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Review Paper on Heat stress in french bean and garden pea

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ABSTRACT

This review paper addresses the effect of high temperature on pea and similar legumes. The areas covered are field pea and its production, temperature stress effects on New Zealand agriculture, seed vigour which discusses hollow heart and conductivity, high temperature stress on seed germination, threshold temperature, high temperature effects on vegetative growth and reproductive development. This is followed by adaptation mechanisms for high temperature stress, and breeding strategies which cover conventional plant breeding. The quality traits refer to protein, sugars, and the effects of high temperature on the grain composition and quality. Because of various factors related to global climate change, ambient temperatures are expected to rise in the future. Heat stress, which is a serious danger to crop output in most nations, can emerge from these temperature rises. Legumes are well-known for their nutritional and health benefits, as well as their impact on agricultural sustainability. Heat stress is a problem for legume crops because it affects the morphology, physiology, and reproductive growth of the plants. As grain legume agriculture grows to warmer areas and temperature fluctuation increases owing to climate change, high-temperature stress during the reproductive stage is becoming a serious constraint for output. The reproductive stage is critical in the life cycle of all plants, and it is vulnerable to high-temperature stress because many metabolic processes are harmed at this time, resulting in lower crop yields. Flower abortion, pollen and ovule sterility, decreased fertilization, and reduced seed filling are all observed in food legumes exposed to high-temperature stress during reproduction, resulting in smaller seeds and poorer yields. Heat tolerance in major legumes can be improved through several breeding approaches to improve field performance. Understanding the processes of molecular responses to high-temperature stress necessitates the use of omics methods to uncover the pathways behind thermo-tolerance.

Keywords Abiotic stresses, Pea, Legumes, Threshold, Adaptation mechanism.

INTRODUCTION

Legumes are members of the Fabaceae/Leguminosae

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family (with about 700 genera and 18,000 species). Cool-season food legumes and warm- or tropical-season food legumes can be separated into two groups based on their capacity to grow in different seasons (Miller *et al.* 2002, Toker and Yadav 2010). Cool-season food legumes include broad bean (*Vicia faba*), lentil (*Lens culinaris*), lupin (*Lupinus* spp.), dry pea (*Pisum sativum*), chickpea (*Cicer arietinum*), grass pea (*Lathyrus sativus*), and common vetch (*Vicia sativa*) (Andrews and Hodge 2010). Warm-season food legumes include pigeonpea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), mungbean (*Vigna radiata* var. *radiata*), common bean (*Phaseolus* spp.) and urd bean (*Vigna mungo*), which are mainly grown in hot and humid conditions (Singh and Singh 2011). Legumes rank third in world crop production, after cereals and oilseeds (Popelka *et al*. 2004), these crops are important source of food, feed, and fodder in several agricultural systems and are grown on a large scale in the semi-arid tropics (Popelka *et al*. 2004, Varshney and Dubey 2009). The principal grain legumes, in order of their respective worldwide consumption, are common beans (*Phaseolus* spp.), field pea, chickpea, broad bean, pigeon pea, mungbean, cowpea, and lentil (Duc *et al*. 2015). Grain legumes alone contribute 33% of human protein nutrition and can fix atmospheric nitrogen in symbiotic association with Rhizobium bacteria, to fulfill the nitrogen requirement of the succeeding crop. Legumes are cultivated in crop rotation worldwide along with other crops but their production potential is constrained by high temperatures (McDonald and Paulsen 1997, Considine *et al*. 2017).

Various abiotic stresses, such as temperature, drought and salt, affect the growth of legumes at different developmental stages (Suzuki *et al*. 2014). Abiotic stresses are the primary cause of crop losses worldwide, reducing the yield of most plants by >50% (Rodríguez *et al*. 2006). Abiotic stresses result in a series of morphological, physiological, biochemical and molecular alterations, which negatively influence plant growth, productivity and yield (Wang *et al.* 2001, Bita and Gerats 2013). Plants experience multiple effects of these stresses including physiological functions such as photosynthesis, respiration, nitrogen fixation, reproduction, and oxidative metabolism (Iba 2002, Farooq *et al*. 2008). Temperature stress has the widest and most far-reaching effects on various crops leading to a severe reduction in yield potential (Bita and Gerats 2013).

