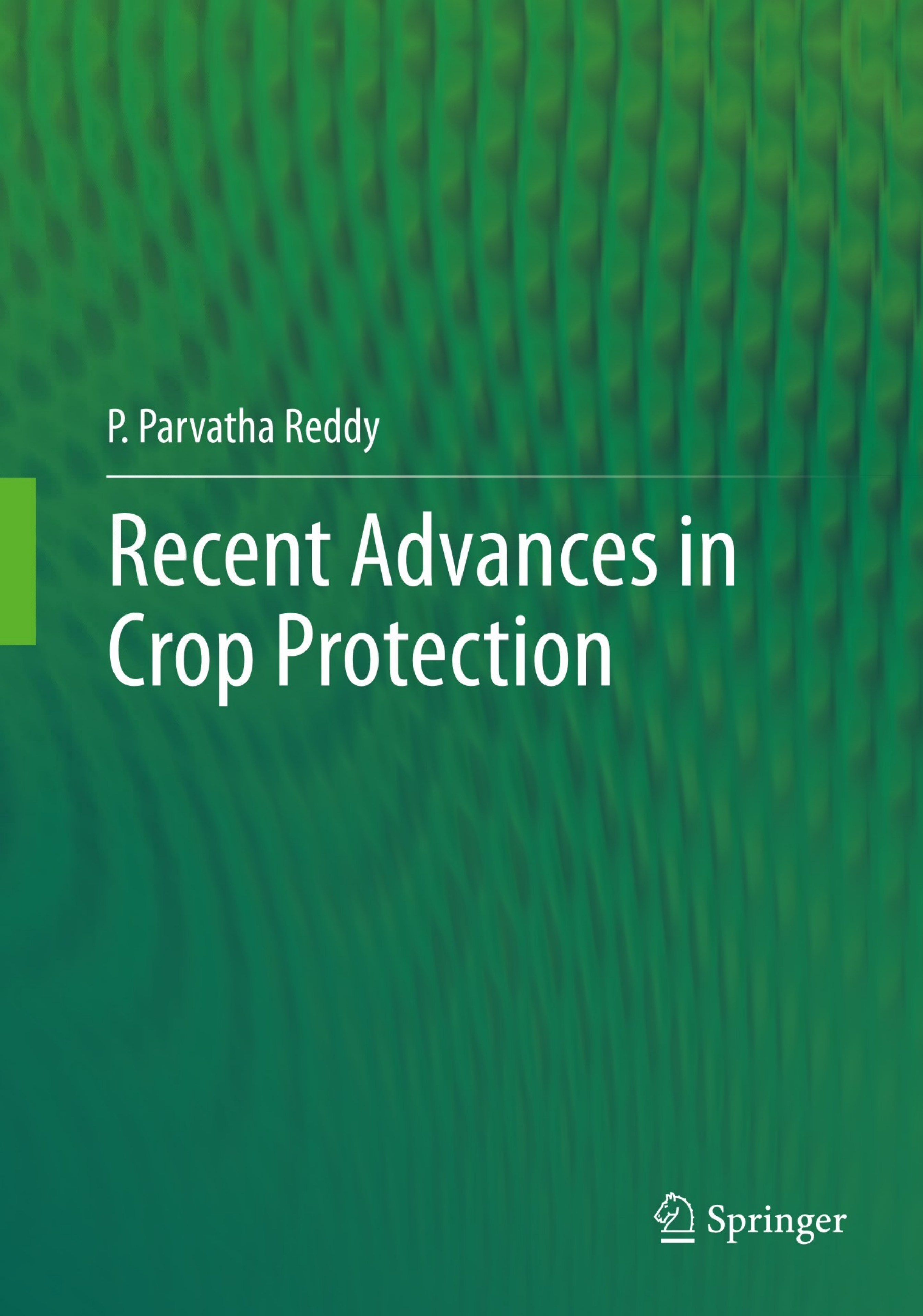

P. Parvatha Reddy

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Preface

In the recent years, the need to increase food production to meet the demands of rapidly increasing population from a limited land resource necessitated the use of intensive farming systems, with the inputs like narrow genetic base, high fertilisers, irrigation, multiple cropping, etc., which favour disease and pest development. The introduction of new high-yielding genotypes susceptible to the pests and the pathogens and changing cropping patterns including cultivation in non-traditional areas have resulted in a spurt of pests and diseases in crop pathosystems, remarkably changing the scenario of biotic stresses. It is not only that those new pest problems emerged but also the minor pests assumed major status and vice versa. The effect of changing global climate, particularly of sharp increase in CO_2 concentration from the current level of 330–670 ppm, increases the susceptibility of plants to pathogens and pests.

