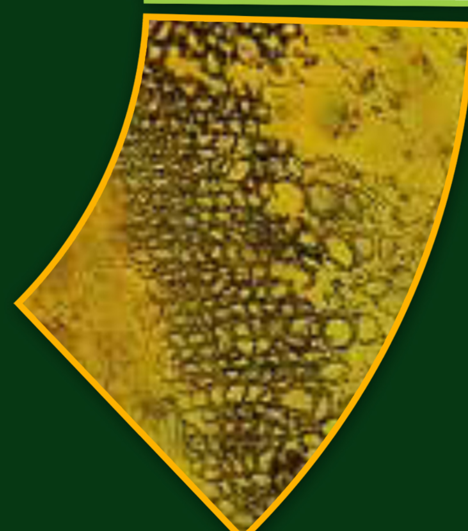

# Advances in Legume Research

## Physiological Responses and Genetic Improvement for Stress Resistance


Editors:

**Phetole Mangena**

**Sifau A. Adejumo**


**Bentham Books**

# Advances in Legume Research: Physiological Responses and Genetic Improvement for Stress Resistance

# (Volume 2)

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**Advances in Legume Research: Physiological Responses and Genetic Improvement for Stress Resistance**

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# FOREWORD

Legumes play important roles in human diets. They serve as the main source of proteins especially for resource-poor families. They represent important sources of human and animal feeds that are rich in protein. More importantly, by their symbiotic interactions with nitrogen-fixing bacteria, apart from their contribution to food security and nutrition, they play a major role in climate change mitigation by serving as an alternative and sustainable strategy for improving soil fertility. Though, the Green Revolution in agriculture has helped in meeting the demands for food security by developing new crop varieties and increasing the use of synthetic nitrogen (N) fertilizer that is also contributing to climate change,, legume production does not depend on the use of synthetic fertilizers. It rather improves soil nutrient status and reduces over-dependence on nitrogen fertilizers. Legumes, therefore, should be considered key components in a sustainable agronomic programme. Their production, however, faces many challenges which are grouped under biotic and abiotic stresses.

To take advantage of these potential benefits of legumes, there is a need for a thorough understanding of the challenges faced by farmers in growing leguminous crops. High up on the list of challenges are the threats posed by a range of biotic stresses. It is therefore of immense value that these stresses are so effectively described in this volume. It is a comprehensive and expansive consideration of how biotic stress impacts legumes and how they can be managed. Further, as the authors are all working in Africa, they offer a unique perspective on the potential of legumes in a continent that is witnessing a substantial increase in human population and where climate change is also a major concern. The United Nations estimates that the human population will reach 8 billion at the end of 2022, representing an increase of one billion new mouths to feed. Against this background, the increase in the production of leguminous crops offers obvious attractions. I, therefore, unequivocally recommend this book to agronomists and to general science readers.

**Luis Mur**
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# PREFACE

When the first volume of **Advances in Legume Research** was published in 2020 it was not anticipated that this next volume would soon begin, with so much interest of our authors sparked by the previous one. As the previous volume reported a vast amount of advanced information regarding both biotic and abiotic stress-induced reductions in the growth and yield of legumes, particularly, cowpea, mung bean and soybean. Presently, we focussed the current volume on pertinent literature and specific new developments that belong to the topic, as chosen for this book. As earlier envisioned, this book is intended to share new developments pertaining to the ways in which biotic stress factors continue to inflict harm on leguminous crops, as they are among the most vulnerable and highly sensitive groups of oilseed crops worldwide. Although it is aimed at both experienced and newcomer researchers/ students, this book offers new insights for individuals looking for new perspectives in the current knowledge of diseases and pests, associated with legumes, as well as the mechanisms in which these crops may or may not resist these attacks. Mostly, the book focuses on the influences of bacteria, fungi, viruses, arthropodous spiders and invertebrate organisms, as well as how climate change drives the population diversity and distribution of these microbial pests in order to limit plant growth and productivity in leguminous crops.

Such a book is highly required, especially to grow our knowledge and understanding of how the genetic diversity of crop plants can be protected, improved and sustained to benefit the current and future generations. This endeavour can be beefed up by establishing efficiently analysed genomics and proteomics data that provide concrete insights underlining molecular mechanisms that play a critical role in enabling crops to effectively adapt and respond to biotic stress, as highlighted in the introductory chapter of this book. As we look ahead to the possible preparation of the next volume, we hope that readers of this and previous volumes will find time and space to provide us with critical comments, suggestions or errors, if any. Finally, we are very indebted to Dr. Mabila and Ms. Noko Monene (Department of Research Administration and Development, University of Limpopo, South Africa) for their continued financial support, Prof. Luis Mur for providing his expertise outlook and reasons why readers must read this book. Also, many thanks are due to our publisher for all the help we received and for patiently waiting for documents. We are especially grateful to the authors and everyone who assisted over the period of preparing this volume.

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# ACKNOWLEDGEMENT

Yet again, the paramount goal of delivering a comprehensive book that clearly elucidates the understanding of physiological and genetic mechanisms to confer biotic stress resistance was made possible by all contributors. As such, we are very much grateful to all the authors and everyone who provided their high-quality contributions. We express our special thanks and appreciation to Bentham Science for the support and help in making this Volume 2 achievable.

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## CHAPTER 1

# Biotic Stress and Breeding of Plants for Stress Resistance

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**Abstract:** Among the different environmental challenges that affect crop production, biotic stress factors are more devastating. They reduce crop yield and pose serious threats to food security. Legumes constitute a large number of crop varieties that are seriously affected by different biotic stress factors. To enhance their growth in the face of these different stressful factors and preserve their useful genomic and functional growth properties, leguminous crops are subjected to continuous genetic manipulations for stress resistance. Successful breeding of stress-tolerant varieties for cultivation under different farming systems may result in reduced crop losses and production costs, limited use of agrochemicals, and eventual yield increases. Crops that are resistant to biotic stress also exhibit better growth and yield characteristics. As established several decades ago, the revolution in genomic research led to the development of many sophisticated and advanced crop improvement techniques that can be applied across a whole range of leguminous crop species such as cowpea, faba bean, lentil, mungbean, pea, soybean, *etc*. However, interest in genetic engineering, chemically-or-physical-y-based mutation breeding, marker-assisted selection, quantitative trait loci and genome editing (CRISPR-Cas) have expanded research beyond biotic stress resistance. These techniques play a key role in applications such as the manufacturing of bioenergy, and crop engineering for the expression of valuable bioactive compounds and recombinant proteins. This chapter briefly reviews the diversity of biotic stress factors (bacteria, fungi, insects, parasitic nematodes and viruses) and possible ways in which these stress factors can be managed and eradicated using various breeding methods. The review shows that the biotechnological tools mentioned above provide beneficial functions in pest management through genetic, physiological and morphological improvements, especially when coupled with other farming practices.

**Keywords:** Biotic stress, Genetic engineering, Resistance, Leguminous crops.

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## DEFINING BIOTIC STRESS

Biotic stress can be broadly defined as any living component of the environment that prevents the plant from achieving its full genetic potential. Therefore, biotic stress refers to all negative influences caused by living organisms such as parasitic nematodes, viruses, disease-causing bacteria, fungi, arachnids, weeds, and insect pests. According to Gull *et al.* [1], biotic stresses reduce growth rates and cause major pre- and post-harvesting losses. The stress negatively influences the rate of photosynthesis as a result of reduction in leaf area, for instance, by insect pests. Microbial pathogens such as *Xanthomonas axonopodis* pv. *citri* also reduce photosynthesis by negatively affecting the activity of key enzymatic proteins such as Rubisco (ribulose 1,5 bisphosphate carboxylase), Rubisco activase and ATPase (Adenosine Triphosphate synthase) [11]. Taiz *et al.* [2] therefore referred to this kind of stress, including abiotic stress, as growth-inhibiting conditions that may not allow plants to achieve maximum growth and reproductive capacities. Legumes are one of the major groups of crop species serving as the most important components of both smallholder and large-scale farming systems across the tropical and subtropical regions and are severely affected by this kind of stress. These crops are predominantly cultivated in regions such as Asia, sub-Saharan Africa and Latin America where they serve as critical sources of good-quality dietary proteins, minerals, and oils.

