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Mungbean Production under a Changing Climate - Insights from Growth Physiology

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Abstract

Global climate change may result in reducing available water and a rise in air temperatures. All these changes will be major limiting factors to future sustainable food and vegetable production largely in the tropics and subtropics. These changes impact the overall growth and development dynamics of crop species and understanding the physiological responses involved holds the key to estimating 'cause-effect' relationships between environment and yields. To address this critical challenge, the World Vegetable Center, South Asia, is exploring physiology based screening approaches for identifying elite mungbean accessions for high temperature tolerance under field and controlled growth conditions. Promising selections have been further subjected to elevated CO_2 environments to determine their physiological responses, growth and yield abilities to help select lines with greater adaptability to the likely climates of the future.

The threat of global warming may pose significant adverse challenges for present vegetable production systems (Peet and Wolfe, 2000). There is mounting evidence that smaller farmers in developing countries are experiencing increased climate change variability (indeed linked to higher greenhouse gas emissions). Shifts in ecological and agro-economic zones, land degradation, reduced water availability, rises in sea levels and increased soil salinization will pose threats for cultivating traditional vegetables in tropical and subtropical parts of the world (Johkan *et al.,* 2011). Developing countries in these parts will be particularly vulnerable and India is no exception (Chatterjee and Solankey, 2015; Bhardwaj, 2012). The yields of many vegetables are sensitive to higher temperatures and water deficits, but their vulnerability to yield depressions would be further compounded by climate change. Rising temperatures are going to be a critical future issue for agriculture. Various food crops including legumes are likely to be adversely affected by elevated temperatures (Gaur *et al.,* 2015). Therefore, it becomes imperative to screen the existing germplasm of food legumes such as chickpea, lentil and mungbean for their responses to high temperature stress to explore the sources and mechanisms of heat tolerance.

The reproductive stage is the most sensitive to rising temperatures resulting in loss of buds, flowers and pods that impact seed yield. Hence, heat tolerance at the reproductive stage is crucial to developing stress-resilient crops. The reproductive stage includes flowering through to seed and pod set. Heat stress disrupts this process mainly due to the loss of pollen viability, pollen germination, poor anther dehiscence, the landing of pollen on the stigma surface and subsequent germination through the style. Heat stress also causes stigmatic surfaces to lose receptivity along with poor ovule viability. However, the male components of the pollination process are affected more than the female components (Kaushal *et al.,* 2013). Therefore, targeting the superior functioning of pollen grains to achieve a successful seed and pod set in heat stressed plants appears to be a vital trait to develop heat tolerant crops (Kumar *et al.,* 2013). Oxidative damage to leaves also increases manifold under heat stress in chickpea (Kumar *et al.,* 2013) resulting in damage to leaf tissue and photosynthetic ability. High temperatures accelerate seed filling, which results in reduced seed size and weight, and reduced yields (Awasthi *et al.,* 2014). A reduction in carbon fixation coupled with decreased sucrose production and its transport to the developing flowers and seeds was found to be a critical limiting factor under heat stress in chickpea (Awasthi *et al.,* 2014). The nitrogen fixation ability of legumes has considerable agricultural and ecological significance, which can be influenced by heat stress. The soil surface heats up markedly, which may influence the nodulation process directly by affecting the rhizosphere. The maintenance of the photosynthetic function of the leaves is vital under heat stress to sustain the synthesis and transport of sucrose and other molecules to these organs (Awasthi *et al.,* 2014). The flowers, seeds and roots depend upon the leaves to import sucrose, amino acids and other molecules for the reproductive function, seed filling and nodulation. More work is required to identify legume genotypes with superior nodulation ability under heat stress.

There may be several reasons for impaired reproductive growth and inhibited seed yield due to heat stress. A loss of chlorophyll concentrations and photosynthetic functions in leaves appear to occur and these effects are exacerbated in combination with drought stress (Kaushal *et al.,* 2013; Awasthi *et al.,* 2014). While, the production of flowers in different genotypes varies under heat stress, a reduction in pod set occurs in all studied cases. Impaired reproductive function leads to poor pod set, directly due to the inhibited development of microspores and megaspores or indirectly due to inhibited sucrose availability to gametes, or both (Kaushal *et al.,* 2013).

