Economic and Eco-friendly Alternatives for the Efficient and Safe Management of Wheat Diseases

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Abstract

The achievement of high cereal production while considering environmental and health safety standards is an essential goal for all countries to meet their own food needs and feed the rapidly growing population around the world. In this regard, wheat (*Triticum aestivum* L.) is a strategic crop of great importance to global food security, especially in developing countries. It is even more important for the consumers of all sectors and regions where people rely on wheat as a significant element in their diets. However, several biotic and abiotic stress factors bring about the limiting and declining of local wheat production in return for the increasing needs of the growing population. To deal with such challenges, procedures allow for the use of agrochemicals as a means of achieving a high wheat yield. However, the unrestricted use of such chemicals causes serious damage to the agricultural ecosystem, particularly in those ecosystems that lack organic soil content and a high level of biodiversity, which help to restore its natural vigor after extensive use of agrochemicals. As a result, these demands to look for other eco-friendly alternatives will help us make satisfactory progress in

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K. A. Abd-Elsalam, H. I. Mohamed (eds.), *Cereal Diseases: Nanobiotechnological Approaches for Diagnosis and Management*,
https://doi.org/10.1007/978-981-19-3120-8_10

controlling wheat disease and successfully restore and sustain our agricultural ecosystem. In this chapter, we're going to talk about natural ways to boost the production of wheat cultivars by making them more able to fight off or at least tolerate wheat diseases.

Keywords

Wheat · Biostimulants · Wheat diseases · Biocontrol · Biotic stress

10.1 Introduction

Triticum aestivum L. is one of the world's most important staple cereals and a major source of 20% of calories and plant-based proteins in human meals (Almoneafy 2006; Mehta 2014b; Tilman et al. 2011; Vidal et al. 2020). As per the latest statistical report of the Food and Agriculture Organization, global wheat production in 2019–20 was about 765,769,635 tons (FAO 2020). Moreover, the current supply of wheat is adequate for world demand, according to the FAO's most recent wheat production valuation (http://www.fao.org/worldfoodsituation/csdb/en/). In the future, as the world's population grows, the wheat supply needs to be expanded further, which is expected to reach nine billion by 2050. Wheat growth and production will be boosted largely by an increase in yield due to high competition for arable lands with limited production (http://www.fao.org/state-of-food-security-nutrition/en/). Integrated disease and pest management, tolerance to warmer climates with increased frequency of abiotic challenges, and reduced water and other resource use can all help to improve this situation (Mehta 2014a). Wheat, like many other crops, is vulnerable to a variety of diseases that, if left unattended, can result in alterations in the chemical properties and quality of wheat grain as well as a significant decrease in yield (Matzen et al. 2019). Many strategies have been used to eliminate or mitigate the negative impact of wheat diseases, such as the use of various agronomic practices, the introduction of resistant varieties, and the use of microbiocidal synthetic compounds or chemical control. The latter is widely used as the most effective and common method of controlling wheat phytopathogens. The haphazard use of synthetic microbiocidals, on the other hand, has several serious drawbacks and threats, including pathogen resistance to these chemicals, eradication of beneficial microorganisms in the surrounding environment, reduction of soil organic content, and a decrease in biodiversity within plant-associated niches. Furthermore, because pathogen sensitivity to these compounds decreases, the applied dose of them must be increased. Due to this dosage increase, the resulting control costs, the environmental threats posed by these compounds, and their negative side effects on human health will significantly rise (Gao et al. 2020). The harmful effects of these synthetic chemicals are exacerbated in arid and semiarid lands due to their lower organic matter content and, as a result, lower biodiversity, which do not allow them to mitigate any deleterious changes caused by uncontrolled application of these chemicals (Santos et al. 2011). Therefore, in this chapter, we highlight and discuss the beneficial effects of some inexpensive, safe, available, and efficient alternatives to managing wheat diseases in order to reduce agrochemical inputs in the agricultural sector and sustain our environmental resources.

10.2 The Well-Reported Eco-friendly Approaches Used in Wheat Disease Management

Several approaches have been evaluated by researchers as safe alternatives to synthetic pesticides for controlling wheat phytopathogens. The search for and evaluation of the biocidal activity of various biological/nonbiological procedures or biologically based means against wheat phytopathogens is still ongoing. In this section, we will look at some well-known methods for controlling wheat diseases.