The high value of legume grain seeds in promoting human and animal livelihoods, economic benefits and the improvement of soil quality (through the establishment of symbiotic relationship with nitrogen-fixing bacteria) led to several crop species being opted for cultivation as either monocrops or mixed cropping systems with cereals. However, they are more susceptible to different biotic stresses compared to other non-leguminous crops because of their proteinous nature. Their vegetative and yield characteristics, such as plant height, leaf/branch number, biomass, fruit and seed quantities are all affected by biotic stress. Some common microbial and insect pests that cause damage and diseases in legumes and other crops are summarised in Table **1**. The table indicates some of the most common types of living organisms that co-exist with plants in their immediate environment. Although some of these organisms have mutually beneficial interactions with plants, others could be parasitic or pathogenic species and become detrimental to plant growth. These organisms include microbial pathogens like *Xanthomonas campestris pv. phaseoli*, *Fusarium oxysporum f.sp. ciceris*, *Leveillula taurica cv. Arn*, Alfalfa mosaic virus (AMV) and herbivorous insects like leafhoppers as well as beetles (Table **1**), including the arthropods not indicated in the table.

**Table 1. Some of the most common biotic stress factors negatively affecting leguminous crops under diverse environmental conditions.**

| Category | Species | Disease/ Common Name | References |
|---|---|---|---|
| Bacteria | *Pseudomonas syringae pv. phaseolicola* | Halo blight | Schwartz [3] |
| - | *Pseudomonas syringae pv. syringae* | Bacterial brown spot | |
| - | *Xanthomonas campestris pv. phaseoli* | Bacterial blight | |
| Fungi | *Fusarium oxysporum f.sp.ciceris* | Fusarium wilt | Hardaningsih [4] |
| - | *Fusarium solani* | Black root rot | |
| - | *Leveillula taurica cv. Arn* | Powdery mildew | |
| - | *Erysiphe spp.* | Powdery mildew | |
| - | *Uromyces cicer-arietini* [Gorgn.] | Rust | |
| - | *Rhizoctonia spp.* | Dry/wet root rots | |
| - | *Sclerotium rolfsii* | Collar rot | |
| Nematodes | *Meloidogyne spp.* | Root knot | Davis and Mitchum [5] |
| Viruses | *Alfalfa Mosaic Virus (AMV)* | - | Chatzivassiliou [6] |
| - | *Beet Western Yellow Virus (BWYV)* | - | |
| - | *Broad Bean Mosaic Virus (BBMV)* | - | |
| - | *Seed Borne Mosaic Virus (SBMV)* | - | |
| - | *Broad Bean Wilt Virus (BBWV)* | - | |
| - | *Bean Golden Mosaic Virus (BGMV)* | - | |
| Insects pests | *Empoasca spp.* | Leafhopper | Edwards and Singh [7]<br>Singh and van Emden [8] |
| - | *Aphis craccivora* | Aphid | |
| - | *Ophiomyia phaseoli syn. Melanagromyza phaseoli* | Beanfly | |
| - | *Ootheca mutabilis,* | Beetle | |
| - | *Mylabris spp.* | Bettle | |
| - | *Medythia guaterna,* | Beetle | |
| - | *Nezara spp* | Bug | |
| - | *Anoplocnemis spp* | Bug | |
| - | *Riptortus spp.* | Bug | |
| - | *Acanthomia spp.* | Bug | |

In response to biotic stress, plants have evolved intricate defense mechanisms to deal with the harmful effects of pests and microbial pathogens. These involve

## CHAPTER 2

# Current Knowledge on Biotic Stresses affecting Legumes: Perspectives in Cowpea and Soybean

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**Abstract:** Legumes are economically important crops for the achievement of food security status in many countries in the tropical and subtropical regions of the world. Among various environmental stresses, biotic constraints to the production of grain legumes such as cowpea and soybean are becoming increasingly significant with the recurring change in climatic patterns and diverse environmental alterations. The economic impact of biotic factors such as disease-causing pathogens (fungi, bacteria, viruses and nematodes), insect pests and parasitic weeds has become overwhelming. These biotic stressors induce a wide range of damage symptoms which include stunting, wilting of stems, defoliation, root rots and premature death of plants. Yield losses due to the activities of biotic stress factors have been very significant. Hence, it is imperative to be informed of the various biotic stressors that affect the growth and yield potential of cowpeas and soybeans in various cropping systems. This review seeks to highlight existing pests and diseases in cowpea and soybean and evaluate their impact on the growth and productivity of these crops. It is hoped that the review will further spur scientific research into how these biotic factors can be managed or even manipulated to ensure agricultural sustainability, high economic returns, and global food security.

**Keywords:** Biotic Stressors, Cowpea, Diseases, Environmental Stress, Legumes, Food Security, Pests, Soybean.

## INTRODUCTION

Leguminous crops belonging to the family Fabaceae are considered the most important grain crops after the grass or Gramineae family (*Poaceae*) [1]. Seeds of legumes are broadly used as direct food sources due to their high nutritional content and the presence of bioactive compounds such as flavonoids and polyphenols as well as micronutrients like essential vitamins and minerals [2, 3]. Amongst the leguminous crops, grain legumes such as peanuts, soybeans, dry

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beans, cowpeas and chickpeas, are considered key components of the human diet as they serve as the major supply of proteins [3]. The economic importance of grain legumes cannot be underemphasized as their mean annual global production from 2008 to 2017 is estimated at over 75 million tonnes [4]. About 14.5% of the global arable cropped area was occupied by grain legumes in 2014 [5].

Grain legumes are also critical sources of plant nutrients in a cereal production system as they possess the ability to incorporate biological nitrogen into the soil [6]. Hence they are crucial to the food security status of many regions of the world especially Africa. Like many other important food crops, legumes are vulnerable to different environmental stresses which could be abiotic or biotic [7, 8]. Abiotic stresses affecting legumes include drought, salinity, heat, high light intensity and nutrient imbalance [9], while major drivers of biotic stress include viruses, fungi, bacteria, nematodes, weeds and other parasites [10]. The occurrence of any stress conditions certainly affects the yield potential of legumes [8]. The composition and quality of grain legumes are negatively impacted by abiotic and biotic stresses [11].

These stress factors can influence the yields of legumes and other beneficiary cereals within a crop production system by inhibiting or promoting nodulation [12]. The response of legumes, like other crops, to environmental stresses varies based on the type of stress (biotic or abiotic), stress severity and plant vigour [13]. Although research shows that abiotic stress factors are known to impact legume production extensively [8, 11, 14, 15], biotic stresses are becoming more frequent owing to global warming and climate abnormalities [16, 17]. Hence, current knowledge of various biotic stress conditions affecting legumes, especially grains, will be more insightful.

## BIOTIC STRESSES IN LEGUMES

Generally, legume growth and development are inhibited by many kinds of biotic stresses that induce direct and indirect physiological alterations [13]. These stress agents directly induce a deprivation of nutrients required by the host crop and can lead to the death of plants. High severity of biotic stress can bring about heavy pre- and postharvest losses [15]. Predominantly, the extent of damage influenced by biotic factors on legumes is highly dependent on the prevalence of one or more abiotic factors [9]. However, the major biotic stressors that can drastically reduce the yield of grain legumes predominantly involve microbial pathogens, pests, and weeds [18]. Therefore, the economic significance of the different biotic factors affecting the two major food legumes; cowpea and soybean, is then discussed below.

## COWPEA

Cowpea (*Vigna unguiculata* L. Walp.) is arguably the most widely adapted, versatile and nutritious grain legume for both warm and dry agro-ecologies of the tropics and subtropics [19]. Cowpea belongs to the family Fabaceae and it is often called black-eye pea, southern pea or crowder pea. It is predominantly unique as a self-fertilizing crop [20]. Through all stages of development, it grows in a wide range of temperature from 18 to 28 °C. In Sub-Saharan Africa, it is widely grown for food and feed because its grain contains high proportion of protein (23 to 32%), energy, micro- and macro-nutrients [21, 22]. Being tolerant to harsh conditions, it is considered a valuable component in crop production systems of poor rural households [23]. Owing to its atmospheric nitrogen fixation ability, it readily serves as a crop for rotation with major cereals crops which are the main determinants of food security in developing countries [24]. Global production of cowpea in 2019 was over 8.9 million metric tonnes of which Africa accounted for over 97% [25, 26] (Fig. **1**) (Table **1**).

