerant line ‘ICCV 92944’ included ‘ICCV 07104’, ‘ICCV 07105’, ‘ICCV 07110’ and ‘ICCV 07115’. Similarly, the International Centre for Agricultural Research in the Dry Areas (ICRDA) also identified heat tolerant faba bean, chickpea and lentil genotypes. One of the examples is ‘FLIP 87-59C’, which is also resistant to drought, has been identified as heat-tolerant genotype. Recently, the ICARDA is targeting lentil genotypes with rapid ground cover, early phenology, a prolonged flowering and podding period leading to increased dry-matter production, more pods, high harvest index, efficient water use and large seeds to adapt to heat stress. Most of the progress in breeding for terminal heat escape has been made in development of short-duration varieties such as ‘Precoz’, ‘Idleb 3’, ‘Bakaria’, ‘BARI M 4’, ‘BARI M 5’ and ‘BARI M 6’ without compromising yield level. In lentil, evaluation of germplasm under delayed planting with and without irrigation resulted in identification of putative heat-tolerant genotypes (‘ILL 3597’, ‘Sel 33108’, ‘Sel 33109’, ‘Sel 33110’ and ‘Sel 33113’) and drought-tolerant genotypes (‘ILL 1878’, ‘ILL 6002’, ‘ILL 759’ and ‘ILL 6465’). Based on delayed sowing in order to expose reproductive phase to high temperature under irrigated conditions in field at

$>37^{\circ}\text{C}$ , 3 genotypes of lentil, ‘IG 4258’, ‘FLIP 2009-55L’ and ‘IG 2507’, were identified as heat tolerant (Kumar *et al.*, 2014a).

In chickpea, development of recombinant inbred lines (RILs) is in progress at the ICRISAT for mapping of quantitative loci (QTL) controlling heat tolerance. The phenotypic and genotypic data available on the reference set are being used for association mapping. In mungbean, extra-early maturing genotypes (‘IPM 205-7’ and ‘IPM 409-4’) have been developed at the IIPR, India, which mature in 46–48 days (Pratap *et al.*, 2013). These genotypes when grown during summer will save 2 irrigations and 1 insecticide spray and better suited for growing at high temperature. Moreover, these genotypes may fit well in rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) or maize (*Zea mays* (L.)–wheat system. As the short window period may be used under the cultivation of summer mungbean, which is more tolerant to high temperature also.

High degree of pollen sterility was observed in pigeonpea at temperature exceeding  $38^{\circ}\text{C}$ . Similarly, frost and low temperature cause significant damage to the standing field crop of pigeonpea. One hundred and fifty minicore collections of pigeonpea, 85 medium- and long-duration lines and 35 early-duration lines were tested at different hot spots (Ludhiana, Kanpur, Badnapur, Khargone and Gulbarga) under National Innovations in Climate Resilient Agriculture (NICRA) project of India. Phenotyping for high-temperature tolerance was developed based on variable fluorescence and imaging. These tolerant genotypes were ‘WRP 1’, ‘JKM 7’, ‘ICP 8700’, ‘JKM 189’, ‘MAL 13’, ‘ICP 995’, ‘BSMR 736’, and ‘NDA 1’. Some promising wild derivatives of *C. scarabaeoides* were identified which flowered and set pods at  $40/20^{\circ}\text{C}$  maximum/ minimum temperature and low soil moisture. Therefore, combined tolerance such as foliar resistance based on variable fluorescence and reproductive tolerance, e.g. pollen viability and *in-situ* germination-proved essential criterion for selection.

#### *Addition of photo- and thermo-insensitiveness*

Pulses are considered to be highly sensitive to photo-thermo-periods. Sensitivity to photo- and thermo-periods is the major factor responsible for high Genotype  $\times$  Environment (G  $\times$  E) interaction, and yield instability of major pulses across different environments. Therefore, development of photo- and thermo-insensitive genotypes had been the primary requirement to address the climate risk. Field studies have been conducted in pigeonpea with different maturity durations (extra-early, early, medium and long durations) in Kenya, to determine the effect of photoperiod and temperature on flowering. It has been found that the extra-short duration genotype ‘ICPL 90011’ was the least

responsive to variation in photoperiod, while the 2 long-duration genotypes 'ICEAP 00040' and 'T 7' were the most sensitive to photoperiod. In chickpea, 'ICCV 960029' and 'ICCV 960030' have been identified as photo- and thermo-insensitive (Table 1).