Presently practised crop protection measures mainly orient towards chemical control. The excessive dependence on chemical pesticides leads to the development of resistance in insect pests and pathogens, outbreaks of secondary pests and pathogens/biotypes and occurrence of residues in food chain. The chemical control also has other limitations such as high cost, low cost–benefit ratio; poor availability; selectivity; temporary effect; efficacy affected by physicochemical and biological factors; resurgence of pests; health hazards; toxicity towards plants, animals and natural enemies; and environmental pollution. Because of high intensive agricultural practices and chemicalisation of agriculture, the age-old environment-friendly pest management practices like sanitation, crop rotation, mixed cropping, adjustment of date of planting, fallowing, summer ploughing, green manuring, composting, etc., to combat plant pests are not being practised in Indian agriculture. The pace of development and durability of resistant varieties had been slow and unreliable.

Considering these limitations, there has been a growing awareness and increasing demand for novel and improved crop protection approaches to guarantee effective and sustainable food production which offers new opportunities for crop protection research. The information on recent advances in crop protection (bacteria, fungi, nematodes, insects, mites and weeds) is very much scattered. There is no book at present which comprehensively and exclusively deals with the above aspects. The present book deals with the most recent advances in crop protection such as avermectins, bacteriophages, biofumigation, biotechnological approaches, bio-priming of seeds, disguising the leaf surface, non-pathogenic strains, plant defence activators, plant growth-promoting rhizobacteria, pathogenesis-related proteins, soil solarisation, strobilurin fungicides, variety mixtures/cultivar mixtures/multilines, biointensive integrated pest management and other recent advances (RNA interference, fusion protein-based biopesticides, seed mat technology and environmental methods). The book is illustrated with excellent quality photographs enhancing the quality of publication. The book is written in lucid style and easy to understand language along with adoptable recommendations for pest management.

This book can serve as a useful reference to policymakers, research and extension workers and students. The material can also be used for teaching postgraduate courses. Suggestions to improve the contents of the book are most welcome (e-mail: reddy_parvatha@yahoo.com). The publisher, Springer (India) Pvt. Ltd., New Delhi, deserves commendation for their professional contribution.

Bangalore P. Parvatha Reddy

About the Author

Dr. P. Parvatha Reddy obtained his Ph.D. degree in plant pathology jointly from the University of Florida, USA, and the University of Agricultural Sciences, Bangalore. He served as the director of the prestigious Indian Institute of Horticultural Research (IIHR) at Bangalore from 1999 to 2002 during which period the institute was honoured with 'ICAR Best Institution Award'. He also served as the Head, Division of Entomology and Nematology at IIHR and gave tremendous impetus and direction to research, extension and education in developing biointensive integrated pest management strategies in horticultural crops. Dr. Reddy has about 34 years of experience working with horticultural crops and is involved in developing an F1 tomato hybrid 'Arka Varadan' resistant to root-knot nematodes. He has over 237 scientific publications to his credit, which also include 22 books. Dr. Reddy has been honoured with the following prestigious awards: 'Association for Advancement Pest Management in Horticultural Ecosystems Award', 'Dr. GI D'souza Memorial Lecture Award', 'Prof. H. M. Shah Memorial Award' and 'Hexamar Agricultural Research and Development Foundation Award' for his unstinted efforts in developing sustainable, biointensive and eco-friendly integrated pest management strategies in horticultural crops.

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Introduction

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Abstract

Because of high intensive agricultural practices and chemicalisation of agriculture, the age-old environment-friendly pest management practices like sanitation, crop rotation, mixed cropping, adjustment of date of planting, fallowing, summer ploughing, green manuring, composting, etc., to combat plant pests are not being practised in Indian agriculture. The pace of development and durability of resistant varieties had been slow and unreliable.

Considering these limitations, there have been growing awareness and increasing demand for novel and improved crop protection approaches to guarantee effective and sustainable food production which offers new opportunities for crop protection research. The most recent advances in crop protection include avermectins, bacteriophages, biofumigation, biotechnological approaches, bio-priming of seeds, disguising the leaf surface, non-pathogenic strains, plant growth-promoting rhizobacteria, soil solarisation, strobilurin fungicides, variety mixtures/cultivar mixtures/multilines, biointensive integrated pest management, pathogenesis-related proteins, RNA interference, fusion protein-based biopesticides, seed mat technology and environmental methods.

