Edited by

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Legumes under Environmental Stress

Yield, Improvement and Adaptations

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Preface

Legumes represent the most utilized plant family with 20,000 species and are among the most important crops worldwide, having major impacts on agriculture, the environment, and human/animal nutrition and health. Legumes rank third behind cereals and oilseeds in world production, accounting for 27% of the world's primary crop production. Grain legumes constitute an important dietary constituent for humans and animals and these alone contribute 33% of the dietary protein nitrogen (N) needs of humans besides being a source of income and livestock feed. These perfectly match the requirements of small-scale, low-income farmers in the developing countries where they accounted for 61.3 million hectares in 2002, compared to 8.5 million hectares in developed countries. The primary dietary legumes are common beans, pea, chickpea, broad bean, pigeon pea, cowpea and lentil. Legumes are also major sources for vegetable oil, with soybean and peanut providing more than 35% of the world's processed vegetable oil.

Legumes are often exposed to environmental stresses (biotic and abiotic) that decrease productivity throughout the world. Abiotic stresses (salt, drought, temperature, UV, nutrient deficiency) alone are responsible for more than 50% yield reductions of some major crops. Abiotic stress causes osmotic and oxidative stress within the plant. The oxidative stress is caused by the generation of reactive oxygen species (ROS). These ROS react with biomolecules like proteins, nucleic acids, membrane lipids, etc. and hamper their normal functioning in the cell. Plants respond to these stresses through synthesis of metabolites and antioxidant enzymes that enhance tolerance mechanisms in plants under stress. Biotechnology approaches are also used for the improvement of legume crops under environmental stresses. The present volume comprises 17 chapters that provide detailed information on legumes, yields, mitigation strategies for different abiotic stresses, and new approaches in alleviating environmental stress in legumes.

Chapter 1 gives an overview of legumes and breeding under abiotic stress. Different abiotic stresses, and breeding of cool and warm season food legumes, are well documented. Chapter 2 discusses the effect of salt stress on leguminous crops. Omics approaches for understanding salt stress responses in legumes are also mentioned. Chapter 3 throws light on the effect of different abiotic stresses on legumes. The effects of nutrient deficiency, methods to control nutrient deficiency and the role of these nutrients in alleviating abiotic stress are well explained. Chapter 4 is about chickpea, its role and responses under abiotic and biotic stress. The role of omics in investigating chickpea under abiotic stress, and breeding of chickpea to resist biotic stress are also explained in detail. Chapter 5 deals with the effect of temperature stress on chickpea at different growth stages. Chapters 6 and 7 explain the effects of pesticides on legumes. Chapter 8 highlights the symbiotic association between legumes and rhizobia under abiotic stress, the nodulation process, and the effect of osmotic stress on nodule integrity and functioning. Chapter 9 deals with microbial strategies for improving legume production under hostile environments. Chapter 10 discusses the role of abscisic acid (ABA) in legumes under abiotic stress. ABA regulation of leaf expansion, and nodulation under abiotic stress is well documented. Chapter 11 describes the exogenous application of phytoprotectants in legumes to combat environmental stress. The roles of phytohormones, compatible solutes, nutrients and trace elements are nicely explained. Chapter 12 is about genetic and molecular responses of legumes under changing environments. Chapter 13 deals with omics approaches and abiotic stress tolerance in legumes. Transcriptomics, proteomics, genomics, metabolomics, transgenomics, functional genomics and phenomics of different legumes under stress are well documented. Chapter 14 discusses microRNA (miRNA)-mediated regulatory functions under abiotic stresses in legumes. Here the authors discuss miRNA identification, functional diversity, and expression profiling under abiotic stress in legumes. Chapter 15 deals with biotechnological approaches to overcome biotic and abiotic constraints in legumes. Chapter 16 explains gene pyramiding and omics approaches to enhance stress tolerance in leguminous plants. Finally, Chapter 17 discusses how to combat phosphorus deficiency on alkaline calcareous soils by using an adsorption isotherm technique for legume crops in arid environments.

This volume is a comprehensive account of current knowledge about the physiological responses and adaptability of legumes to salt, temperature and other environmental stresses. We have tried our best to ensure the accuracy of the information in this volume, however, there is a possibility that some errors remain, for which we seek readers' indulgence and feedback. We are also very grateful to the authors for their valuable contributions. Gratitude is also due to the publisher, John Wiley & Sons, Ltd., particularly Gudrun Walter (Editorial Director, Natural Sciences), Fiona Seymour (Senior Project Editor), Laura Bell (Assistant Editor), Renee Last, and all the other staff members of Wiley, who were directly or indirectly associated with us in this project for their constant help, valuable suggestions, and efforts in bringing out the timely publication of this volume.