High-temperature stress and its threshold in plants

Temperature is a major factor affecting seed yield and quality in legumes (Ruelland and Zachowski 2010, Christophe *et al*. 2011). Increases in air temperature, even by one degree above a threshold level, is considered heat stress in plants (Teixeira *et al*. 2013). Heat stress for most subtropical and tropical crops is when temperatures increase above 32–35°C (Bita and Gerats 2013), however, a daily maximum temperature above 25°C is considered the upper threshold for heat stress in cool-season crops (Wahid *et al.* 2007). The impact of heat stress depends on the intensity, duration of exposure, and the degree of the elevated temperature. Extreme variations in temperature, both high and low, can have serious implications on plant development by impairing plant growth and function (Wahid *et al.* 2007). Temperature stress imposes challenges in plants at various organizational levels with deleterious effects on vegetative and reproductive growth (Hamidou *et al*. 2013). Furthermore, increased frequency of temperature stress can disrupt the physiological processes of plants resulting in photosynthetic inhibition, reduced nitrogen anabolism, higher protein catabolism, and accumulation of the end products of lipid peroxidation (Jagtap *et al*. 1998, Jiang and Huang 2001a,b). Heat-stressed plants show shorter vegetative and pod-filling periods (Adams *et al*. 2001), poor crop stand and consequently reduced yield. High-temperature stress affects reproductive development, as reported in legumes such as chickpea (Kaushal *et al*. 2013, Kumar *et al.* 2013), pea (Guilioni *et al.* 1997), common bean (Gross and Kigel 1994, Vara Prasad *et al*. 2002), mungbean (Tzudir *et al.* 2014, Bindumadhava *et al*. 2016), cowpea (Ahmed *et al*. 1992) and cereals such as rice (*Oryza sativa*, Madan *et al*. 2012), wheat (*Triticum aestivum*, Wahid *et al.* 2007), barley (*Hordeum vulgare*, Barnabás *et al*. 2008), and maize (*Zea mays*, Kumar *et al.* 2012a). High temperature negatively affects flower initiation, pollen viability (germination and tube growth), stigma receptivity, ovule viability, ovule size, fertilization, seed/fruit set, seed composition, grain filling, and seed quality (Barnabás *et al.* 2008). Cool-season food legumes are more sensitive to heat stress than warm-season food legumes. The critical temperature for heat tolerance seems to be higher in chickpea than in faba bean, lentil, and field pea, and the reverse is true for cold tolerance (Devasirvatham *et al.* 2013).

Impact of heat stress on plant

Field pea and bean are very sensitive to high temperatures and seed production starts to decline when the maximum daytime temperature increases to above 25 to 30 °C (Guilioni *et al.* 1997, Guilioni *et al*. 2003, Pumphrey and Ramig 1990). In addition, when the temperature is over 35ºC, it is considered more severe for pea seed production (Munier-Jolain *et al.* 2010). The high temperature effects at flowering stage, anthesis, growth and development, and grain-filling stages have been extensively studied in maize (*Zea mays*), sorghum (*Sorghum biocolar*), common beans (*Phaseolus vulgaris*), cowpeas (*Vigna unguiculata*) (Luo 2011), rice (*Oryza sativa*) (Chaturvedi *et al.* 2017) and wheat (*Triticum aestivum* L.) (Gupta *et al.* 2015) using phenological, morphological and physiological approaches. High temperature (25-35°C) and water deficit was also cited to be the cause of hollow heart disorder in peas after onset of pod wrinkling (Halligan 1986, Heydecker and Kohistani 1969). Pea seed production has been extensively studied in New Zealand including plant production, pest and diseases, irrigation requirements, fertilizer (Wilson 1987) nutrition, time of sowing, and harvesting methods on seed quality and yield (Padrit 1996), population density, production factors and seed quality characters under field conditions (Castillo *et al*.1993), sowing, growth and development (Nguyen 2012). However, impact of increased temperature on pea seed production has not been studied with little information available to date.