In the recent years, the need to increase food production to meet the demands of rapidly increasing population from a limited land resource necessitated the use of intensive farming systems, with the inputs like narrow genetic base, high fertilisers, irrigation, multiple cropping, etc., which favour disease and pest development. The intensive agriculture, especially the introduction of new high-yielding genotypes susceptible to the pests and the pathogens, and changing cropping patterns including cultivation in nontraditional areas have resulted in a spurt of pests and diseases in crop pathosystems, remarkably changing the scenario of biotic stresses. It is not only that those new pest problems emerged but also the minor pests assumed major status and vice versa. The intensification of cropping systems has led to increase in biotic stresses on account of introduction of new pest problems (e.g. cotton leaf curl, type B of whitefly, spiralling whitefly), increased intensity of the existing pests (e.g. white rust of mustard, leaf blight of wheat, sheath blight of rice) and development of resistance to pesticides (e.g. American bollworm, whitefly).

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1.1 Emerging Pest Scenario

1.1.1 Emerging Insect Pest Scenario

The change of insect pest scenario in Indian agriculture was more influenced by the introduction of new agricultural production technology based on high-yielding varieties and increased use of inputs like irrigation water, fertilisers and pesticides during the last four decades. Many ecological attributes, which are favourable for plant growth, also favour multiplication of pests. Basic principles of herbivore were highlighted in several pestilence episodes. Most of these intense pestilences in various crops could be mitigated through regulated plant nutrition system. The quality of plant nutrition is the determinant of the intensity and build-up of agricultural pests, which are capable of adapting to large changes in the environment. Consequently, there is a change in the insect pest scenario in almost all the crops due to changes in agroecosystem.

The *desi* tall varieties of rice were found to suffer from only five insect pests, namely, yellow stem borer, hispa, rice bug, rice grasshopper and surface grasshopper. Following the introduction of high-yielding dwarf varieties and many river command area projects, and also the associated chemical intensive technology, there has been a considerable increase in area under rice. Extensive sole cropping of rice is very common in many river and tank command areas, which favoured the development and multiplication of multitude of pests. Similarly, leaf folder has emerged as a serious pest in Kerala, Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Punjab and Haryana. Gall midge has been observed to occur during *rabi* in Godavari delta of Andhra Pradesh and coastal Maharashtra. Gundhi bug, which was earlier confined to north and north-eastern states of India, has been frequently causing serious damage to rice in parts of Tamil Nadu and Andhra Pradesh. There is a need to cultivate mosaics of varieties of crop plants in monocropping systems in large geographic tracts to prevent generation and invasions of various pests as a tool to avoid enormous biotic stresses.

1.1.2 Emerging Disease Scenario

Plant disease epiphytotics have been a major cause to change agricultural patterns and even food habits in many parts of the world. For example, cereal rye was replaced by potato due to ergot (*Claviceps purpurea*) disease, and potato was replaced by wheat due to late blight (*Phytophthora infestans*) in Europe. Some other similar devastating diseases which had far-reaching impact on agriculture were wheat rust in Mexico, coffee rust in Sri Lanka and Brazil, southern corn blight in the USA, cassava mosaic and maize rust in Africa, Panama disease (*Fusarium oxysporum* f. sp. *cubense)* of banana in South America and Liberia, bunchy top of banana in Australia, swollen shoot of cocoa in Ghana, bacterial rot (*Pseudomonas solanacearum*) of potato in Kenya and many others. In India, the brown spot of rice (*Cochliobolus miyabeanus*) caused the great Bengal famine in 1943; red rot of sugar cane caused severe epiphytotics in Uttar Pradesh and Bihar during 1938–1942; wheat rust in Uttar Pradesh and Madhya Pradesh in 1946–1947; *Helminthosporium* blight of wheat and barley in Uttar Pradesh and Bihar during 1979–1981; leaf curl of cotton in Punjab and Rajasthan during 1994–1995; tungro disease of rice in Punjab during 1998–1999; and necrosis disease of sunflower in Karnataka are just a few examples of the serious problems caused by plant diseases. Ironically, most of these diseases have caused destruction in crops grown under rain-fed agriculture, indicating vulnerability of such cropping systems.

In wheat, rusts were the most serious problems until the mid-1970s, but currently with the wide use of rust-resistant varieties (although there is overwhelming evidence of the yellow rust-resistant wheat variety, PB 343 appears to be susceptible to this dreadful disease in the ‘green revolution area’ of the country), a minor disease of the past, namely, Karnal bunt, has assumed serious proportions. Karnal bunt in some wheat-growing states and breakdown of resistance in PB 343 variety for yellow rust race, 78S 84, have emerged as serious disease problems. The rice tungro virus and the bacterial leaf blight of rice are the most devastating diseases in the new varieties.