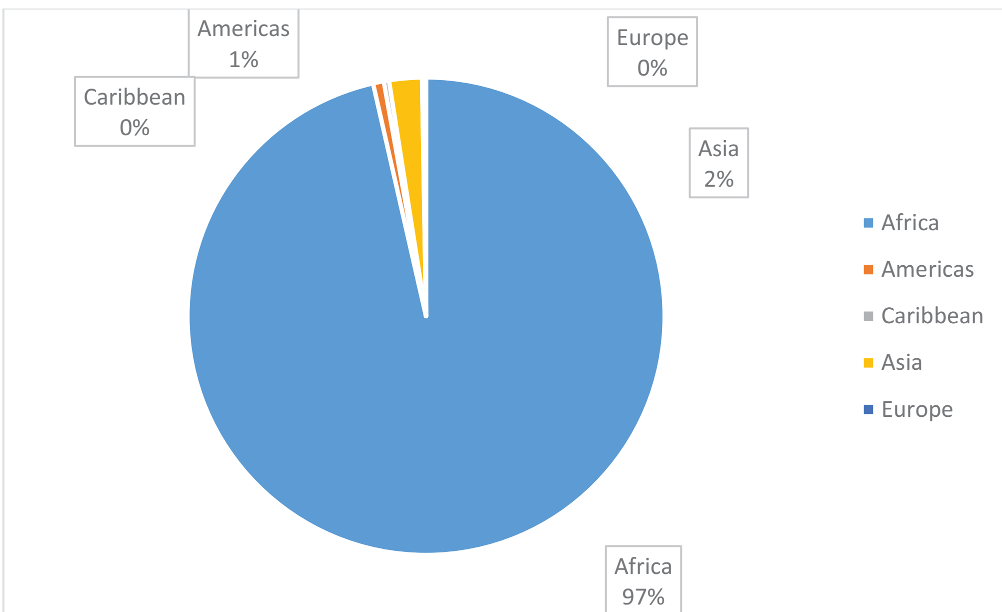


**Fig. (1).** Production of cowpea based on different regions of the world. FAOSTAT [26].

# CHAPTER 3

# Indexing for Bacterial, Fungal and Viral Pathogens in Legume Plants

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**Abstract:** Microorganisms found in plants exist as epiphytes or endophytes. Most epiphytes remain on plant surfaces and the latter may be intracellular pathogens, opportunistic and adapted microbial colonisers that originate from the surrounding environment. The main purpose of agricultural practices is thus, to develop disease-free varieties by propagating plants under controlled environmental conditions. Such conditions should be optimal for plant production and reduce disease development. The former requires strict certification schemes *via* several routes that include (i) indexing with subsequent removal of infected or contaminated materials from the production chain (ii) meristem and other tissue culture production systems and (iii) the use of thermo or chemotherapy for phytosanitation. Other methods also require balancing and proper adjustments in fertilizer usage and crop rotation. Therefore, this chapter reviews the role of microbial pathogen indexing as a means of controlling bacterial, fungal, and viral diseases that have a significant role to play in agriculture.

**Keywords:** Agriculture, Bacterial diseases, Fungal diseases, Indexing, Microorganisms, Microbial pathogens, Viral diseases.

## INTRODUCTION

Microorganisms found in plants exist as epiphytes or endophytes. Most epiphytes remain on the plants' surface and the latter may be intracellular pathogens, opportunistic and adapted microbial colonisers that originate from the surrounding environment [1]. The adverse effect of the presence of bacterial infections in most legumes cannot go unnoticed as they affect growth, and cause leaf spots, specks and blights, galls, and cankers [2]. Among the bacterial diseases in plants, those that are caused by gram-negative bacteria are the most widespread and destructive. The bacteria of the genus *Pseudomonas*, *Ralstonia*, *Agrobacterium*, *Xanthomonas*, *Erwinia*, *Xylella*, *Pectobacterium*, and *Dickeya* [3] are among the

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most disruptive genus causing great losses to the agricultural industry. They have a broad crop host range that includes leguminous and non-leguminous crops such as cotton, rice, cereals walnut, soybean, and sugarcane.

These pathogens affect different plant parts including the leaves, stems, and fruits. Unlike viruses, most bacterial plant diseases do not require insects as a vector, but rather rain, wind, soil, seed dispersal or any other means of transport to gain entry into the plants. Microbial pathogens are generally eliminated by chemical microbicides that usually contain copper in combination with ethylene bis-dithiocarbamate like mancozeb, streptomycin and oxytetracycline [4]. Approximately 300,000 species of flowering plants that include cereals, lumber, pulses, barley, corn, rice, sorghum, wheat, and nuts house over 100,000 fungal species. Those include fungal species such as *Magnaporthe oryzae*, *Botrytis cinerea*, *Puccinia* spp., *Fusarium graminearum*, *Fusarium oxysporum*, *Blumeria graminis*, *Mycosphaerella graminicola*, *Colletotrichum* spp., *Ustilago maydis* and *Melampsora lini* [5–8].

These may be pathogenic and saprophytic fungi that cause the development of several diseases including anthracnose, botrytis rots, downy mildew, *Fusarium* rots, powdery mildews, rusts, *Rhizoctonia* rots, *Sclerotinia* rots and *Sclerotium* rots [9]. These microbes cause deterioration in the growth, yield, and quality of crops, and often result in the utter destruction of superior varieties that are much more valuable for agriculture [10]. For example, dramatic losses of revenue estimated at over 11 million US dollars per year as a result of low seedling survival rates caused by *Fusarium circinatum* have been recorded as reported by Storer *et al.* [10]. Generally, all bacterial, viral, and fungal plant pathogens require a wound to gain entry to cause disease development in plants. Plant tissue wounding caused by beetles (*Ips conophthorus*, *Ernobium,* and *Pissodes nemorensis*) serves as infection sites in mature plants.

In legumes, these microorganisms have evolved mechanisms to actively transverse the plant's outer structural barriers, the cuticle, and the epidermal cell wall structures. For example, fungal pathogens can secrete a cocktail of hydrolytic enzymes, including cutinases, cellulases, pectinases, and proteases to gain entry into tissues [11]. Moreover, these fungal pathogens can easily spread through contaminated planting pots, irrigation water, and supporting mediums [12]. Viral plant infections cause several complex diseases resulting in necrotic cells, tissues or organs and failure for plant organs to develop fully (hypoplasia) causing dwarfing or stunting. Hypoplasia conditions may also cause tissue overgrowths like the formation of crown gall diseases caused by *Agrobacterium* spp. or club root. The most common symptoms of viral infection in plants range from mosaic patterns, chlorotic, yellowing, and leaf rolling to flower deformation [4].

Diseases like the Red clover nepovirus A (RCNVA) remain the most detrimental and cause dramatic effects on plant vigour and yield. Moreover, members of the genera *Ampelovirus, Clostrerovirus,* and *Vitivirus* were also found to be more controversial serving as causal agents for leaf roll and rugose wood. Although these viruses are not much implicated in legume crop diseases; however, they generally cause severe diseases which remain difficult to quantify and estimate because of the complexity related to their mode of transmission and symptoms. Commonly, farmers do not become aware of the real damage until it is too late with the losses culminating in the magnitude of millions of Rands every year [13]. Mixed infection, viral strain, environment, and cultivar response to infection are some of the complex mechanisms of viral plant infections that necessitate specific and accurate indexing methods for their effective control [14].