In this review, an attempt has been made by the World Vegetable Center (World Veg) to assess the possible impact of climate change on the plant metabolism and associated physiology of mungbean. WorldVeg maintains the world's largest collection of mungbean germplasm and the crop is cultivated on over 6 million hectares in warmer regions of the world. It is one of the most important high protein food legumes in South and Southeast Asia, particularly in the Indian sub-continent which accounts for almost 45 per cent of global production. As a short duration (60-65 days) legume, it has wide adaptability with low input requirements (Nair *et al.,* 2012). However, its productivity is very low in India, Bangladesh and Pakistan. Poor crop management is exuberated by a harsh growing climate and abiotic stresses such as high temperatures at flowering and increasing soil salinity (Kaur *et al.,* 2015; Bindumadhava *et al.,* 2016).

Physiological responses to changing CO_2 concentration in the environment

Global climate models predict that by 2100 there will be a gradual increase in atmospheric CO_2 concentration from current levels of around 400 ppm CO_2 to a maximum of as much as 550 ppm and an increase in average global temperatures of 2.2°C (Anon., 2014). As increasing CO_2 concentrations in the atmosphere are known to be the principal driver of climate change (Bhardwaj, 2012), it is important to assess their effects on plant growth and development (Sigut *et al.,* 2015; Peet and Wolfe, 2000). Carbohydrates synthesized during photosynthesis provide the necessary energy source for plant growth, but, the photosynthetic function under high temperatures and light intensities is limited by the ambient CO_2 concentration. Increated photosynthesis under elivated CO_2 can increas dry matter production (Taiz and Zieger, 2015).

This CO_2 fertilizer effect is used commercially to stimulate crop growth in greenhouses and other controlled environments using elevated CO_2 concentrations (Lobell and Gourdji, 2012). This effect is more pronounced in C_3 crops, such as rice, wheat, legumes (*e.g.,* soybean, mungbean etc.) but, less so in C_4 crops (*e.g.*, maize, millet and sugarcane). While, the present CO_2 atmospheric level limits photosynthesis in C_3 plants, higher CO_2 levels will activate the rate limiting enzyme RuBisCO, for carboxylation, leading to accelerated biochemical reactions (Bindumadhava *et al.,* 2011; Sheshshayee *et al.,* 1996). This initial jump is temporary, due to feedback inhibition and incompetent functional sinks. However, C_4 plants avoid this effect with a built-in CO_2 concentration ability in the vascular bundles of mesophyll cells (Taiz and Zieger, 2015). Thus, if the CO_2 level is doubled, the photosynthesis of only C_3 plants increase by 35-50 per cent (Johkan *et al.,* 2011). However, this response may be only short-term, and the response under long-term exposure to elevated CO_2 may be less which is often the case when photosynthetic production exceeds plant growth (Nakano *et al.*, 1997; Sigut *et al.,* 2015).

In most crops, increased CO_2 improves water use efficiency due to the higher carbon fixation function triggered by photosynthesis and declining stomatal conductance, potentially decreasing drought susceptibility and reducing water requirements. When substrate CO_2 is high, it prevents stomatal control of its diffusivity between outside and inside the leaves (Bindumadhava *et al.,* 2011). However, the effect of decreased transpiration on vegetable crop yields is unlikely to be large since vegetables are irrigated in most production areas (Anon., 2004). However, physiological disorders such as tip-burn in lettuce, blossom-end rot in tomato and bell-pepper, are sometimes associated with excessive transpiration and tissue water deficits (Rogers and Dahlman, 1993).