M.M. Azooz
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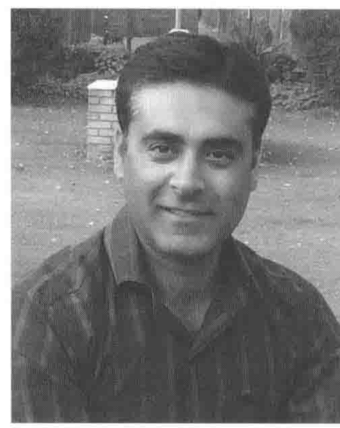

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CHAPTER 1

Legumes and breeding under abiotic stress: An overview

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1.1 Introduction

The present world population of 7.2 billion is expected to reach 9.6 billion by the middle of the 21st century due to the high growth rate, particularly in developing countries. There is a need to produce about 70% more food to feed this excessive population (Varshney & Roorkiwal, 2013).

Legumes belong to the family Fabaceae/Leguminosae (with about 700 genera and 18,000 species). Legume crops can be divided into two groups according to their ability to grow in different seasons, namely cool season food legumes and warm or tropical season food legumes (Miller *et al.*, 2002; Toker & Yadav, 2010). The cool season food legumes include broad bean (*Vicia faba*), lentil (*Lens culinaris*), lupins (*Lupinus* spp.), dry pea (*Pisum sativum*), chickpea (*Cicer arietinum*), grass pea (*Lathyrus sativus*) and common vetch (*Vicia sativa*) crops (FAOSTAT 2009; Andrews & Hodge, 2010). These are among the world's oldest cultivated plants (Materne *et al.*, 2011). Dry pea, chickpea, broad bean and lentil are the four major cool season grain legume crops produced for human consumption. They are grown on all continents except Antarctica. Lupin species – e.g. *Lupinus albus* (white lupin) and *Lupinus luteus* (yellow lupin) – and vetches – in particular, common vetch – are important for animal feed (Andrews & Hodge, 2010). On the other hand, the warm season food legumes include pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), soybean (*Glycine max* L.), mung bean (*Vigna radiata* var. *radiata*) and urd bean (*Vigna mungo*) crops, which are mainly grown in hot and humid climatic conditions. Warm season food legumes are popular in different parts of world; for example, pigeon pea is mainly grown in India and African countries, cowpea and soybean are important crops in the USA, while mung bean and urd bean are important crops in Southeast Asian countries, especially in the Indian subcontinent (Singh *et al.*, 2011).

Legumes rank third after cereals and oilseeds in world production and have major effects on the environment, agriculture, and animal and human nutrition and health (Graham & Vance, 2003; Dita *et al.*, 2006; Mantri *et al.*, 2013). Legumes are a primary source of amino acids and provide around one-third (20–40%) of all dietary protein (Zhu *et al.*, 2005; Kudapa *et al.*, 2013). Legumes produce secondary metabolic compounds that can protect the plant against pathogens and pests (Kudapa *et al.*, 2013).

Legumes are second to cereals in providing food for humans worldwide (Kamal *et al.*, 2003; Ashraf *et al.*, 2010; Kudapa *et al.*, 2013). In comparison with cereal grains, legume seeds are rich in protein, and thus are a source of nutritionally rich food (Ahlawat *et al.*, 2007; Ashraf *et al.*, 2010; Kudapa *et al.*, 2013). Grain legumes such as chickpea, pigeon pea, cowpea, dry pea, lentil, mung bean, urd bean, bean (*Phaseolus vulgaris* L.), broad bean and grass pea are the main source of dietary protein for vegetarians, and are an integral part of the daily diet in several forms worldwide. In addition, grain legumes, predominantly peanut (*Arachis hypogaea* L.) and soybean are also major sources for vegetable oil, providing more than 35% of the world's processed vegetable oil (Sharma *et al.*, 2010).

Legumes under Environmental Stress: Yield, Improvement and Adaptations, First Edition. Edited by Mohamed Mahgoub Azooz and Parvaiz Ahmad.

Legumes play an important role in diet and they are often referred to as 'poor man's meat'. Legumes are an important source of protein, oil, fibre and micronutrients, and play a vital role in cropping cycles due to their ability to fix atmospheric nitrogen (El-Enany *et al.*, 2013; Mantri *et al.*, 2013).