Sheath blight has become serious on rice in the nonconventional areas. Maize and millets are now devastated by downy mildews. Blight of cotton became a major problem when the indigenous diploid cottons were replaced by exotic cotton tetraploid cottons. The new exotic cotton varieties are also highly susceptible to a new disease known as 'parawilt of cotton' of unknown aetiology. During the past few years, the viruses of cotton (particularly whitefly-transmitted leaf curl) have become dangerous and required special efforts to check the spread to different areas. Such examples of changing disease scenario are available for pulses, oilseeds, vegetables, fruits, etc., that is, the crops in which productivity has increased tremendously. Certain diseases of complex or unknown aetiology, for example, parawilt of cotton, coconut root wilt, dieback in citrus, mango malformation, crown rot of oil palms, and brown bast disease of rubber need special efforts to develop management practices to minimise the losses.

1.1.3 Emerging Plant-Parasitic Nematode Scenario

Plant-parasitic nematodes, the unseen enemies of the farmer, have been recognised as serious perpetual problems in agricultural production all over the world. Favourable weather and almost continuous availability of host crops in the tropical and subtropical regions including India favour their build-up. Being soil-borne and with wide host range, nematodes are one of the toughest pests to control. International estimates have put crop losses due to nematodes at over $100 billion (Sasser and Freckman 1987). The root-knot nematodes cause intense pestilence problem in vegetables, fruit crops, rice, pulses, fibre and oilseed crops.

Extensive nematode quarantine and control efforts in developed countries have paid rich dividends. India suffers heavy quantitative and qualitative losses in various food, fibre and commercial crops due to nematodes. A number of new nematode problems have emerged in the intensive cropping systems.

Rice revolution in the country has brought about many second-generation nematode problems such as a new root-knot nematode species *Meloidogyne triticoryzae*, which damage the rice and wheat in the north-western plains with rice–wheat cropping system. *Meloidogyne graminicola* infestation was intense in rice crop of Mandya district in Karnataka. *Molya* disease in wheat caused by the cereal cyst nematode, *Heterodera avenae,* in Haryana and Bihar has emerged as a serious disease problem.

1.2 Impact of Climate Change

The effect of changing global climate, particularly of sharp increase in temperature, through the last century on the intensity of pests and diseases is largely unknown. It now appears that the southern Asia will become warmer and unseasonably much wetter. The major changes in global temperature and climate are expected to be mainly due to atmospheric CO_2, methane and chlorofluorocarbons. Initial experiments have already shown that an increase in atmospheric CO_2 concentration from the current level of 330–670 ppm increases the susceptibility of plants to pathogens and pests. Practically, there is no data on the effect of ongoing climatic variability on diseases and pests. Most of the studies have been more concerned with the influence of day-to-day weather conditions rather than with year-to-year climatic variability on pest and disease appearance and build-up. Climatic variability can affect any part of the life cycle of the pathogen, insect, nematode as well as the interaction between or amongst these organisms. The integrated pest management (IPM) strategies strongly rely on natural controlling factors such as weather and natural enemies of various pest organisms. Based on physiography, soil, climate and growing period, 21 agroecological regions (AERs) have been identified. Most of the major disease problems in rain-fed agriculture occur in sub-humid and semi-arid conditions which represent 72% of the total geographical area (329 m ha) of the country. The other AERs have relatively fewer serious disease problems. Utilising the current scientific tools, appropriate information on the biological transportations that the herbivorous organisms undergo in crop fields should be studied.

There is a strong need to revamp the direction of research in plant protection in order to acquire better understanding of the internal processes of each crop species alone and in combination with others of a cropping system and in sequence. This could be best addressed through discovering a new paradigm of crop health management. Agrarian husbandry has to be made more meaningful with crop health management in which defined health attributes of the crops have to be pursued. Having currently a national pool of around 1,000 plant protection scientists (in Entomology, Plant Pathology, Nematology, Acarology, Apiculture, vertebrate organisms, etc.) in DARE (ICAR and SAU systems), reorganisation of resources has to be rationalised to involve effectively in the prioritised research programmes in plant protection.