10.2.1 Applying of Biogenic Nanoparticles

Nanotechnology has been suggested as a potential new technology for satisfying worldwide demands for sustainable agriculture and crop loss deterrence (Rai-Kalal et al. 2021). Within this context, numerous researchers have focused their efforts on developing nano-formulations that are low-cost, biodegradable, environmentally friendly, and exhibit biocontrol activities towards phytopathogens (He et al. 2019; Partila 2019). To minimize hazardous waste produced by the nanomaterials industry, "green" synthetic processes should be used to supplement the increasing demand for these materials. Biogenic NP synthesis is a very appealing, greener, and more eco-friendly production option due to the use of lower toxicity compounds, pressures, and surrounding temperatures during the synthesis (Chhipa 2019). As a safe and eco-friendly technology, a variety of prokaryotic and eukaryotic organisms are utilized in the biosynthesis of metallic nanoparticles such as platinum, gold, silver, zirconium, iron, cadmium, and palladium, as well as metal oxides like titanium oxide and zinc oxide (Luo et al. 2018). Around 75% of the potential application of nanoparticles in agriculture was directed toward the primary goal of controlling plant diseases (He et al. 2019; Luo et al. 2018). Of their physicochemical properties and nano size, they can easily penetrate the cellular envelops and membranes of microbial phytopathogens' internal compartments and induce a fatal effect on them (Khan and Rizvi 2014). Due to the obvious differences in charges between nanoparticles and microorganism macromolecules, they can act as electromagnetic absorbers and attach to the cell surface, causing oxidation of microbe surface molecules, and eventually cell death (Lin and Xing 2007). Many researchers have used biogenic nanoparticles as an efficient, low-cost, and safe method of managing wheat diseases. Most of the time, these materials were able to help wheat plants fight off phytopathogens, and this was usually accompanied by a boost in plant growth. For instance, Satti et al. (2021) biosynthesized and applied 40 mg/L titanium dioxide nanoparticles from *Moringa oleifera* Lam. aqueous leaf extract, which resulted in biocontrol of *Bipolaris sorokiniana* that causes spot blotch in wheat. Additionally, the biosynthesized silver nanoparticles (AgNPs) have been demonstrated to inhibit fungal growth and reduce mycotoxin production of *Fusarium graminearum*, which cause Fusarium head blight in wheat. According to electron microscopy images, nanoparticle treatment caused hypha deformation and collapsing, which resulted in the leaking of genetic materials and proteins outside of the fungal hypha (Ibrahim et al. 2020). In a different research, researchers revealed that applying biogenic AgNPs significantly reduced *Bipolaris sorokiniana* infection in wheat plants in vivo. AgNPs caused lignin deposition in the host plant's vascular bundles, according to further histochemical analysis (Mishra et al. 2014). Table 10.1 shows some remarkable outcomes.

10.2.2 Harnessing of Beneficial Microorganisms (Biological Control)

Using beneficial microbes to improve plant growth and agricultural sustainability is a promising strategy. Beneficial microorganisms associated with plants can alleviate the harmful effects of pathogenic/environmental stresses in plants, boost plant growth, improve the cycle of biologically active compounds (e.g., enzymes, hormones, and vitamin), and decompose organic matter residues in agricultural soil (Saberi-Riseh et al. 2021; Smolińska and Kowalska 2018). These microorganisms can also effectively colonize the plant phytosphere, i.e., rhizosphere, phyllosphere and anthosphere. As a result of their capability to promote plant growth, improve plant health, and control plant diseases, beneficial microorganisms are a promising strategy for long-term plant disease management (Almoneafy et al. 2021). They can directly benefit plants by exerting an antagonistic effect on plant pathogens via colonization of infection site, competition for nutrient uptake, and occupation of niche (Köhl et al. 2019). The indirect mechanisms include interaction with plants that involves the induction of plant resistance to phytopathogens and the promotion of plant growth by facilitating nutrients uptake and phytohormones' production (Vos et al. 2015; Wang et al. 2021). Furthermore, their positive interaction with the concerned plant causes changes in the plant's secondary metabolite status (Etalo Desalegn et al. 2018). This method is useful and promising when applied to all arable lands, and its benefit increases in arid and semiarid lands because its soil organic content is increased, which improves its ability to retain water for a longer period. Moreover, it strengthens the environment's ability to recover from the detrimental consequences of randomized agrochemical application (Kaushal and Wani 2016). Biocontrol of phytopathogens through microbial agents or their metabolites is a cheap and environment-friendly component of a successful wheat disease management program (Sood and Kaushal 2021; Xu et al. 2021). In order to combat these pathogens, the quest for biocontrol agents for wheat diseases and the importance of various beneficial microorganism–pathogen interactions have been highlighted in numerous reports. In this regard, one of the most notable examples of antagonistic bacteria protecting plant roots can be found in soils that suppress wheat take-all disease. Take-all decline (TAD) is well-known to result from the accumulation of populations of 2,4-diacetylphloroglucinol