#### Complementing with sources of heat tolerance

Sources of heat tolerance have been identified in some legumes by exposing the crop to high temperatures at reproductive phase. Extensive screening of germplasm for heat tolerance across chickpea germplasm indicates a large genetic variation in heat tolerances (Krishnamurthy *et al.*, 2011) that can be used in the breeding programmes for development of heat-tolerant varieties. Several thermo-tolerant chickpea lines, e.g. 'ICC 1205', 'ICC 15614', 'ICC 8950', have also been identified. A heat-tolerant chickpea variety 'JG 14' has been released for late-sown condition in India and Myanmar (Gaur *et al.*, 2010, 2014). Improving reproductive stage tolerance through selection and short-duration varieties escaping terminal heat and drought should be the primary goal to develop climate-resilient pulses. A large number of pulses genotypes were identified based on multilocational trials and controlled environments, showing tolerance to drought, heat, water-logging, frost and insensitive to photo-thermoperiods. For examples, identified drought-tolerant chickpea are 'RSG 888', 'PG 5', 'BGD 72', 'Vijay', 'PG 96006', 'ICC 4958', 'Tyson', 'Katila' and 'K 850' (Basu *et al.*, 2007a, b). Similarly, thermo-tolerant and photo-insensitive genotypes in blackgram, viz. 'PGRU 95016', 'IPU 99-89', 'IPU 94-1', 'IPU 99-79' and 'BGP 247'; thermotolerant genotypes in greengram, viz. 'IPM 02-3', 'IPM 02-10' and 'PM 5', were identified, and photo- and thermo-insensitive lines in wild *Vigna* species included *V. glabrescens* ('IC 251372'), *V. umbellata* ('IC 251442') (Pratap *et al.*, 2014). Some wild accessions of pigeonpea (*C. scarabaeoides*) have combined tolerance to drought and heat. Sources of drought resistance in pigeonpea were explored in wild species *C. sericius*, *C. scarabaeoides* and *C. aquitifolius* based on osmotic adjustment. Some of these wild species are having very high osmotic adjustment (OA) up to 2.5 MPa. Out of 50 pigeonpea genotypes from the ICRISAT evaluated at Ludhiana, Kanpur, Khargone, Badnapur and

Gulberga, the lines, namely 'BDN 2008-1', 'Bennur Local', 'ICP 1156', 'BDN 2008-12', 'TJT 501', 'GRG 2009', 'ICP 995', 'ICP 4575' and 'ICP 14832' appeared superior at pod-filling stage under rainfed condition. Likewise, 'ICP 1126', 'JKM 7', 'JKM 189' and 'ICP 4575' appeared better under rainfed at Badnapur.

#### Enabling drought stress

Climate change driven high carbon gain per unit availability of water enables faster dry-matter accumulation, hence water-use efficiency (WUE) of all cool-season pulses may greatly increase. However, benefits of high WUE cannot be derived due to shortening of crop duration and adverse effects of high temperature that induces pollen sterility. Biomass was found to be the most sensitive to water stress. The leaf expansion is affected even under mild water stress with a leaf-water potential declined to  $\leq 1.2$  MPa. The biomass have a linear relationship with yield under rainfed condition is the indicator that source (leaves and stems) are the major limiting factor for low yield. Field screening for drought tolerance is largely based on drought-susceptibility index. The genotypes which have low yield relative to its rainfed counterpart have higher drought-susceptibility index (DSI). The lower the DSI, the greater is the drought tolerance of the line. The line-source sprinkler technique was used to compare moisture responses of a range of chickpea lines grown on receding soil moisture which showed a linear response of both aerial biomass and grain yield to moisture applied. Matching phenology and early biomass accumulation, dehydration postponement, root characteristics, osmotic adjustment, lethal leaf-water potential, membrane stability, proline accumulation, water-use efficiency are some of the potential traits identified for selecting drought-tolerant lines in pulses. Matching the phenology to the water supply with early biomass and setting of reproductive organs before the onset of terminal drought is largely considered as drought-escape mechanism. In environments, wherein terminal drought is likely, selection for shorter time to flowering has been highly successful.