Temperature increases will occur concurrently with a CO_2 increase and both interact closely (Idso *et al.,* 1987). High temperature affects the photosynthetic functions and causes irregularities in CO_{2-} physiological processes. For instance, in tomato, overall productivity is reduced by high temperatures due to bud drop, abnormal flower development, dehiscence and viability, ovule abortion, poor viability and reduced carbohydrate availability (De La Peña and Hughes, 2007). Some universal strategies to ameliorate the effects of global warming on food production include the development and use of heat-tolerant varieties, appropriate nutrient and water management, coordination of growing periods, and the control of pests/diseases. In particular, the use of heat-tolerant crops and pest/disease control are perhaps the most promising approaches (Johkan *et al.,* 2011). Any useful effect of elevated CO_2 might be offset by the adverse global warming effect. Increased temperatures accelerate many physiological processes *viz.,* photosynthesis to an upper limit. Extreme temperatures can be harmful beyond the physiological limits of a plant (Lynch and Lande, 1993). Temperature distresses vegetable crops in several ways by influencing crop duration, flowering, fruit growth, ripening and quality. Since vegetables are basically succulent and usually consist > 90 per cent of water, drought stress, mostly at critical periods of growth, will drastically reduce productivity and quality (Chatterjee and Solankey, 2015). Nonetheless, it is suggested that indeterminate types are less sensitive to periods of heat stress since the time of flowering could be extended compared with determinate types (Hall and Allen, 1993). Under heat stress, the reported effect of elevated CO_2 on photosynthesis and growth are however highly variable and differ among functional groups of plants (Wang *et al.,* 2012; Sigut *et al.,* 2015; Bindumadhava *et al.*, 2017.

Heat stress has detrimental effects at several plant levels leading to drastic reductions in growth and yield (Bindumadhava *et al.*, 2016; Wahid *et al.,* 2007). It results in a scorching effect leading to mild to severe browning of leaves. Leaf damage intensifies due to oxidative damage and a reduction in anti-oxidative defenses (Kumar *et al.,* 2013). The roots, flowers and seeds depend on the leaves to supply sucrose, and other molecules for nodulation growth, reproductive function and seed filling. Hence, maintenance of the photosynthetic function of the leaves is vital under heat stress to sustain synthesis and the transport of sucrose to these organs (Awasthi *et al.,* 2014). Sucrose, is set to decrease in leaves and seeds owing to heat stress conditions, which may be linked to reduced RuBisCO activity and sucrose synthesizing enzymes. Heat stress affects sucrose production in leaves and impairs its transport to developing reproductive sinks (Kaur *et al.,* 2015). It also reduces nitrogen fixation, by heating up the soil surface hampering nodulation and affecting rhizosphere activity, thus, reducing the nodules in mungbean roots (Kumar *et al.,* 2013). Photosynthesis may be inhibited as a result of loss of chlorophyll, disruption of electron flow and reduced CO_2 assimilation (Sinsawat *et al.,* 2004). At a cellular level, heat stress leads to membrane damage, enzyme inactivation in mitochondria and chloroplasts, impaired protein synthesis and carbon metabolism (Hasanuzzaman *et al.,* 2013).

Mungbean physiology efforts at WorldVeg, South Asia, India

Starting in February, 2015 WorldVeg initiated a study on mungbean to explore the dual effect of high temperature with elevated CO_2 levels. A total of 45 elite mungbean accessions representing genotypes from different sources in India were used. Agronomic and physiological traits were assessed along with final pod and seed yields in both a walk-in growth house and in field conditions. Sets of accessions were sown at two planting times, in the last week of March (normal-sowing) and the last week of April (late sowing) when day / night temperatures during most of the reproductive phase were >40 / 25°C (producing heat stress for the later sowings). The response of these accessions to higher temperatures (during peak growth and the reproductive stages in the late sowing) was determined over the whole growth and production cycle. Change in growth behaviour (reduced leaf area, tip burning, accelerated chlorosis) was noticed in late sown plants. Further a change in pattern of both pod and seed size and morphology was also observed (Fig. 1). However, we found the effect of heat stress was more pronounced on pod morphology than the seed, which needs to be confirmed in subsequent experiments. Similar pattern was reported in chickpeas (Kumar *et al*., 2013; Kaushal *et al*., 2013). Based on sustained growth, physiology (photosynthetic efficiency, chlorophyll function, stomatal & transpiration efficiency, functional water relations), reproductive status (flowering initiation, effective number of flowering clusters, resistance of flower abortion, pollen germination & viability, stigma receptivity) and final yield traits (number of pods, pod setting, pod and seed yield/plant), ten putative high temperature tolerance accessions were identified for further investigation (Sharma *et al.,* 2016).