Table 10.1 Some effective instances of nonbio/bio-derived agents used to safely manage wheat diseases

Type of controlling approach	Pathogen	Disease's name	Resulted effect	Reference
Biogenic nanoparticles (titanium nanoparticles)	*Bipolaris sorokiniana*	Spot blotch disease	Significant reduction of disease severity	Satti et al. (2021)
Biogenic nanoparticles (silver nanoparticles)	*Fusarium graminearum*	Fusarium head blight	Inhibition of fungal growth and reduction of mycotoxin in wheat grains	Ibrahim et al. (2020)
Biogenic nanoparticles (silver nanoparticles)	*Bipolaris sorokiniana*	Spot blotch disease	AgNPs deposited lignin in the vascular bundles of the host plant	Mishra et al. (2014)
Plant extracts (extracts of 5 plants)	*Puccinia triticina*	Wheat leaf rusts	Treatment resulted in a significant decrease in the coefficient of infection of wheat leaf rust as well as an increase in wheat yield	Draz et al. (2019)
Plant extracts (*Curcuma zedoaria* rhizomes or its substance)	*Puccinia triticina*	Wheat leaf rusts	In vivo, the treatment significantly suppressed wheat leaf rust	Han et al. (2018)
Plant extracts (extracts of neem, clove, and garden quinine)	*Puccinia triticina*	Wheat leaf rusts	Treatment completely prevented the development of leaf rust in treated plants	Shabana et al. (2017)
Plant extracts (*Agapanthus africanus* extracts)	*Puccinia triticina*	Wheat leaf rusts	The treatment increased the activities of -1,3-glucanase, chitinase, and peroxidase in both susceptible and resistant wheat cultivars	Cawood et al. (2010)
Plant extracts (aqueous leaf extracts of *Jacaranda mimosifolia*)	*Puccinia triticina*	Wheat leaf rusts	Plant extract treatment alone or in combination with 0.05% Amistar Xtra increased PR protein expression in treated plants	Naz et al. (2014)
Plant resistance inducers (*N*-hydroxypipecolic acid)	*Fusarium graminearum*	Fusarium head blight	Treatment boosts immune response, enabling wheat plants to defend themselves against pathogens	Zhang et al. (2021)
Plant resistance inducers (saccharin)	*Zymoseptoria tritici*	Septoria tritici blotch	Treatment reduced disease severity by 77% by eliciting and priming	Mejri et al. (2020)

(continued)

Table 10.1 (continued)

Type of controlling approach	Pathogen	Disease's name	Resulted effect	Reference
			lipoxygenase and PR gene-related defense pathways	
Plant resistance inducers (several chemical inducers)	*Mycosphaerella graminicola*	Septoria leaf blotch	The treatment had a suppressive effect on Septoria leaf blotch, as well as an increase in wheat grain yield	El-Gamal et al. (2021)
Plant resistance inducers (salicylic acid)	*Zymoseptoria tritici*	Septoria tritici blotch	Treatment resulted in the induction of pathogen resistance in wheat-treated plants by increasing the expression of both the PAL and PR2 genes	Mahmoudi et al. (2021)