Indexing for bacterial, fungal and viral pathogens in plants permits the production and use of planting material free from phytopathogenic infections. Even though that remains the case, indexing does not exclusively serve as a method of control and prevention for disease development. The approach remains a vital necessity in the agricultural industry. The main purpose is to develop disease-free varieties by propagating plants under controlled environmental conditions. Such conditions should be optimal for plant production and reduced disease development. The former requires strict certification schemes *via* several routes that include (i) indexing with subsequent removal of infected or contaminated materials from the production chain (ii) meristem and other tissue culture production systems and (iii) the use of thermo or chemotherapy [15]. Furthermore, Pant and Hambly-Odame [16] reported that the latter also requires balancing and proper adjustments in fertilizer usage and crop rotation. Therefore, this chapter reviews the role of microbial pathogen indexing as a means of controlling bacterial, fungal, and viral diseases that have a significant role to play in agriculture, especially leguminous crop production.

## INDEXING APPROACHES

The most critical element of developed and optimised indexing systems is that they should not overlook minor infectious microorganisms while focusing on the major ones. Such an approach may be detrimental to the agricultural industry. For example, the impact of minor viruses such as fleck, vein mosaic, and rupestris pitting is amplified by a synergistic negative effect of other major viruses. Furthermore, the mutagenic and revolving nature of microbials may also create a constant spree of emerging new pathogens. The mutagenic rate in viruses is so high such that a single RNA molecule gives rise to a population of mutant sequences (haplotypes or variants) originating from the master sequence

**CHAPTER 4**

# Viral Diseases of Legumes and Their Managements

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**Abstract:** Legumes are very important food crops that are widely cultivated for their high-quality proteins, oils, and vitamins throughout the world. In total, 168 viruses are officially assigned by the International Committee on Taxonomy of Viruses. These viruses belong to 39 genera in 16 families and have been reported to affect various leguminous crops in different parts of the world. Among these viruses, TSWV (Tomato Spotted Wilt Virus), CMV (Cucumber Mosaic Virus), TMV (Tobacco Mosaic Virus), BYMV (Bean yellow mosaic virus), and BCMV (Bean Common Mosaic Virus) have global economic importance. This review therefore focuses on the economic importance of the abovementioned viruses influencing legume growth and development by looking at aspects such as viral traits, transmission, viral biology, plant host symptoms and the options used to control and manage some viruses such as the CMV (Cucumber Mosaic Virus), TMV (Tobacco Mosaic Virus), BYMV (Bean yellow mosaic virus), and BCMV (Bean Common Mosaic Virus).

**Keywords:** Crop yield, Disease management, Legumes, Plant virus, Viral morphology, Infection biology.

## INTRODUCTION

Legumes belong to the family Leguminosae (Fabaceae), which is regarded as one of the largest and most important families of flowering plants, constituting about 650 to 750 genera, 18,000 to 19,000 species of herbs, climbers, shrubs, and trees [1]. The family is regarded as podded fruits, and the commonly used legumes include peas, lentils, peanuts, cowpeas, chickpeas, clovers, kidneys, mung beans, pigeon peas, soybean, and vetches. Legumes are used as human and animal food since they are the richest source of protein, starch, minerals, and vitamins. They also play an important role in agriculture and agroforestry by improving soil quality. These legumes can convert atmospheric nitrogen into nitrogenous compounds that are usable by plants [2]. The main limiting factor in legume

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production is yield losses that are due to pests and disease. Among all various pathogens, viruses are considered to pose the most significant effect [3]. The cultivated legumes are susceptible to natural infections caused by viruses, where resultant diseases cause a severe impact on the vegetative growth and productivity of legumes worldwide.

In total, 168 viruses belonging to 39 genera and 16 families were recorded in different parts of the world by the International Committee on Taxonomy of Viruses and they were attributed to major losses in various leguminous crops [4]. TSWV (Tomato Spotted Wilt Virus), CMV (Cucumber Mosaic Virus), TMV (Tobacco Mosaic Virus), BYMV (Bean yellow mosaic virus), and BCMV (Bean Common Mosaic Virus) are the most economically important viruses responsible for legume losses worldwide [5]. Among these, three viruses (TSWV, CMV, and TMV) are among the top economically important plant viruses mostly in non-leguminous crops [6], meanwhile, two viruses (BCMV and BYMV) are particularly regarded as economically important in reducing legume growth and productivity. Most of the legume-infecting viruses are seed-borne, with viral transmission vectored through insect pests [5]. Therefore, this chapter discusses the biology and management of some of the economically important plant viruses reported to date and evaluates their influence on the growth and productivity of leguminous crops.

## TOBACCO MOSAIC VIRUS

The tobacco mosaic virus was discovered for the first time in 1879 by Adolf Mayer in the Netherlands [7]. In plant virology, the TMV is the most ancient virus and a member of the *Tobamovirus* group, which includes the *Odontoglossum* ringspot virus as well as the Sammon's opuntia virus. Numerous strains of Tobacco Mosaic Virus exist, where each strain causes different symptoms in both fruit and foliage crops [8, 9]. However, TMV can remain infective for many years, while attached to the materials used for plant support such as soil particles, culture medium, greenhouse surface, and greenhouse structures [9]. This is due to its ability to withstand high temperatures of up to 50ºC [8, 10, 11]. TMV is the positive sense single-stranded (ssRNA) virus [8], however, it was also recognized first because of its easiness to affect plants and noticeable symptoms [12].

Tobacco mosaic virus was reported to be a widely distributed virus that affects several vegetables, ornamental and leguminous plants, as well as various species in Solanaceae [12, 13]. The TMV is not transmitted by insects, nematodes, or other vectors, however, it has been reported to be transmitted easily by virus-infested saps [10], particularly, through direct contact with wounded areas on the surfaces of plants [11, 14]. This virus can also be transferred by grafting seed coats to new plants from the infected mother plants [12]. The virus can also be disseminated mechanically during normal field operations and human activities [9, 10].

**Infection Biology**

Different pathogens that infect plants interfere with various physiological functions which often results in the development of different symptoms. Changes that result from the multiplication of the virus cause a reduction in plant yield and reduced quality of the product [15]. Symptoms in infected plants vary according to the strains of the Tobacco Mosaic Virus, the type of plant species that get infected, and the developmental stage at which a particular plant is infected [12]. Pepper plants infected by the virus developed recognisable disease symptoms early in their seedling and immature stages [15]. However, all viral diseases are generally associated with direct or indirect biochemical aberration induced by the virus. It has also been reported that the first symptoms after virus infection appear as necrosis and chlorosis on the uppermost younger leaves along the main veins, followed by wilting and leaf spots [15].

Generally, the infected pepper shows reductions in leaf numbers, leaf area, mottled leaves, deformed and distorted leaf phenotype, as well as stunted shoot growth. As such, this contributes to a reduction in photosynthetic activity. Photosynthetic activities provide the plant with the energy that is required for its growth and defence against diseases and pests. Since MTV is associated with the reduction in leaf numbers and total leaf area, which are parameters linked to photosynthesis, this reduction causes a decline in plant growth, resulting in shortened slender plant stems, and reduced biomass. Infections caused by TMV also cause a reduction in relative water content and photosynthetic pigments (chlorophylls) [15]. Compared to leguminous crops, infected tobacco plants produce TMV more abundantly than enclosed crystallized virion bodies [11]. The first symptoms in tobacco plants are vein clearing at the youngest leaves, followed by a distinct mosaic of light-green and dark-green areas at early developmental stages [10]. Mosaic symptom development involves changes in chloroplast structures whereby some of the TMVs are detected earlier in chloroplast metabolism [16]. The virus causes light and dark green mottled areas in tomato leaves. In most cases, the area appearing dark green becomes thicker than the portion of the leaf which is lighter in colour. Young shoot growth usually becomes stunted with distorted leaf curling. Additionally, some strains produce mottling, streaking and death of the fruits [12]. Tobacco Mosaic Virus infection resembles water stress which also causes an increase in cytoplasmic ABA. Generally, the TMV infection causes a two to six-fold increase in the concentration of ABA in the leaf. The ABA is important in controlling the

# CHAPTER 5

# Economic Importance and Control of Vertebrate Pests in Legumes

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**Abstract:** One of the constraints to crop production across the world is vertebrate pests. They have been implicated as the most destructive pests which inflict both pre-harvest and post-harvest damages on agricultural production. Legumes are one of the crops usually attacked by vertebrate pest species, though the degree of depredation varies from one crop type to another. Meanwhile, there has been a misconception among farmers, especially in some of the developing countries, that vertebrate pest species belonging to the order Rodentia are very difficult to control. This is evident in their crop cultivations whereby two rows are planted in addition to every eight rows of crop, for rodent pest species that may come and inflict damage on the cultivated crop. Some of the rodent pest species that cause economic damage to legumes on the field include *Arvicanthis niloticus*, *Xerus erythropus*, *Cricetomys gambianus*, *Rattus rattus*, *R. norvegicus*, and *Mus sp*., while avian pest species include *Francolinus bicalcaratus*, and *Ploceus cucullatus*. There is a need to effectively manage these vertebrate pest species. Some of the rodent pest management approaches include the use of sanitation measures, exclusion of the vertebrate pest species, and modification of their habitat, and Trap Barrier System, while some of the avian pest management approaches include cage, nets or synthetic fibres, bird scarers, chemical repellents, sound-making devices, chemical poisoning, and trapping.