Under conducive environmental conditions, legumes develop symbiotic associations with arbuscular mycorrhizal (AM) fungi, leading to the formation of sites of phosphorus nutrient exchange called arbuscules (Parniske, 2008; Mantri *et al.*, 2013).

Biological fixation of nitrogen (N) is considered more ecofriendly than industrial N fixation because the NH_3 produced in the former process is readily assimilated into organic forms by the plant (Valentine *et al.*, 2011). Biological nitrogen fixation (BNF) in legume nodules occurs with differentiated forms of rhizobia, termed bacteroids, within specialized structures called symbiosomes, inside the host plant cells (Arrese-Igor *et al.*, 2011). Thus, these symbiotic associations have strongly driven the investigation and application of biotechnology tools for legumes (Dita *et al.*, 2006).

It is estimated that crops grown on 90% of arable lands experience one or more environmental stresses. Abiotic stress causes more than 50% of crop loss worldwide (Rasool *et al.*, 2013; Rodziewicz *et al.*, 2014). 'Abiotic stress' is a broad term that includes multiple stresses (drought, waterlogging, salinity, heat, chilling and mineral toxicities) and negatively affects the adaptability and yield of legumes. Application of biotechnology tools to legume crops can help in solving or reducing the problems resulting from abiotic stress.

This chapter aims to review the main abiotic stresses that have a negative impact on the production of some important food legumes. It also summarizes the selection criteria and available genetic resources for stress resistance under abiotic stress conditions.

1.2 Legumes under abiotic stress

1.2.1 Legumes under drought

Drought is a type of water stress that is imposed due to lack of rainfall and/or inadequate irrigation. About 60% of all crop production suffers from drought conditions (Grant, 2012; Naeem *et al.*, 2013). For legumes, drought stress has adverse effects on total biomass, pod number, seed number, seed weight and quality, and seed yield per plant (Toker *et al.*, 2007b; Charlson *et al.*, 2009; Khan *et al.*, 2010; Toker & Mutlu, 2011; Impa *et al.*, 2012; Hasanuzzaman *et al.*, 2013; Pagano, 2014). Drought alone resulted in about a 40% reduction in soybean yield (Valentine *et al.*, 2011). Faba bean and pea are known to be drought-sensitive, whereas lentil and chickpea are known as drought-resistant genera (Toker & Yadav, 2010). Singh *et al.* (1999) arranged warm season food legumes in increasing order of drought tolerance: soybean < blackgram < greengram < groundnut < Bambara nut < lablab < cowpea. Sinclair and Serraj (1995) reported that legumes such as faba (broad) bean, pea and chickpea export amides (principally asparagine and glutamine) in the nodule xylem are generally more tolerant to drought stress than cowpea, soybean and pigeon pea, which export ureides (allantoin and allantoic acid).

The symbiotic nitrogen fixation (SNF) rate in legume plants rapidly decreased under drought stress due to (i) the accumulation of ureides in both nodules and shoots (Vadez *et al.*, 2000; Charlson *et al.*, 2009), (ii) decline in shoot N demand, (iii) lower xylem translocation rate due to a decreased transpiration rate, and (iv) decline of metabolic enzyme activity (Valentine *et al.*, 2011). Several reports have indicated that drought stress led to inhibition in nodule initiation, nodule growth and development as well as nodule functions (Vadez *et al.*, 2000; Streeter, 2003; Valentine *et al.*, 2011). The decrease in SNF under drought conditions was associated with the reduction of photosynthesis rate in legumes (Ladrera *et al.*, 2007; Valentine *et al.* 2011).

In many nodules of legumes, water stress resulted in stimulation of sucrose and total sugars (González *et al.*, 1995, 1998; Ramos *et al.*, 1999; Streeter, 2003; Gálvez *et al.*, 2005; Valentine *et al*,. 2011). This was consistent with a study on pea mutants, which showed that sucrose synthase (SS) is essential for normal nodule development and function (Craig *et al.*, 1999; Gordon *et al.*, 1999).

Drought stress induces oxidative damage in legumes and this has a harmful effect on nodule performance and BNF (Arrese-Igor *et al.*, 2011). Some reports suggest that nodules having an increment in enzymatic antioxidant defence can display a higher tolerance to drought/salt stress in common bean (Sassi *et al.*, 2008) and chickpea (Kaur *et al.*, 2009). In addition to this, Verdoy *et al.* (2006) reported improved resistance to drought stress in *Medicago truncatula* by overexpression of Δ-pyrroline-5-carbolyate synthetase resulting in accumulation of high proline levels.