(2,4-DAPG)-producing fluorescent *Pseudomonas* spp. during wheat monoculture. This is due to the unique fungicidal activity of 2,4-DAPG against the causal agents of this disease, *Gaeumannomyces graminis* var. *tritici* (Durán and de la Luz Mora 2021; Kwak et al. 2012; Kwak and Weller 2013). Similarly, Yang et al. (2014) discovered that the in vitro growth of *Gaeumannomyces graminis* var. *tritici* and *Rhizoctonia solani* AG-8 was inhibited by cyclic lipopeptide (CLP) produced by *Pseudomonas fluorescens* HC1–07. In another study, *Bacillus velezensis* CC09 was shown to demonstrate 66.67% disease-control efficacy (DCE) of take-all and 21.64% DCE of spot blotch by efficiently colonizing the wheat leaves, roots, and stem and leaves, respectively (Kang et al. 2018). Furthermore, wheat powdery mildew was significantly suppressed by *B. subtilis* (4×10^5 CFU ml^{-1}) during in vitro via inhibition of conidial germination and normal appressorium development, or in vivo via induction of disease resistance in wheat (Xie et al. 2021). Additionally, pathogenicity-related genes of *Gaeumannomyces graminis* var. *tritici* were downregulated in pathogen-inoculated roots of wheat treated with the biocontrol agent *Bacillus velezensis* CC09 (Kang et al. 2019). Similarly, *Bacillus amyloliquefaciens* subsp. *plantarum* XH—9 demonstrated a high capacity to colonize wheat roots and significantly reduced *Fusarium oxysporum* in roots of the treated plants as revealed by qRT PCR analysis (Wang et al. 2018). Despite the fact that antagonistic fungi have been shown to have biocontrol capacity against various cereal pathogens, chemical fungicides are not quietly replaced by commercial fungal biocontrol. So far, research on bio-management of wheat pathogens by antagonistic fungi has primarily focused on using *Trichoderma*. *Trichoderma harzianum,* for example, outperformed *T. viride* as a bioagent, inhibiting the growth of spot blotch disease by 60.82% in vitro (Kaur et al. 2021). Arbuscular mycorrhizal fungi (AMF), which share symbiotic relationship with nearly all plants, are important fungi that live in the rhizospheric soil and could be used to control wheat diseases. AMF has been shown in this symbiosis to improve growth and crop yield, as well as to provide tolerance against different stress factors, including protection against many phytopathogenic fungi and heavy metal toxicity (Eke et al. 2016; Spagnoletti et al. 2017, 2018). In this context, inoculation with AMF *Rhizophagus intraradices* significantly reduced the population density of *Fusarium pseudograminearum* by 75.7% and 39% disease severity in wheat grown in greenhouse (N.C. Schenck and G.S. Sm.), via a mechanism of redox balance and competition for root colonization compared to the untreated control (Spagnoletti et al. 2021). Plant endophytic microorganisms may be better adapted than epiphytic microorganisms to enter, colonize, and secrete secondary metabolites within the plant (Busby et al. 2016; Ulloa-Ogaz et al. 2015). In this respect, pre-colonization of wheat with endophytic fungi *Sarocladium zeae*, followed by *F. graminearum* inoculation, resulted in a significant reduction of fusarium head blight symptoms (57.9%) and a 61.2% reduction in mycotoxin content in harvested wheat heads (Kemp et al. 2020). Remarkable results are listed in Table 10.2.

10.2.3 Applying of Plant Extracts

Plant-derived natural products have grown into one of the leading resources for discovering novel compounds with distinct biological functions, resulting in remarkable number of novel phytopathogen-controlling agrochemicals (Agarwal et al. 2020; Lorsbach et al. 2019; Umetsu and Shirai 2020). Several natural plant products have been shown to reduce foliar pathogen populations and limit disease development, implying that these plant extracts could be used as eco-friendly alternatives and components in integrated pest management approaches (Draz et al. 2019). Several plant species have been found to contain natural substances that are either toxic to several wheat pathogens or can induce plant systemic resistance against them (Draz et al. 2019; Han et al. 2018). In this context, numerous related experiments have been performed to investigate the effectiveness of plant extracts in controlling leaf rust in wheat caused by *Puccinia triticina*. For example, pre-application of five plant extracts significantly reduced the coefficient of infection of wheat leaf rust, and the yield was significantly increased (Draz et al. 2019). Likewise, spraying *Curcuma zedoaria* rhizomes or its isolated substance sesquiterpene ketolactone showed significant activity against wheat leaf rust in vivo (Han et al. 2018). In another study, spraying four-day post-inoculated wheat plants with clove, neem, and garden quinine extracts resulted in complete prevention of leaf rust development in treated plants (Shabana et al. 2017). More intriguing results were observed during foliar application of *Agapanthus africanus* extracts, which unanimously improved the in vitro activities of three pathogenesis-related proteins (PR); i.e., chitinase, -1,3-glucanase, and peroxidase; in susceptible and resistant wheat cultivars, regardless of whether they were infected or uninfected with leaf rust (Cawood et al. 2010). Furthermore, it has been reported that spraying wheat leaves as a pretreatment with bioformulations consisting of aqueous leaf extracts from