**Keywords:** Legumes, Rodent pests, Pre-harvest damage, Post-harvest damage, Avian pests, Management approach.

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## INTRODUCTION

Vertebrate pests are pest animals characterized by the possession of a backbone. They are any vertebrate whether indigenous or exotic, wild or domestic, that has been implicated as the causes of economic, environmental, social, and health problems [1]. Species of vertebrates known to be pests could be found in any of the vertebrate classes which include amphibians, reptiles, birds, and mammals. However, class Mammalia has the highest pest species followed by class Aves [2]. Among the class Mammalia, rodent pest species have been identified as the most destructive categories of pests, globally [3]. Unfortunately, they are the most often overlooked pest species especially in developing countries and so are given little or no attention [4]. Even though a lot of people in developing countries share their insufficient households and diets with rodents and avian pest species, scientists and agriculturists are still not able to properly document quantitative losses by these vertebrate pest species. A twofold loss which comprised a percentage of their produce both at pre- and postharvest stages is suffered by the farmers' households [5]. Enormous amounts of produce damage and scarcities in some continents have been reported to be caused by vertebrate pest damage, particularly, by rodents [6]. Small mammals inflict a greater danger to crops of peasant farmers in Africa due to the injury and losses caused by them and their high costs of management compared to other countries worldwide [7].

Small mammals pose a significant constraint to crop production in agricultural ecosystems globally and managing them is still a major problem for researchers and agriculturalists. While few studies are relatively available to provide correct estimations of losses of crops due to rats in African countries, new research on farmer's familiarity, attitude, and practices in rat management showed that small mammals are regarded as the most persistent pest to manage [8, 9]. About 25 small mammal species have been recorded as pests in agriculture in African countries, causing different damage and losses in different crops [7]. According to the estimate, about one-fifth of the produce cultivated yearly worldwide are never consumed by individuals because of rodents-inflicted injury [10]. Aves can wreak injury to the vegetative and reproductive stages of all agricultural crops, starting from sowing, planting, and harvesting. Old-style methods usually rely on scaring birds by just rebounding the avian species to adjoining growing crops. However, it is an expensive management strategy [11].

## RODENTS AND BIRDS AS VERTEBRATE PESTS OF LEGUMES

For small mammals (rodents and insectivores), damage to legumes is negligible [5]. Except for groundnuts, grain legumes are not the favorite foods of rats and mice. Most losses are not due to rodents but fungi and invertebrates of the class

Insecta. Skilled viewers come to an agreement that losses of legumes after harvest frequently surpass those of cereal crops. In addition, the avian damage to grain legumes is restricted to the field where avian pest species such as *Ploceus cucullatus* (weaverbirds) depredate the crop by removing the seeds from the pod [12]. Birds that do not live inside the farm or village structures like rodents, hardly ever depredate stored produce. Only the out-of-door conditions where cereals or legumes are unprotected during processing that aves can consume them, or they may have access to grain produce where they are kept under exposed storage conditions. Thus, the damage to stored produce because of avian activities is minimal compared to those caused by small mammals especially rodent species [1, 5].

## IMPACT OF VERTEBRATE PESTS ON LEGUMES

Vertebrate pest species, especially those found in the classes Mammalia and Aves, inflict both pre-harvest and post-harvest damages to grain legumes [13]. Table **1** shows some of the legumes and the types of damage done by some vertebrate pests.

**Table 1. Vertebrate pests and type of damage inflicted in some leguminous crops.**

| Crop | Type of Damage | Vertebrate Pest Indicted |
|---|---|---|
| *Arachis hypogaea* (groundnut) | Removal of newly sown and germinating seeds | Cane rat (*Thryonomys swinderianus*)<br>Bush fowl (*Francolinus bicalcaratus)*<br>Nile harsh-furred rat (*Arvicanthis niloticus*) |
| | Removal of pods | Red-legged ground squirrel (*Xerus erythropus*) |
| | Eating of roots and/or groundnut. | Mole rat (*Nesokia indica*) |
| | Removal of groundnut in the pod. | Lesser bandicoot rat (*Bandicota bengalensis*) |
| | Removal of groundnut but the plant is not usually damaged. | Indian gerbil (*Tatera indica*) |
| *Vigna unguiculata* (Cowpea) | Nibble on the cowpea grain in the store. | Mouse (*Mus minutoides*) |
| | Gnawing the stored cowpea. | Roof Rat (*Rattus rattus*)<br>Norway Rat (*Rattus norvegicus*) |
| | Eating the seeds inside the pod. | Weaverbird (*Ploceus cucullatus*) |
| *Pisum sativum* (Garden pea) | Destruction of leaves, shoots, and mostly pods and seeds. | Rat (*Rattus sp*) |

# CHAPTER 6

# Effect of Spider Diversity and Abundance in Legume Agroecosystems

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**Abstract:** An agroecosystem refers to a complex system comprising a couple of different interacting factors, involving species, ecological, and management processes. This system contains lesser species diversity of both plants and animals than a natural ecosystem. The variation in species of plants and insects is critically important to serve as a complex food chain and web whose interactions function to stabilise this ecological unit. However, among the groups of herbivores and predators found in agroecosystems, spiders play a key role in most crop fields by preying on a variety of pests. Besides this, the current pace of research on this subject shows that the role of spiders in regulating pest species and serving as potential biological control agents has been largely ignored. So far, information on agricultural spider communities, diversity and their role as biological pesticides remain scant in various parts of the world with the exception of countries such as the United States of America, Australia, and some parts of the Middle East Asia. Thus, this chapter outlines the most relevant information on the diversity, abundance and effect of arthropodous spiders on agroecosystems, particularly those that are involved in the cultivation of legume crop species. The paper also discusses current relevant threats to spiders, conservation measures, the threat of species extinction, and the role that these arthropods play in agriculture, especially by reducing the growth and productivity of species such as soybean (*Glycine max* L.) and cowpea (*Vigna unguiculata*).

**Keywords:** Agroecosystems, Arthropods, Legumes, Soybeans, Spiders.

## INTRODUCTION

An agroecosystem refers to a complex system comprising a couple of different interacting factors, involving species, ecological, and management processes [1]. This system contains lesser species diversity of both plants and animals than a natural ecosystem. Typically, one to four major crop species and six to ten major

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pest species can be found in this ecosystem [1, 2]. In most cases, the status and conditions of agroecosystems are largely influenced by anthropogenic activities. Some of these activities include ploughing, inter-cultivation, and application of pesticides, leading to the alteration of the diversity of species, especially of pests. However, influences by man can be more detrimental, causing the agroecosystem to be more susceptible to pest damage and catastrophic outbreaks that are concomitantly attributed to the lack of species diversity. The variations in species of plants and insects are critically important to serve as a complex food chain and web whose interactions function to stabilise this ecological unit [2].