The postponement of drought either through reducing water loss or reducing transpiration or reducing stomatal density and an increase in the leaf reflectance through pro-

**Table 1.** Some of the food legume genotypes showing photo- and thermo-insensitivity

Food legumes	Photo-thermo-insensitive
Chickpea	'ICCV 92944', 'ICCV 96029', 'ICCV 96030'
Blackgram	'PGRU 95016', 'IPU 99-89', 'IPU 94-1', 'IPU 99-79', 'BGP 247'
<i>Vigna</i> germplasm	<i>V. umbellata</i> ('IC 251442'), <i>V. glabrescens</i> ('IC 251372')
Pigeonpea wild accessions	<i>C. scarabaeoides</i> 'ICP 15761'
Pigeonpea	'ICPL 90011'



duction of glandular hairs in chickpea are considered to be adaptive traits through which leaf reduces water loss and intercepts non-photosynthetic radiation. On the other hand, anatomical difference in pod wall also imparts tolerance to drought in blackgram. Waxy cuticle above epidermis along with high density tall hairs of pod wall prevent moisture loss and pod wall remains photosynthetically active under drought. Pod-wall photosynthesis is independent of plant water status. In pulses, wide genetic variability among root characters such as density and depth, total root biomass is prevalent, which could be a source of genetic advance for drought tolerance. The lines of chickpea with increased drought tolerance through increased root biomass have been identified (Kashiwagi *et al.*, 2005).

The degree of osmotic adjustment (OA) has also been shown to be correlated with yield under dryland conditions in pulses. Osmotic adjustment has been shown to maintain stomatal conductance and photosynthesis at low leaf-water potential, delay leaf senescence, reduce flower abortion and improve root growth and water extraction from the soil. A significant genotypic variation in osmotic adjustment was observed in chickpea (Basu *et al.*, 2007a, b) and pigeonpea (Subbarao *et al.*, 2000), greengram and blackgram and this trait is being used for drought tolerance. The lethal leaf-water potential, i.e. the lowest water potential experienced by the last viable leaf, was a key measure of dehydration tolerance. However, soybean has more dehydration tolerance than others. The ability of cells to continue metabolism at low leaf water status is termed dehydration tolerance. Membrane disorder is often measured as leakage of solutes from the cell. Electrolyte leakage measured by conductivity meter has been used as a screening technique for heat and dehydration tolerance. Accumulation of proline in cell in response to water deficit is another mechanism protecting protein structures as cell dehydrate, and as an organic nitrogen source.

Significant genetic variation was observed in water-use efficiency (WUE) among the chickpea genotypes. Kashiwagi *et al.* (2006) reported highly significant relationship between  $\Delta 13^{\circ}\text{C}$  and transpiration efficiency (TE) in chickpea. The method can be applied for large-scale screening of pulses for higher water-use efficiency in less time and more precisely. Chickpea lines 'ICC 4958' and 'FLIP 87-59C' and faba bean line 'ILB 938' showed good drought-tolerance parameters in different experiments (Stoddard *et al.*, 2006). Thus, increased WUE may have tremendous impact on crop growth and grain yield under drought.

There is a clear relationship between the amount of water transpired and yield across a diverse range of crop

species. Water and soil resource being limited, the only options for increasing biomass production in pulse is to increase the water-use efficiency (WUE), i.e. more biomass per unit of water. Passioura (1977) explained the principle that grain yield is the simple function of transpiration, water-use efficiency and harvest index (HI):

$$\text{Yield} = \text{Transpiration} \times \text{WUE} \times \text{HI}$$

where WUE = water-use efficiency; HI = Harvest index

### CLIMATE-CHANGE MITIGATION VIA 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 (Bahl, 2015). Pulses are climate smart since they simultaneously adapt to climate change and contribute towards mitigating its effects (FAO, 2016). 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-à-vis climate change and pulse production from mitigation point of view is given here:

#### *Adopting diversification in practice*

Diversification of farming is an effective approach to reduce the risk associated with farming in unpredictable environments. Diversification of cropping to reduce risk is especially important under dryland conditions. Crops differ in their response to a given environment and this difference is used to reduce the risk associated with growing one crop. Mixed cropping or intercropping is an example of a successful approach to crop diversification where two or more crops are grown together in various possible configurations. Therefore, efficient utilization of resources by increasing cropping intensities following inter- and multiple-cropping systems. Actually, multiple-cropping systems, such as intercropping or crop rotations with pulses, have a higher soil carbon sequestration potential (FAO, 2016). Therefore, alternate land-use systems such as alley cropping, agri-horticultural and silvi-pastoral systems, which utilize the resources in better way and stabilizing pulse production. This system withstands climate extremes as pulses are hardier than most crops and help to nourish the soil (FAO, 2016).

Many a time, the farmer's land is divided into several convenient fields or plots (spatial diversification) which may differ in their topography, soil and hydraulic proper-



ties. Some fields may be prone to flooding while others do not hold water. Certain fields may be on a warmer slope while others on a cooler one. 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 farmer. Planting of several crop varieties (varietal diversification) 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. Ideally the crop is planted at the beginning of the rainy season, rainfall peaks when crop evapotranspiration peaks and it terminates just before harvest time. Planting date can be set to optimize production. Similarly, higher rainfall intensities forecast during cropping season may prohibit planting *in situ* (under field condition) where certain contingency planning could help compensate the productivity loss (Praharaj *et al.*, 2015; Sankaranarayanan *et al.*, 2010).

Technology based on contingency planning for pigeonpea under high rainfall condition following onset of monsoon during July in Northern India indicated that polyethylene-raised transplanted pigeonpea seedlings could perform better under ridge planting than that in flat condition. In addition, when pigeonpea transplanting was made at 3 weeks after seeding (WAS), seedling survival and their growth, development and yield were higher than those grown up to 4 and 5 WAS. Furthermore, 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 (Praharaj *et al.*, 2015). 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 (Mishra *et al.*, 2012a).

#### *Fallow and conservation tillage*

The fallow system is designed to conserve soil moisture. The fallow system has advantages like improved availability of soil nutrients and the eradication of certain soil-borne pests. Increasing storage of soil moisture by the

fallow system with or without conservation tillage is standard agricultural practice in dryland farming. The benefit of fallow and conservation tillage in terms of increasing available soil moisture to the crop depends on soil water-holding capacity, climate, topography and management practices.

Conservation tillage is basically meant for minimized tillage operations to conserve soil structure and to maintain ground cover by mulch, such as stubble. These practices reduce water runoff and increase soil infiltration. Conservation tillage is the usual practice under dryland systems. 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 post-rainy season precipitation (Mishra *et al.*, 2012b). Varieties do behave differentially under water adequacy/ deficit conditions. For example, amongst the chickpea genotypes, small seed and semi-spreading genotype 'JG 16' proved the most productive and efficient water user under adequate *rabi* rainfall situation, whereas 'KWR 108' seemed to perform better under scanty-rainfall situation (Mishra *et al.*, 2012b). Thus, appropriate selection of pulses (and other crops) varieties could be useful when appropriate land configuration for planting was considered depending on climatic characteristics of the location (Singh *et al.*, 2015). 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 (Singh *et al.*, 2015). 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 under severe attack. The advanced agricultural practices and or adoption of recommended management 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, increased cation-exchange capacity. Overall, optimum organic matter level in soils retain water and nutrients, which in turn are highly benefi-

cial from pulse production point of view, which are usually grown in rainfed regions. The addition and maintenance of soil organic carbon improves soil structure, texture and tilth (Hati *et al.*, 2008), activates a very large portion of inherent microorganisms. It is obvious from the above account that SOC is directly linked to soil health. 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 (Venkatesh *et al.*, 2013).

#### *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 (Suri *et al.*, 2012). These systems obviously lessen the emissions of gases through production and transportation of synthetic fertilizers due to less demand for them. The inclusion of pulses in crop rotation reduces the need for fertilizer inputs. Pulses supply their own nitrogen and contribute nitrogen to succeeding crops (Lemke *et al.*, 2007). Actually, pulses help lowering emissions of GHGs due to lower fertilizer requirements (Venkatesh *et al.*, 2013). A number of components of organic agriculture could be implemented along with other sustainable farming systems such as conservation tillage, to obtain additional climate-change mitigation benefits.