1.3 Need for Novel Approaches to Crop Protection

Presently practised crop protection measures mainly orient towards chemical control. The excessive dependence on chemical pesticides leads to the development of resistance in insect pests and pathogens, outbreaks of secondary pests and pathogens/biotypes and occurrence of residues in food chain. The chemical control also has other limitations such as high cost, low cost to benefit ratio; poor availability; selectivity; temporary effect; efficacy affected by physicochemical and biological factors; resurgence of pests; health hazards; toxicity towards plants, animals and natural enemies; environmental pollution; etc. Because of high intensive agricultural practices and chemicalisation of agriculture, the age-old environment-friendly pest management practices like sanitation, crop rotation, mixed cropping, adjustment of date of planting, fallowing, summer ploughing, green manuring, composting, etc., to combat plant pests are not being practised in Indian agriculture. The pace of development and durability of resistant varieties had been slow and unreliable.

Considering these limitations, there have been growing awareness and increasing demand for novel and improved crop protection approaches to guarantee effective and sustainable food production which offers new opportunities for crop protection research. The most recent advances in crop protection include avermectins, bacteriophages, biofumigation, biotechnological approaches, bio-priming of seeds, disguising the leaf surface, non-pathogenic strains, plant growth-promoting rhizobacteria, soil solarisation, strobilurin fungicides, variety mixtures/cultivar mixtures/multilines, biointensive integrated pest management, pathogenesis-related proteins, RNA interference, fusion protein-based biopesticides, seed mat technology and environmental methods.

1.4 Recent Advances in Crop Protection

1.4.1 Avermectins

The avermectins are a new class of macrocyclic lactones derived from mycelia of the soil actinomycete, *Streptomyces avermitilis* (soil inhabiting which is ubiquitous in nature). These compounds were reported to be possessing insecticidal, acaricidal and nematicidal properties (Putter et al. 1981). They are commonly distributed in most of the cultivated soils and are in widespread use, especially as agents affecting plant-parasitic nematodes, mites and insect pests. The water solubility of avermectin B1 is approximately 6–8 ppb, and its leaching potential through many types of soil is extremely low. These physical properties also confer many advantages upon the use of avermectins as pesticides. Their rapid degradation in soil and poor leaching potential suggest that field applications would not result in persistent residues or contamination of ground water.

1.4.2 Bacteriophages

A bacteriophage (from ‘bacteria’ and Greek *phagein* ‘to eat’) is any one of a number of viruses that infect bacteria. Bacteriophages are amongst the most common biological entities on earth. Kotila and Coons (1925) isolated bacteriophages from soil samples that were active against the causal agent of blackleg disease of potato, *Erwinia carotovora* subsp. *atroseptica*. They demonstrated in growth chamber experiments that co-inoculation of *E. carotovora* subsp. *atroseptica* with phage successfully inhibited the pathogen and prevented rotting of tubers. These workers also isolated phages against *Erwinia carotovora* subsp. *carotovora* and *Agrobacterium tumefaciens* from various sources such as soil, rotting carrots and river water (Coons and Kotila 1925). Thomas (1935) reported that treatment of corn seed infected with *Pantoea stewartii*, the causal agent of Stewart's wilt of corn, with bacteriophage isolated from diseased plant material reduced the disease incidence from 18 to 1.4%.

Despite the promising early work, phage therapy did not prove to be a reliable and effective means of controlling phytobacteria. Since the early 1990s, various approaches were attempted to improve the competitive advantage of phages in the environment in order to improve their efficacy including prevention of development of phage-resistant mutants, proper selection of efficient phages, timing of phage application, maximising chances for interaction between phage and target bacterium, overcoming adverse factors in phyllosphere on phage persistence, development of solar protectants to increase phase bioefficacy and delivery of phages in the presence of phage-sensitive bacterium.

1.4.3 Biofumigation

Biofumigation is an agronomic technique that makes use of some plants' defensive systems. The main plant species in which this is found are the Brassicaceae (cabbage, cauliflower, kale and mustard), Capparidaceae (cleome) and Moringaceae (horseradish). In suitable conditions, the biofumigation technique is able to efficiently produce a number of important substances. In the above plant families, one of the most important enzymatic defensive systems is the myrosinase–glucosinolate system. With this system, tissues of these plants can be used as a soft, eco-compatible alternative to chemical fumigants and sterilants. In a number of countries over the past few years, several experiments have been carried out to evaluate the effectiveness of the myrosinase–glucosinolate system, in particular using the glucosinolate-containing plants as a biologically active rotation and green manure crop for controlling several soil-borne pathogens and diseases. The use of this technique is growing, and it is studied in several countries at a full-field scale (the USA, Australia, Italy, the Netherlands and South Africa), thus triggering the interest of some seed companies, with a positive effect on the 'biofumigation' seed market, which is significantly growing year after year. New potential has also been found for the dehydrated plant tissues and/or for defatted meal pellets production and use. An intense discussion amongst researchers of this topic in various countries seems to be of fundamental importance particularly to define and develop future common strategies. The current strategies include biofumigation as part of an integrated approach to methyl bromide replacement in agriculture.