The conversion of ecological units to agriculture also leads to the invasion by unplanned diversity of weed plants, herbivores, predators, microbial pathogens, and other organisms that persist in the system. Among the group of herbivores and predators found in agroecosystems, arthropods spiders play a key role in most crop fields by preying on a variety of pests. However, the current pace of research on this subject shows that the role of spiders in regulating pest species and serving as potential biological control agents has been largely ignored. So far, information on agricultural spider communities, diversity and their role as biological pesticides remain scant in various parts of the world except for countries such as the United States of America, Australia, and some parts of Middle East Asia [3]. The functions of spiders as pest predators for herbivores and granivores remain promisingly beneficial for agriculture and offer an alternative pest management strategy for both small- and large-scale farmers.

Isbister [4] emphasised on the myths and reputation of spiders as also being the "predators of man" or being dangerous to people and animals as one of the main reasons why credit is still due to them for use as important natural pests control agents. But among over 30,000 known spider species, only about twenty-three of species are considered poisonous. As a result, this chapter outlines the most relevant information on the diversity, abundance, and effect of arthropodous spiders on agroecosystems, particularly those that involve the cultivation of legume crop species. The paper also discusses current relevant threats to spiders, conservation measures, threat of species extinction and the role that these arthropods play in agriculture, especially by reducing the growth and productivity of species such as soybean (*Glycine max* L.) and cowpea (*Vigna unguiculata*).

## BIOLOGY OF SPIDERS

### Structural Morphology and Life Cycle

Arthropods are invertebrates that form a significant part of the animal kingdom. They are easily identified and distinguished by the distinct morphological traits that they possess. Their features include an exoskeleton, paired jointed appendages and a segmented body. They possess abilities to survive in aerial, aquatic and terrestrial environments. For instance, the class Arachnida consists of eleven (11) orders of joint-legged invertebrates that also include spiders [5]. However, compared to other invertebrate animals, spiders form part of the phylum Arthropoda, subphylum Chelicerata [6]. These species are further classified into the order Araneae which consists of 112 families, 4072 genera with approximately 47000 species. The suborder Araneae are classified into two suborders known as the Mesothelae which consists of one family with 87 species which are characterized by traces of segmentation on their abdomen and the Opisthothelae which have no traces of segmentation on their abdomen [7, 8]. The biology of spiders indicates that they all undergo the same general stages of development. In general, many species go through the egg, spiderling, and adult stages as indicated in Fig. (**1**). But, having stated that slight differences in their developmental stages may obviously exist based on species variation within the taxa. During the egg or embryonic stage, the female spider builds an egg sac using silk and deposits her eggs inside it and fertilize them as they emerge. One egg sac may host up to a hundred eggs depending on the species. The eggs usually take a week to hatch but some spiders, especially those that are found in temperate regions, may employ specific strategies and other unique characteristics such as overwintering of the egg sacs, and then emerge in spring. Some spider species protect their egg sacs while others abandon the egg sacs in secure places. The spiderling stage commences as soon as they hatch from their eggs [9]. At this stage, the spiders are much smaller in size and immediately disperse through a process known as ballooning or walking. Most species become mature after shedding at least ten times. Males are usually fully mature by the time they leave the sac, but female spiders take more time to mature since they are usually larger than male spiders. In the adult stage, spiders become fully developed for mating, and after the events of mating between the two, female spiders will then live and survive for a longer period than male spiders which usually die after this process. The life span of spiders can be up to two years, but variability also exists between different species [3, 9].

Spiders consist of chelicera, which is a pair of appendages in the front of their mouth that allows for tearing apart of their prey instead of chewing. Furthermore, these chelicerae also contain two fangs at their tip which are connected to spiders' poisoning glands [10, 11]. The body of spiders is also divided into prosoma and opisthosoma as previously indicated. The prosoma consists of the eyes and locomotory appendages while the opisthosoma consists of the abdomen. Spinnerets and silk glands secrete silk which is a significant distinguishing character of spiders as earlier described by Haupt [10]. According to Haupt [10], Araneae also contains within its species some of the most venomous web-spiders whereby the venomous capabilities of some of species remain unknown. Spiders

## CHAPTER 7

# Role of Climate-Driven Factors on Bean Leaf Beetle, Corn Earworm and Stinkbug Populations, Control and their Effects on Soybean Growth and Productivity

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**Abstract:** Soybean is a crucial crop that is recognised globally for its high-value protein, vitamins, carbohydrates, fibre, and oils. However, the production of soybeans is frequently influenced by biotic stress factors such as bean leaf beetles (*Cerotoma trifurcate*), grasshoppers (*Schistocerca americana*), corn earworms (*Helicoverpa zea*) and stinkbugs (*Halyomorpha halys*). However, these insect pests were discovered to be both beneficial and harmful to crop growth and productivity, particularly, in soybeans. According to the literature, the rise in temperature causes an increase in insect pest populations, thereby severely influencing the growth, and yield quality of many crops. Less precipitation also contributes to drought stress, and plants undergoing water-deficit stress produce fewer secondary metabolites rendering them vulnerable to attacks by these insects. Similar effects were also revealed due to the rise in atmospheric $CO_2$ levels that led to the adverse weather effects that caused enhanced reproduction and spread of pest insects. This chapter, therefore, explores the role of climate change-induced factors, such as temperature, precipitation patterns and rising atmospheric $CO_2$ on insects' distribution, and reproductive patterns, as well as their subsequent influence on crop growth and productivity in soybeans. The review also briefly discusses the chemical, biological and biotechnological approaches of insect pest control that have been employed effectively to combat losses of crop production. Side effects, cost effectiveness and the ability of new biotechnological methods to target specific pests are also discussed in this chapter.

**Keywords:** Biotic stress, Climate change, Chemical control, Biological control, Insect pests, Genetic engineering, Soybean.

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## INTRODUCTION

Soybean, *Glycine max* (L.) Merr., is a grain legume known to be an important agricultural crop globally and economically. This crop is grown worldwide, however, production is affected by various factors like abiotic, and biotic stress such as drought, feverish temperatures and insect pests. There are over 700 species of plant feeding insects for soybean but, the most notable damage is demonstrated by only eight species of insects found in the United States (US) [1]. These entails the velvetbean caterpillar, *Anticarsia gemmatalis*; the soybean looper, *Pseudoplusia includens*; the green cloverworm, *Plathypena scabra*; the Mexican bean beetle, *Epilachna varivestis*; the bean leaf beetle, *Cerotoma trifurcata*; the green stink bug, *Acrosternum hilare*; and the corn earworm, *Helicoverpa zea* [1, 2]. The bean leaf beetle is a native species in the eastern part of the US and a major pest in all soybean-growing areas across the globe [2].

The larvae of this beetle are said to feed on the roots, root hairs, and nodules of soybean, while the adults defoliate the leaves and feed on the external pod tissues [3]. *Helicoverpa zea* is an economically significant insect and said to be dominant also in the United States of America. This pest largely attacks soybean plants, affecting mainly the leaves during vegetative stages. The size of the *Helicoverpa zea* caterpillar, the development stage of the plant, the time of damage it inflicts, and the plant's ability to recover are some of the factors that can affect the yield of soybeans [4]. However, to compensate for the damage done to the reproductive tissues, soybeans can produce more pods or increase their seed's weight [3, 4]. Furthermore, the harmful insects known as the stinkbugs are also part of the growing problem of soybeans, and they feed on the pods while causing severe damage to the developing seeds [5].

Therefore, this chapter explores the role that insect pests play in soybean fields and examine the influence of climate change-induced factors such as temperature, precipitation patterns and rising atmospheric $CO_2$ on the insects' distribution, reproductive patterns, as well as their subsequent influence on crop growth and productivity in soybean. The review also briefly discusses the chemical, biological and biotechnological approaches of insect pest control that have been employed effectively to combat losses of crop production. Side effects, cost effectiveness and the ability of new biotechnological methods to target specific pests are also discussed in this chapter.