Table 10.2 Some successful examples of environmentally friendly biological agents/products used to control wheat diseases

Type of controlling approach	Pathogen	Disease's name	Resulted effect	Reference
Biological control (*Pseudomonas fluorescens*)	*Gaeumannomyces graminis* var. *tritici*	Take-all disease	Take-all declination in wheat plants caused by the toxic effect of 2,4-DAPG on the pathogen	Durán and de la Luz Mora (2021)
Biological control (*Pseudomonas fluorescens* HC1–07)	*Gaeumannomyces graminis* var. *tritici* and *Rhizoctonia solani AG-8*	–	In vitro inhibition of fungal growth	Yang et al. (2014)
Biological control (*Bacillus velezensis* CC09)	*Gaeumannomyces graminis* var. *tritici* and *Bipolaris sorokiniana*	Take-all disease + spot blotch disease	66.67% and 21.64% disease-control efficacy of take-all and spot blotch, respectively	Kang et al. (2018)
Biological control (*B. subtilis*)	*Blumeria graminis* f. sp. *Tritici*	Wheat powdery mildew	Treatment inhibited conidial germination and normal appressorium development in vitro and induced disease resistance in wheat in vivo	Xie et al. (2021)
Biological control (*Bacillus velezensis* CC09)	*Gaeumannomyces graminis* var. *tritici*	Take-all disease	Pathogen pathogenicity-related genes are downregulated as a result of bioagent treatment	Kang et al. (2019)
Cultivar mixtures	*Zymoseptoria tritici*	Septoria tritici blotch	AUDPC of susceptible plants was reduced by 68% in the heterogeneous mixture and by 32% and 34% in the homogeneous mixtures with 75% and 25% of resistant plants, respectively	Vidal et al. (2017)
Cultivar mixtures	*Puccinia striiformis* f. sp. *tritici*	Wheat yellow rust	In comparison to pure stands, heterogeneous mixtures reduced the variability of disease severity and yield	Vidal et al. (2020)
Cultivar mixtures	*Zymoseptoria tritici*		Adding 25% of a resistant cultivar to a	Ben M'Barek et al. (2020)

(continued)

Table 10.2 (continued)

Type of controlling approach	Pathogen	Disease's name	Resulted effect	Reference
		Septoria tritici blotch	pure stand of a susceptible cultivar reduces disease severity by nearly 50%	
Biofumigation (*Brassica carinata* as a break crop)	*Bipolaris sorokiniana* and *Fusarium culmorum*	Common root rot and fusarium foot rot	Treatment reduced the incidence and severity of fusarium foot rot by 40.6% and 56.3%, respectively, and completely eliminated common root rot on wheat	Campanella et al. (2020)
Biofumigation (white mustard meal)	*Fusarium culmorum* Sacc	Common root rot	In a greenhouse trial, treatment reduced pathogen infection by 38% and improved wheat growth and grain quality parameters in a field trial	Kowalska et al. (2021)
Biofumigation (mulch layer and botanical extracts of three plants)	*Fusarium graminearum*	Fusarium head blight	Treatment resulted in consistent suppression of fusarium head blight and a significant reduction of mycotoxins in wheat grains	Drakopoulos et al. (2020)
Biofumigation (isothiocyanates compounds)	*Fusarium graminearum*	Fusarium head blight	In vitro inhibition of conidial germination and mycelium radial growth is enhanced by isothiocyanates, allyl, and methyl isothiocyanates	Ashiq et al. (2021)