1.4.4 Biotechnological Approaches

Biotechnology offers many opportunities for agriculture and provides the means to address many of the constraints placed to productivity. It uses the conceptual framework and technical approaches of molecular biology and plant cell culture systems to develop commercial processes and products. With the rapid development of biotechnology, agriculture has moved from a resource-based to a science-based industry, with plant breeding being dramatically augmented by the introduction of recombinant DNA technology based on knowledge of gene structure and function. The concept of utilising a transgenic approach to host plant resistance was realised in the mid-1990s with the commercial introduction of transgenic maize, potato and cotton plants expressing genes encoding the insecticidal δ-endotoxin from *Bacillus thuringiensis*. Similarly, the role of herbicides in agriculture entered a new era with the introduction of glyphosate-resistant soybeans in 1995. Currently, the commercial area planted to transgenic crops is in excess of 90 million hectares with approximately 77% expressing herbicide tolerance, 15% expressing insect resistance genes and approximately 8% expressing both traits. Despite the increasing disquiet over the growing of such crops in Europe and Africa (at least by the media and certain NGOs) in recent years, the latest figures available demonstrate that the market is increasing, with an 11% increase between 2004 and 2005.

1.4.5 Bio-priming of Seeds

Bio-priming is a new technique of seed treatment that integrates biological (inoculation of seed with beneficial organism to protect seed) and physiological aspects (seed hydration) of disease control. It is recently used as an alternative method for controlling many seed and soil-borne pathogens. It is an ecological approach using selected fungal antagonists against the soil and seed-borne pathogens. Biological seed treatments may provide an alternative to chemical control. Seed priming, osmo-priming and solid matrix priming were used commercially in many horticultural crops, as a tool to increase speed and uniformity of germination and improve final stand. However, if seeds are infected or contaminated with pathogens, fungal growth can be enhanced during priming, thus resulting in undesirable effects on plants. Therefore, seed priming alone or in combination with low dosage of fungicides and/or biocontrol agents have been used to improve the rate and uniformity emergence of seed and reduce damping-off disease.

1.4.6 Disguising the Leaf Surface

The leaf surface provides the first barrier that fungi must overcome in order to gain access to the leaf, but it also provides chemical and physical cues that are necessary for the development of infection structures for many fungal pathogens. Film-forming polymers can coat the leaf surface, acting not just as an extra barrier to infection but also disguising the cues necessary for germling development. Kaolin particle films can envelop the leaf in a hydrophobic particle film barrier that prevents spores or water from directly contacting the leaf surface and, as a result, can suppress infection. Adhesion of fungal spores to the leaf surface, which is important to keep spores on the leaf surface and for appropriate development of the fungus on the leaf surface, can be inhibited, leading to reduced infection and lesion development. Polymer and particle films have been shown to provide disease control in the field, whilst research on agents that inhibit spore adhesion on leaf surfaces is still in its infancy. There is an urgent need for research on the practicality of using these innovative methods under field conditions and on ways of integrating them into current crop protection programmes.

1.4.7 Non-pathogenic Strains

Non-pathogenic (avirulent) or low virulent (hypovirulent) strains are capable of colonising infection site niches on the plants' surfaces and protecting susceptible plants against their respective pathogens. Such phenomena have been demonstrated for a considerable number of plant pathogens (*Agrobacterium* spp., *Rhizoctonia* spp., *Fusarium* spp. and *Pythium* spp.). Non-pathogenic strains of various pathogens are potential candidates for development of biocontrol preparations. Some strains are already used in agriculture. The modes of protection differ amongst the non-pathogenic strains, and one strain can protect by more than one mechanism. Competition for infection sites, or for nutrients (such as carbon, iron) as well as induction of the host plant resistance, has been demonstrated for several pathogens such as *Rhizoctonia* spp., *Fusarium* spp. and *Pythium* spp. Mycoparasitism was shown for *Pythium* spp. The non-pathogenic *F. oxysporum* are easy to mass produce and formulate, but application conditions for biocontrol efficacy under field conditions have still to be determined.