## BIOLOGY OF BEAN LEAF BEETLE, CORN EARWORM AND STINKBUG INSECT PESTS

### Bean Leaf Beetle (*Cerotoma trifurcata*, Family Chrysomelidae)

*Cerotoma trifurcate* also known as the bean leaf beetle (BLB) belongs to the Chrysomelidae family, order Coleoptera [6]. Bean leaf beetle are classified according to their appearance in colour. The colour of adult beetles differs from red to orange, as well as light yellow as exemplified in Fig. (**1**). The wing covers (elytra) of the adult BLB are soft and beige when first spotted. There are four squarish black markings on the underside of the wings, but these can be from few to nothing at all, and they are usually rimmed with a black margin. Black frons (faces) are typically found on female beetles, while tan frons are typically found on male ones [7]. The first tarsal segment of a male beetle also has a covering of dense setae (hairs), which are believed to be part of the mating process, this feature is not there in female beetles [7, 8]. The overall life span of this insect is usually 1 to 2 months [9].

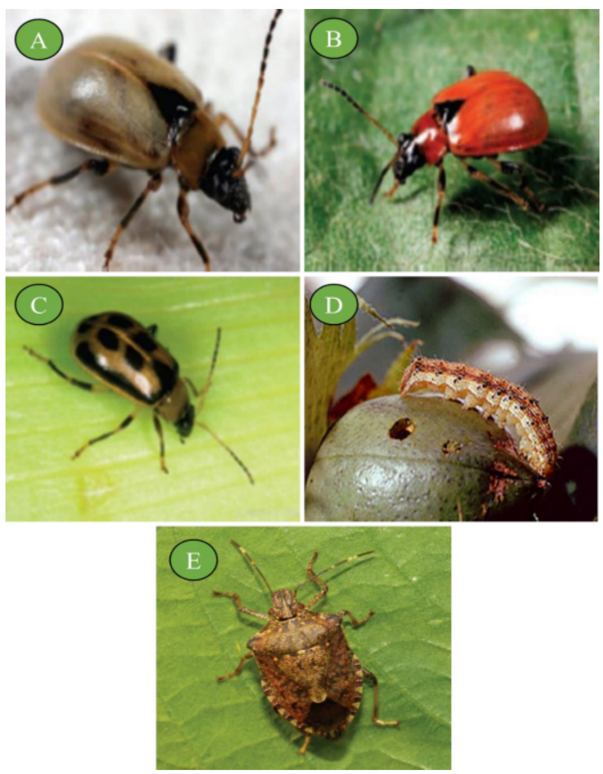


**Fig. (1).** Examples of adult bean leaf beetles with different colours (**A**-**C**) [7], corn earworm *Helicoverpa zea* (**D**) [12] insect pests and adult brown marmorated stinkbug (**E**) [15].

## CHAPTER 8

# Sustainable Crop Nutrition for Ameliorating Biotic Stress in Grain Legumes and Ensuring Food Security

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**Abstract:** Environmental stress generally causes considerable yield loss in leguminous crop production. This stress could be biotic (Insect pests, disease pathogens, weeds, vertebrate pests, *etc.*) or abiotic (Drought, heat, cold, salinity, flooding, heavy metal contamination, *etc.*). Either biotic or abiotic stress, both are capable of causing total yield loss. Unfortunately, crops are simultaneously exposed to these stress factors on the field. The response and level of tolerance to both stress factors, however, depend on the crop's genetic and nutritional status. The level of infection or infestation is determined by the cropping system and soil nutrient status. The induction of defense mechanisms by plants in response to pathogenic attack is dependent on environmental conditions like plant nutrient status. It means that there is a complex signaling network with crop nutrition that enables the plants to recognize and protect themselves against pathogens and other environmental stresses. The disease severity could be reduced by adequate crop nutrition due to host nutrient availability, plant composition of secondary metabolites, and the effect on the plant defense mechanisms. Shortages in essential nutrients on their own can predispose plants to attack by pests and pathogens. Therefore, the only sustainable method for growing crops in the face of different environmental stresses is good crop nutrition. A well-fed crop is more resistant to environmental hazards than poorly-fed crop. Though leguminous crops can fix atmospheric nitrogen themselves, the nutritional requirements for healthy crop production are more than just one element. The ability to fix nitrogen, if combined with appropriate crop nutrition will place the plant in a better position to withstand environmental stresses. This chapter discusses some of the different nutrient elements required by leguminous crops and their functions, crop nutrition abiotic stress tolerance, and mechanisms of nutrient-induced resistance in leguminous crops.

**Keywords:** Fertilisers, Legumes, Environmental Stress, Crop health, Crop yield.

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## INTRODUCTION

In grain legume production, biotic stress factors such as insect pest attack and pathological diseases have been reported to be the important constraints limiting grain yield [1]. To increase grain yield in the face of biotic stress, different strategies have been proposed. The most important strategy is adequate plant nutrition. A balanced nutrient supply is a basic requirement to protect plants against all forms of stress [2]. The plant growth rate is proportional to nutrient availability and accessibility. A decline in soil fertility has been found to increase the negative crop response and susceptibility to both biotic and abiotic stress. Poor nutrition impairs crop response and tolerance to stress factors. The low grain yields in legumes have been attributed to poor crop management practices and poor soil fertility [1]. Liebig's "Law of the Minimum (1855) stated that 'The genetically fixed yield potential of crops is limited by the nutrition' [2]. The yield potential of any crop is, therefore, determined by the amount of nutrients supplied and taken up by the plant. The presence and availability of essential mineral elements in the soil, therefore, have a significant impact on the plant's health and determine the plant's response to environmental stresses.

Meanwhile, most farmers do not apply additional nutrients to sole cowpea production due to its ability to fix atmospheric nitrogen. But for greater resistance and enhanced tolerance to environmental stress, the addition of fertilizers is needed to boost cowpea tolerance. In fact, nitrogen itself is needed as a starter dose in areas where soils are poor in nitrogen before nodules begin to fix atmospheric nitrogen [3]. Though, nodulation and N fixation can be inhibited by high field N levels due to the inhibition of nitrogenase activity through a feedback mechanism, but moderate/optimal soil nitrogen level is required for effective nodulation [4]. Besides, in the absence of other nutrients like phosphorous, which is critical to cowpea yield, nitrogen fixation is also strongly affected [5]. Phosphorus is the most limiting soil fertility factor for cowpea production in many tropical soils because it stimulates growth, initiates nodule formation, and promotes rhizobium-legume symbiosis apart from other benefits. It means that cowpea nitrogen-fixing ability might also be affected under P deficiency. Again, it has been observed that under stress, the physiological mineral nutrient demand is always higher than that of normal growth. More carbon and nutrients are needed to be able to carry out the stress-induced metabolic activities and ameliorative processes.

The fixed nitrogen might therefore not be able to support leguminous crops under biotic stress. Appropriate and sufficient fertilization is the key to sustainable crop production, especially under stress. The success of pest attack, though, positively correlates with the plant's nutrient status in some reports [6], but the survival or loss encountered is reduced in a well-fed plant. The plant's nutrient status is related to its capacity to ameliorate the negative impacts caused by stress conditions [3, 7]. Best compensatory performance under biotic stress has been reported under proper nutritional management compared to only pest control [6]. Improvement of phosphorus, nitrogen, potassium (P, N, K) and cation contents in the topsoil has been found to increase cowpea grain yield under biotic stress compared to unfertilized fields with pest control [1]. Malnutrition, therefore, predisposes crops to biotic stress. The rate of recovery is also affected or delayed in the absence of balanced nutrition for crops.

Beneficial mineral nutrients should, however, be able to promote growth and yield under stress and strengthen the natural resistance of plants against abiotic and biotic stresses. Apart from mineral nutrients, water is also an essential component of crop nutrition. Legumes like other crops also require more moisture for N fixation. Water is required to export N products from the nodules to the rest of the plant. In the absence of water, N products build up in the nodule and inhibit further fixation by the nodules. With regard to response to biotic stress, lack of water has also been reported to promote insect attack compared to well-watered plants. For instance, aphid performance was found to be the highest in crops subjected to moderate drought stress [8]. Similarly, extreme moisture stress can inhibit nodule initiation or cause nodule shedding in some legume species. It can also reduce N fixation potential by depriving the nodules of sufficient oxygen for rhizobial respiration. Soil nutrient availability and water status can, therefore, have a strong influence and diverse effects on how legumes respond to biotic stresses. The importance of macro and micro-elements in the performance of leguminous crops and tolerance to biotic stresses are discussed in this chapter.