Jacaranda mimosifolia only and/or combined with 0.05% Amistar Xtra improves leaf rust resistance due to the extract's ability to increase PR protein expression in treated plants (Naz et al. 2014). Plant extracts, on the other hand, were used to counter other diseases that afflicted the wheat plant and demonstrated remarkable efficacy in controlling those diseases. For instance, several studies have reported that plant extracts have remarkable antimicrobial activities against *Bipolaris sorokiniana* and other wheat fungal pathogens (Bahadar et al. 2016; Magar et al. 2020; Naz et al. 2018; Perelló et al. 2013). Findings related to the controlling effect of plant extracts are listed within Table 10.1.

10.2.4 Cultivar Mixtures for Wheat Disease Management

Cultivar mixtures/multiline cultivars can be an efficient technique for managing crop diseases, especially those caused by airborne pathogens. Though some seedlings can be affected by certain elements of the pathogen population, the host mixture overall elicits considerable resistance, owing primarily to host diversification (Brooker et al. 2021; Mundt 2002; Zhang et al. 2018). Several mechanisms can be used to demonstrate disease suppression among combinations of susceptible and resistant plant cultivars. In this regard, de Vallavieille-Pope (2004), Finckh et al. (2000), and Mundt (2002) demonstrated several potential mechanisms for elucidating the reductive effect of cultivar mixtures on plant diseases. Such mechanisms include pathogen spread restriction because of the resistant plants present among susceptible plants, induction of host resistance as a result of infection by avirulent strains, which can decrease subsequent infection by virulent strains, and competition among pathogen populations for available host tissues (Fig. 10.1). Vidal et al. (2017) recently demonstrated four mechanisms by which cultivar mixtures reduce disease. The first is the density effect, which involves distancing the susceptible cultivars within the mixture, minimizing the amount of inoculum reaching them. Second, there is the barrier effect, which is represented by the interception of pathogen spores in the mixtures by resistant plants. Third, induced resistance occurs when an avirulent pathogen race infects an incompatible host. Finally, microclimate modification occurs as a result of the varied characteristics of mixed cultivars, such as plant height, canopy structure, and so on, which alter the microenvironment, making it unsuitable for the development of plant diseases. Cultivar mixtures are not used to get rid of phytopathogens. Instead, they are used to reduce disease development in

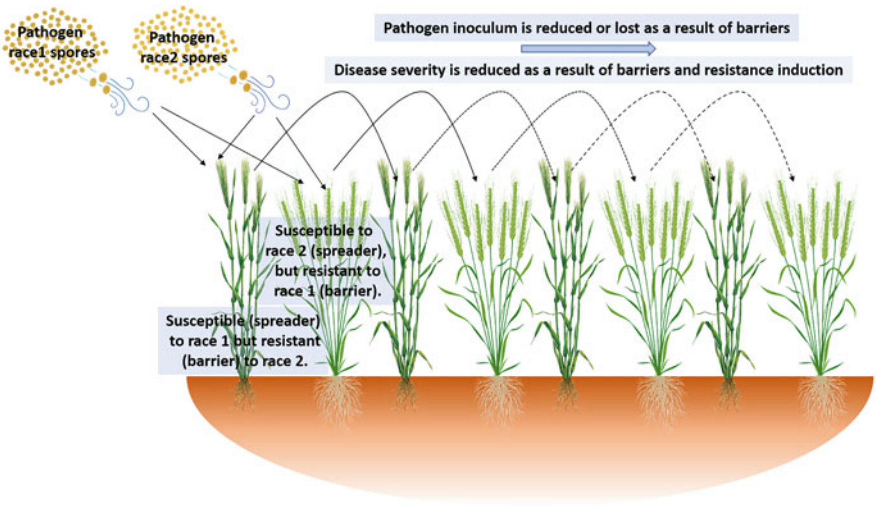

Fig. 10.1 Some of the known mechanisms by which cultivar mixtures can suppress foliar diseases in wheat