1.4.8 Plant Growth-Promoting Rhizobacteria

Plant growth-promoting rhizobacteria (PGPR) were first defined by Kloepper and Schroth (1978) to describe soil bacteria that colonise the roots of plants following inoculation onto seed and that enhance plant growth and/or reduce disease or insect damage. There has been much research interest in PGPR, and there is now an increasing number of PGPR being commercialised for crops. Organic growers may have been promoting these bacteria without knowing it. The addition of compost and compost teas promote existing PGPR and may introduce additional helpful bacteria to the field. The absence of pesticides and the more complex organic rotations are likely to promote existing populations of these beneficial bacteria. However, it is also possible to inoculate seeds with bacteria that increase the availability of nutrients, including solubilising phosphate, potassium, oxidising sulphur, fixing nitrogen, chelating iron and copper.

PGPR such as *Pseudomonas* and *Bacillus* species have attracted much attention for their role in reducing plant diseases. The work to date is very promising and may offer organic growers with some of their first effective control of serious plant diseases. Some PGPR, especially if they are inoculated on the seed before planting, are able to establish themselves on the crop roots. They use scarce resources and thereby prevent or limit the growth of pathogenic microorganisms. Even if nutrients are not limiting, the establishment of benign or beneficial organisms on the roots limits the chance that a pathogenic organism that arrives later will find space to become established. Numerous rhizosphere organisms are capable of producing compounds that are toxic to pathogens like HCN.

1.4.9 Soil Solarisation

The use of clear polyethylene film to cover moistened soil and trap lethal amounts of heat from solar radiation was first reported by Katan and colleagues in Israel in the mid-1970s (Katan et al. 1976). DeVay and associates at University of California, Davis, began an intensive research programme on the promising technique shortly thereafter, and the term ‘soil solarisation’ was soon coined to describe the process by cooperators in the San Joaquin Valley. Researchers found that solarisation could be a useful soil disinfestation method, especially in areas with hot and arid conditions during the summer months, such as the Central Valley and southern deserts. In certain cases, the treatment has also been effective, primarily for weed management, in cooler coastal areas (Elmore et al. 1993). The pesticidal activity of solarisation was found to stem from a combination of physical, chemical and biological effects, as described in several comprehensive reviews.

Solarisation is a technique that elevates soil temperatures beneath a clear plastic layer to reduce soil-borne pests. The capacity of soil solarisation to suppress propagule numbers of soil-borne pathogens relies on many factors. The temperatures obtained in the moistened soil covered by the transparent sheeting and the exposure time of the organisms to these elevated temperatures are both important characteristics of this pre-plant soil treatment. Solarisation has been effective in disease control in many geographical locations around the world. It is most successful in regions with the appropriate meteorological parameters such as high air temperatures and extended periods of high radiation.

1.4.10 Strobilurin Fungicides

Natural strobilurins are produced by certain forest mushrooms and secreted into the decaying wood on which they grow. The powerful fungicidal activity of this secretion prevents invasion by other fungi, so protecting the nutrient source of the original mushroom. This fungal antibiotic fights infections of the plants. After German scientists first discovered strobilurins in 1977, it didn’t take long for people to realise its potential for use as a fungicide. Thus, the development of what would become one of the most important classes of fungicides began.

The fungus *Strobilurus tenacellus*, which grows on fallen pine cones, produces strobilurin A. This rather insignificant grey to yellowish-brown mushroom grows to a height of 5–7 cm and is edible, with a mild, slightly bitter taste, but it is remarkable for its fungitoxic activity. Through the production of strobilurin, it is capable of keeping other fungi at bay that might otherwise compete for nutrients. All fungi need to produce their own energy supply in order to grow and produce new spores. This supply is especially important during the early establishment phase of the disease life cycle. It is produced by a complex series of chemical processes in the mitochondria that are part of every living fungal cell. Strobilurins work by blocking electron transfer within this chemical process, thus denying the fungus energy and preventing development, even at the earliest stages of the life cycle, the spore germination stage.

1.4.11 Cultivar Mixtures

Wolfe (1985) defined cultivar mixtures as 'mixtures of cultivars that vary for many characters including disease resistance, but have sufficient similarity to be grown together'. Cultivar mixtures do not cause major changes to the agricultural system, generally increase yield stability and in some cases can reduce pesticide use. They are also quicker and cheaper to formulate and modify than 'multilines', which are defined as mixtures of genetically uniform lines of a crop species (near-isogenic lines) that differ only in a specific disease or pest resistance (Browning and Frey 1981).

Cultivars used in the mixture must possess good agronomic characteristics and may be phenotypically similar for important traits including maturity, height, quality and grain type, depending on the agronomic practices and intended use. Cultivar mixtures in barley for the control of powdery mildew are an example of phenotypically similar mixtures, whereas red- and white-grained sorghum mixtures used in Africa are an example of phenotypically different mixtures.