## CROP NUTRITION AND BIOTIC STRESS RESPONSES

There are strong interactions between nutrients and other environmental factors, especially, biotic factors. A balanced nutrient supply is the basic requirement to protect plants against all forms of stress. The importance of individual nutrients for maintaining or promoting plant health and growth has been well documented [7]. The level of crop response to biotic stress is dependent on its nutrient status, the type of nutrient available to such crop, and the quantity. It has been observed that an adequate supply of mineral elements in the growth medium is paramount, for plants to survive under different environmental stresses including biotic stress [7, 9]. The growth and survival of leguminous crops under biotic stress are also dependent on the soil nutrient status and ability to fix atmospheric nitrogen effectively. The increased nutrition enables the plants to repair and compensate for the damage caused by insects or pathogens without a reduction in yield. The

# CHAPTER 9

# Physiological Response of Legumes to Combined Environmental Stress Factors

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**Abstract:** Legumes are considered the second most important source of food after cereals, and their production can be affected by abiotic and biotic stresses. The incidence of biotic and abiotic stress conditions resulting from climate change is expected to increase in the future and may affect legume production drastically. Abiotic stresses could result in escalated biotic stress occurrence. Although responses to abiotic and biotic stress differ in most cases, combined abiotic and biotic stress responses could be expressed in synergistic or opposing forms. In view of the impending escalation in climate change, responses of legumes to stressful environments are expected to vary among crops. However, collective information on combined biotic and abiotic stress in legumes is not readily available. This paper seeks to gather available information on the responses of legumes to biotic, abiotic, and combined stress with a focus on physiological responses. This review will, therefore, help in providing information and encourage further research into combined stress factors in legumes.

**Keywords:** Biotic stress, Abiotic stress, Combined stress, Physiological responses, Climate change, Legume production.

## INTRODUCTION

Legumes are the largest source of vegetable protein in human diets and livestock feed, they therefore, perform a very important function in reducing protein malnutrition as described by Dita *et al.* [1] and Choudhary *et al.* [2]. Legumes can be either grain or forage, whereby grain legumes include soybean (*Glycine max*), chickpea (*Cicer arietinum*), groundnut (*Arachis hypogaea*), cowpea (*Vigna Unguiculata*), pea (*Pisum sativum*), common bean (*Phaseolus vulgaris*) and pigeon pea (*Cajanus cajan*) amongst others. Meanwhile, forage legumes include alfalfa (*Medicago sativa*), and birds foot trefoil (*Lotus japonicus*), both of which

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have been used as model legume crops for decades. The production of legumes is, however, limited by various biotic and abiotic factors. Abiotic factors, such as drought, extreme temperatures, mineral nutrient imbalances, and salinity are the most important stress factors affecting legumes. Biotic factors such as fungi, viruses, bacteria, nematodes, insects, and weeds are very limiting to the growth and productivity of both grain and forage legumes. Abiotic and biotic stress factors individually severely affect crop yield in general and a combination of these factors can also be detrimental [3].

Many of these biotic and abiotic stress factors are common to all legumes; however, the incidence and severity of these stress vary according to leguminous crop species and the location in which they are grown [1]. These factors manifest in altering physiological activities and metabolism in plants resulting in eventual yield loss of up to 90% or total yield loss depending on the intensity and severity of the stress factor imposed on plants. In the field, these stresses rarely occur in isolation, but they often take place in varying combinations simultaneously [4]. The stress could be in abiotic-abiotic stress combinations or abiotic-biotic stress combinations. Current evidence suggests differences and uniqueness in the plant's ability to respond to a combination of stress as compared to individual stress responses [3]. Furthermore, these stress factors usually affect and influence crop's responses physiologically, morphologically, biochemically, and molecularly, and result in a completely new physiological state in certain cases where the stress has ended, especially when tolerance has been exceeded [5].

Recent predictions have reported expected changes in climatic conditions, predicting sporadic rainfall patterns, warmer temperatures and global warming which will bring about increased incidence of biotic and abiotic stress. Such environmental stress conditions may in turn limit agricultural productivity [6 - 10]. According to Mittler [11], Atkinson and Urwin [12] and Suzuki *et al.* [13] influences of these negative conditions on plants may trigger additive, negative, or interactive effects. In this case, the interactions between various abiotic and biotic stresses may cause significant growth and yield outcomes. On the other hand, abiotic stress can enhance the susceptibility of the crop to pathogen attack while these pathogens may alter the crop's response to abiotic stress factors [3]. Therefore, as this chapter indicates, studying the interactions between stresses and the variations in crop response, particularly to combined stress effects remains pivotal for breeding purposes and developing strategies for stress-tolerant crops.

## BIOTIC STRESS IN LEGUMES

### Fungal Diseases

The major biotic stress affecting legumes is fungal diseases even though other biotic stresses (viruses, nematodes, insects, bacteria, and weeds) can still result in drastically reduced legume growth and productivity [1]. Fungi, which are biotrophic pathogens cause severe foliar diseases which serve as major constraints in legume production [14]. Fungal foliar diseases that are important affecting legumes are rusts, powdery mildews, and downy mildews. Rust species infecting grain and forage legumes belong to the genus *Uromyces* such as *Uromyces appendiculatus* in common bean, *U. ciceris-arietini* in chickpea, *U. vignae* in cowpea and *U. striatus* mostly infecting alfalfa. Other rust species belonging to other genera that affect legumes include *Phakopsora pachyrhizi* often found in soybeans, *Puccinia arachidis* of groundnut [15] and *Asian rust* that also infects soybean [16]. Other fungal diseases, such as necrotrophic fungal diseases comprise *Ascochyta* blight and *Botrytis* gray mildew which are most common in chickpeas [17]. Soil-borne pathogens known to attack legume crops causing drastic effects in seedlings and adult plants of chickpeas, soybeans, and lentils comprise species of *Fusarium*, *Pythium,* and *Rhizoctonia* [18].

### Viral Plant Diseases

Among the many plant pathogens, viral diseases that affect legumes are of particular importance in crop species grown in the subtropical and tropical regions [19]. The viral diseases are transmitted either through seeds or vectors and can also be transmitted by means of mechanical inoculation in cases where induced infections are needed for indexing or research purposes. Legume viruses that are commonly transmitted through seeds include *Bean Common Mosaic Virus* (BCMV), *Cucumber Mosaic Virus* (CMV), *Alfalfa Mosaic Virus* (AMV), *Soybean Mosaic Virus* (SMV), *Peanut Mottle Virus*, *Peanut Stripe Virus*, *Bean Yellow Mosaic Virus* (BYMV) and *Bean Golden Mosaic Virus* (BGMV). These viruses are considered the most limiting viral pathogens in bean production, especially in the Caribbean and also in some parts of Central America. Coyne (year) reported that these viruses resulted in drastic yield losses of up to 100% in many crop fields where they occurred. Other important legume viruses include Groundnut Rosette, which is of high importance in Africa, chickpea stunt occurring both in Africa and Asia [20], pigeon pea sterility mosaic virus, pea bud necrosis virus, and Tobacco streak virus which mainly affects groundnuts [21, 22].

# SUBJECT INDEX



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Phetole Mangena is a senior lecturer at the University of Limpopo and earned his Ph.D. in botany from this University in September 2019. He published numerous research articles on in vitro and in vivo genetic improvement and mutagenic breeding of soybean and other leguminous crops. He has also received several awards, including the NRF emerging researcher award in the National System of Innovation of South Africa. He also does academic writing, having published a book about indirect gene transfer, Plant Transformation via Agrobacterium tumefaciens and edited two more books in legume research. He continues contributing to the field of plant physiology and biotechnology, mentoring aspiring scientists and serving as editor for Frontiers in Agronomy, Frontiers in Plant Science, Plant Science Today, Research Journal of Biotechnology and Journal of Experimental Biology and Agricultural Sciences.

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