Fig. 1. Pod (a) and seed (b) morphology of a few selected mungbean accessions from normal and late sown season (see the heat induced changes in pod shape, size and length in late-sown genotypes; for details refer Sharma *et al*., 2016)

To simulate future climate change scenarios, these selected accessions were exposed to elevated CO_2 environments to determine their growth and yield responses. They were grown in Open Top Chambers (OTC) at the controlled climate management facility at the ICRISAT campus in Hyderabad, India. Container-grown plants of 10 mungbean accessions were placed randomly inside OTCs for growth and yield assays (maintained at three CO_2 concentrations; 390 ppm, 550 ppm and 700 ppm). Changes in growth rates and yield traits were measured regularly up to final harvest. Among the accessions, an appreciable increase in growth traits (plant height ~ 45 %, leaf area ~ 52%, total dry matter ~ 78%) in both elevated levels of CO_2 (550 and 700 ppm) was observed along with increased yield traits (pod yield ~ 78% & seed yield ~ 45%) (Fig. 2). Among the two CO_2 levels, 550 ppm had more pronounced effect on growth and yield attributes than 700 ppm. Exposure to 550 ppm CO_2 resulted in 12-13 days early maturity in a few accessions. Subsequent assays are underway to examine the physio-biochemical efficiencies contributing to the differential response of CO_2 fertigation in heat tolerant accessions. This is perhaps the first information in mungbean on assessing the growth and yield responses of promising heat tolerant accessions to elevated CO_2 conditions. It offers useful clues towards developing a growth model to address future climate challenges.

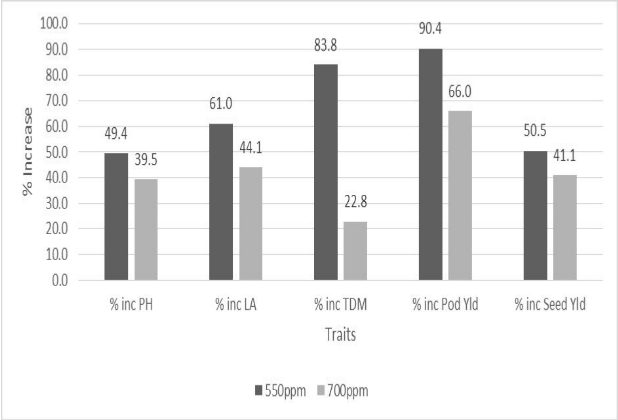

Fig. 2. Per cent increase in growth and yield traits of CO_2 enriched plants over ambient CO_2 (control) across all mungbean accessions [(PH- Plant Height, LA – Leaf Area, TDW – Total Dry Weight, Pod yield (pod weight/plant) and Seed yield (seed weigh/plant)].

Climate change is predicted to have a major impact on agriculture and horticulture. Knowing the possible effects of increasing air temperatures and CO_2 on annual vegetables and legume crops can help to select lines that will be more adapted to these conditions. In this study, it was found that 9-10 mungbean accessions with intrinsic tolerance to high temperature stress and five of them showed intrinsically higher performance under elevated CO_2 conditions. Hence, they can be seen as elite promising candidates for subsequent analysis for climate resilience. Further, higher CO_2 influx at different growth stages will be used for developing a futurist mungbean model. Exploring intrinsic physiological mechanisms and phenotypic traits that imparts tolerance to adverse climate, assumes greater importance in the present time.

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