The principles driving use of variety mixtures for disease control are soundly based on ecology. Epidemics are the exception in natural and semi-natural ecosystems, reflecting the balance derived from the co-evolution of hosts and pathogens. However, in modern agriculture in particular, this balance is far from equilibrium, and epidemics would be frequent were it not for highly effective pesticides and a plant breeding industry which introduces new cultivars to the market with new or different resistance genes. Such a situation is generally profitable when commodity prices are high, but it is costly and rates very poorly on sustainability and ecological or environmental parameter scales.

1.4.12 Biointensive Integrated Pest Management (BIPM)

Biointensive IPM is defined as 'A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks' (Benbrook 1996).

Biointensive IPM incorporates ecological and economic factors into agricultural system design and decision-making and addresses public concerns about environmental quality and food safety. The benefits of implementing biointensive IPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts and more effective and sustainable pest management. An ecology-based IPM has the potential of decreasing inputs of fuel, machinery and synthetic chemicals – all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society.

The primary goal of biointensive IPM is to provide guidelines and options for the effective management of pests and beneficial organisms in an ecological context. The flexibility and environmental compatibility of a biointensive IPM strategy make it useful in all types of cropping systems. Biointensive IPM would likely decrease chemical use and costs even further.

1.4.13 Plant Defence Activators

1.4.13.1 Chemical Plant Defence Activators

A number of natural and synthetic compounds induce plant defences against pathogens and herbivores and act at different points in plant defence pathways (Karban and Baldwin 1997; Gozzo 2004). The non-protein amino acid DL-β-aminobutyric acid (BABA) is a potent inducer of plant resistance and is effective against a wide range of biotic and abiotic stresses. BABA is rarely found naturally in plants, but, when applied as a root drench or foliar spray, it has been shown to protect against viruses, bacteria, oomycetes, fungi and phytopathogenic nematodes, as well as abiotic stresses such as drought and extreme temperatures (Jakab et al. 2001). BABA-induced resistance (BABA-IR) can provide effective protection for crop plants in many botanical families, including legumes, cereals, Brassicas and Solanaceae (Jakab et al. 2001). Unlike other chemical inducers (e.g. INA and BTH), BABA does not directly activate the plant's defence arsenal and therefore does not cause direct trade-off effects on plant growth due to energetically demanding investment in defence mechanisms. Instead, BABA appears to condition the plant for a faster and stronger activation of defence responses once the induced plant is exposed to stress, a process known as 'sensitisation' or 'priming' (Conrath et al. 2002).

BTH [benzo (1, 2, 3) thiadiazole-7-carbothioic acid S-methyl ester] is strongly effective against *Peronospora tabacina*, causative agent of blue mould, the most important worldwide distributed tobacco disease. Applied in minimal amounts (around 50 g ha^{-1}), BTH provides field protection lasting until flowering without negative influence on growth, development and yield of tobacco. BTH appears more efficient than metalaxyl, the commonly used blue mould fungicide. It ensures 90% disease reduction on the 17th day after its application versus only 46% for metalaxyl (Tally et al. 1999). It is noteworthy that BTH is an effective inducer of resistance in tobacco not only against fungal pathogens but also against viruses and bacteria (Tally et al. 1999). BTH was also found to be effective in inducing SAR in wheat (Görlach et al. 1996), pea (Dann and Deverall 2000), potato (Bokshi et al. 2003), cotton against *Alternaria* leaf spot, bacterial blight and *Verticillium* wilt (Colson-Hanks et al. 2000), tomato against bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*) (Soylu et al. 2003).

1.4.13.2 Biological Plant Defence Activators

Plants are endowed with several defence genes which are involved in synthesis of antifungal, antibacterial and antiviral compounds like pathogenesis-related proteins (PRs), phenolics, phytoalexins, lignin, callose and terpenoids conferring resistance against plant pathogens. Most of the defence genes are sleeping genes (quiescent in healthy plants) which require specific signals to activate them. Several antagonistic organisms have been shown to provide signals, which activate the defence genes, and they are called 'biological plant defence activators' or 'biological plant activators'. Several elicitors have been isolated from these antagonistic organisms. Elicitors are the primary signal molecules of the antagonists, which elicit host defence mechanisms. The elicitor provides necessary signal for activation of the defence genes. Lipopolysaccharides, chitin oligomers and glucans, siderophores, some enzymes (xylanases), a low molecular weight protein (oligandrin) and salicylic acid are some of the plant defence activators produced by antagonistic organisms.

1.4.14 Pathogenesis-Related Proteins (PRs)

The defence strategy of plants against stress factors involves a multitude of tools, including various types of stress proteins with putative