Temperature effects on seed germination

Successful crop production depends on the seed quality, rate of germination, seed mass and seed vigour. According to Huang (2016) stated the optimum temperature to encourage germination and growth development in pea is 13-20 °C and 15-25 °C respectively which is also accepted as the threshold for pea germination and growth and is in agreement with Sita *et al.* (2017). When the air temperature is above the optimum level, it can affect vegetative development by reducing germination percentage, seedling emergence, increase abnormal seedlings, poor seedling vigour and reduced radical and plumule development in legumes (Sita *et al*. 2017).

Temperature stress and threshold temperature

Temperature is a major factor affecting seed yield and quality in legume crops. The increase in air temperature by one degree above the threshold can induce detrimental effects on plant growth development, seed and yield. In most of the sub-tropical and tropical crops, the temperature threshold is 32-25 °C (Sita *et al*. 2017). However, in the cool season crops the maximum threshold is 25 ºC (Wahid *et al.* 2007). The effect of temperature stress depends on intensity, duration of the exposure and the degree of the elevated temperature (Davisirvatham *et al.* 2012, Sita *et al*. 2017).

Effect of temperature stress on vegetative growth performance

Vegetative parts of a plant respond to high temperature stress in various ways by showing different symptoms on the plant parts. Some of these common responses are scorching, sun burning of leaves, twigs, branches and stems, senescence of leaves, followed by abscissions, imbibition of shoot and root growth, and discoloration of fruits which can severely reduce yield. Furthermore, exposure of plants to high temperatures reduce shoot growth, root number, root diameter, cause leaf wilting, leaf curling, leaf yellowing and reduce plant height and biomass (Siddiqui *et al*. 2015). All these reduce the value of the plant as a source of nutrients for the developing seed.

Effect of temperature stress on reproductive development

The high temperature effects on reproductive organ development has been widely reported in many legumes including common beans (Gross and Kigel 1994), chickpeas (Kaushal *et al*. 2013, Kumar *et al.* 2013), and peas (Guilioni *et al.* 1997), whilst in cereal crops it was reported in barley, maize, rice and wheat (Sita *et al.* 2017, Wahid *et al*. 2007). The reproductive organs starting from flower initiation through to seed development respond differently to high temperature stress (Sita *et al.* 2017). High temperature is lethal to flower buds and fruits, pods and seeds (Kaushal *et al*. 2016).

Adaptation mechanism to temperature stress

Plants escape high temperatures by accelerating their growth to complete a full life cycle prior to an oncoming high temperature stress or heat stress event. This strategy is widely used in native plant species (Shavrukov *et al*. 2017).

The avoidance mechanism can be achieved in plants by changing leaf orientation, transpiration cooling, alteration of membrane lipid composition, closure of stomata and reduce water loss, increased stomatal and trachomatous densities, large xylem vessels are some of the common avoidance strategies in plants (Hasanuzzaman *et al.* 2013, Zhang *et al.* 2016).

The mechanism of heat tolerance has been linked to increased tolerance of photosynthetic apparatus (Asthir 2015).The heat tolerance mechanisms include protection and repair of damaged cells structures and structural proteins and enzymes (Shah *et al.* 2011).

CONCLUSION

Heat stress causes severe agricultural losses, which is a risk to world food security with consequences that will challenge human welfare. Among the crop growth cycle, the reproductive phase is more susceptible to high-temperature stress than the vegetative phase. While the male reproductive organs are more sensitive to heat stress than the female counterpart, the complete reproductive process from gamete formation to fertilization and seed maturation are highly vulnerable to raised temperatures. Microsporogenesis is disrupted at high temperatures due to damage caused by the tapetal layer and nutrient imbalance in developing pollen, resulting in sterility. Heat stress has detrimental effects on ovule development and viability. Fertilization is impaired due to reduced pollen viability, stigma receptivity, and pollen tube growth. Further, reduced seed filling, increased seed abortion and smaller seeds affect the seed weight. All these effects may occur due to diminished photosynthetic rates, which result from metabolic and cellular dysfunction, and lead to reduced photosynthate supply to developing seeds.

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