#### *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. Zonal Agricultural Research Stations have developed crop-specific recommendations in different agro-climatic regions based on research. The recommendations emerged should be passed to farmers for adoption. Crop-specific agronomic practices hold tremendous scope to raise pulse-productivity potential in water-stress region under changing climatic conditions. For example, typical practices involves incorporation of the fertilizers in furrows below the seed as limited soil-moisture restricts nutrients availability to plants. 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. len-

til, 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 (Kumar *et al.*, 2012).

#### *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 (DAC, GoI, 2012). Similarly, adoption of sprinkler irrigation has tremendous potential in saving irrigation water and expanding area under irrigation. The technique is successfully running in many districts of the country having limited water resources. 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 (Kumar *et al.*, 2014b).

Water-harvesting approach includes collection of runoff from large contributing areas and concentrates it for use in smaller crop area. Presently, basic water-harvesting systems involve an external contributing area to induce runoff. The water is diverted into a receiving area comprising cultivated plots, individual trees or small terraces. The resulting yield increase in the receiving (crop) area is proportional to the amount of water gained in that area.

Micro-irrigation at critical stages generally considered at flowering through sprinkler or drip may prove beneficial for increasing productivity of pulses. Though water shortage is the main limiting factor, it is also equally important to eliminate other limiting factors such as poor nutrient status, weeds, biotic stresses, etc, which can reduce the efficiency by which the crop uses the limited moisture.

Therefore, development of a sustainable dryland-farming system needs improved soil- and water-conservation practices and the associated tillage systems, optimization of crop growth and available moisture, optimum weed control, sustainable soil fertility management, optimized plant-population density and spatial arrangement of plants with respect to the expected soil-moisture regime, control of soil-biotic stress factors that reduce root development and avoidance of monocropping and the diversification of farming.

### Use of biofertilizers

The use of certain biofertilizers, such as arbuscular mycorrhizal (AM) fungi enhances water-use efficiency (11–24%) in rainfed pea (Kumar *et al.*, 2016). Apart from enhancing overall nutrient-use efficiencies particularly of phosphorus, a technology involved 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. However, there is a dire need to conduct further researches in this area and generate database. Similarly, pulses need less nitrogen as external input because much of their N requirement is met through biological N-fixation. It is, therefore, important that farmers are encouraged to adopt agronomic practices that facilitate N fixation especially seed treatment with crop-specific *Rhizobium* strains.

### Balanced nutrient management

Biological N<sub>2</sub> 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, pulse crops respond well to 20–60 kg P<sub>2</sub>O<sub>5</sub>/ha. Widespread deficiency of certain micronutrients, especially of zinc and secondary nutrient, especially of sulphur in pulse-growing pockets of different states and boron deficiency in eastern and north-eastern states having acid soils have necessitated the use of said nutrient fertilizers (DAC, GoI, 2012). 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 (DAI, GoI, 2012). In the recent years, inclusion of sulphur and micronutrients, viz. Zn, B, Mo and Fe, in pulse-production system have resulted in considerable improvement in productivity in many pulse-growing pockets. 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

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. The drought tolerance-characters of pulses are well characterized and genotypic variability of the drought-tolerant morpho-physiological traits has been established. Yield stability of pulses requires less genotype × environment interaction and wider adaptability across the environment. The physiological trait such as water-use efficiency is considered to be the most important to contribute grain yield and biomass under drought condition. Rapid screening for water-use efficiency in large number of germplasm is now possible by using carbon-isotope discrimination technique. In addition to physiological and breeding approaches to enhance yield, efficient agronomic practices need to be evolved to minimize the irrigation water and conserve soil moisture to increase the water productivity. 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, micro-irrigation facilities are some of the better options to address climate change-related issues. Therefore, improved agronomic practices hold tremendous potential to combat adverse impact of climate change on pulse production. 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<sub>2</sub> emission effects on climate change.

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