the mixture by lowering the amount of inoculum needed for a severe infection (Kumar et al. 2021; Vidal et al. 2017, 2020). Besides, it has also been demonstrated that cultivating mixtures of cultivars with varying disease resistance levels and agronomic traits in the same field at the same time produces higher yields than pure cultivars (Fang et al. 2014; Župunski et al. 2021). Similarly, Kristoffersen et al. (2020) revealed that cultivar mixtures reduced (by 10.6%) the severity of *Septoria tritici* blotch caused by *Zymoseptoria tritici* and improved yields by 1.4% across all tests in a meta-analysis of 406 trials conducted over 19 years. However, in another study, cultivar mixtures reduced wheat stripe rust to a lesser extent than susceptible pure stands (Huang et al. 2011). Recently, it was stated that increasing the number of cultivars with regard to diversification in agronomical characteristics such as plant height and earliness did not have a negative impact on the performance of the mixtures, but rather contributed to stabilizing the reduction of pathogen spread within the mixtures population and improving their yield when compared to their corresponding pure stands (Vidal et al. 2020). Another meta-analysis study found that disease reduction of wheat stripe rust provided by cultivar mixtures may be more effective during intensive disease infection and moderate wheat sowing density (Huang et al. 2012). Due to the fact that farmers prefer susceptible components within cultivar mixtures for their agronomical traits over resistant components, researchers are increasingly investigating the performance of mixtures with a considerable ratio of the resistant cultivar which offer a comparable level of disease reduction as pure resistant components. In this regard, Ben M'Barek et al. (2020) revealed that mixing 25% resistant cultivar with pure stand of susceptible cultivar leads to a considerable reduction (nearly 50%) in *Septoria tritici* blotch disease severity when compared to the pure susceptible component. Canopy architecture of cultivar mixture components must be considered in addition to disease resistance in order to improve cultivar mixture performance in disease reduction (Vidal et al. 2017). Furthermore, wheat cultivar mixtures had no beneficial effect on soil collembola as beneficial insects contribute to the regulation of the activities of decomposing microorganisms, consuming fungal phytopathogens in soil, and regulating the activity of mycorrhizal fungi (Salmon et al. 2021). Additionally, cultivar mixtures have proven to have a higher potential for yield increase when compared to pure components, particularly in low pesticide input cropping systems (Borg et al. 2018). The presentative findings related to the role of cultivar mixtures in the reduction of wheat diseases are summarized in Table 10.2.

10.2.5 Estimation of Plant Resistance Inducers' Mitigating Effect Against Wheat Phytopathogens

Agents that improve plant resistance to pathogens by stimulating the plant's particular defense mechanisms, or its own induced resistance, are called Plant resistance inducers (Alexandersson et al. 2016). To deal with biotic stresses or pathogens, plants typically have an advanced immune system. Plants physically defend themselves by barriers like dense cuticles, waxes, and unique trichomes that inhibit pathogens and insects from staying on plants. Additionally, chemical complexes are produced by plants as defense against pathogens and herbivores (Moustafa-Farag et al. 2020). However, in order to properly deal with such a challenge, the plant must first identify a biotic stress casual factor or pathogen as an unfriendly component that must be dealt with. Pathogens can be recognized by plants via two pathways that activate defense responses. First, pathogen-associated molecular patterns (PAMPs) including peptidoglycans, fungal chitin, bacterial lipopolysaccharides, and quorum sensing are recognized by the pattern recognition receptors. PAMP-triggered immunity is the most basic form of defense (PTI) (Monaghan and Zipfel 2012). The second pathway of the immune system (ETI) comprises secretion of plant resistance proteins (R), which through effector-triggered immunity process detect pests'/ pathogens' specific effectors (Avr proteins) and activate the plant defense response. As a result, hypersensitive responses (HR) are triggered, which involve programmed cell death in affected cells and their adjacent regions (Spoel and Dong 2012). Generally, phytohormones such as ethylene (ET), salicylic acid (SA), and jasmonic acid (JA) act as signaling molecules for two types of efficient plant pathogen resistance. The first type is called systemic acquired resistance (SAR) that occurs when necrotizing pathogens infect the cells and are associated with large amount of SA and pathogenesis-related proteins (Grant and Lamb 2006). The second type of plant resistance is induced systemic resistance (ISR), which is activated by the application of plant resistance inducers, which can be either biotic, such as non-pathogenic root-colonizing microorganisms or any other non-virulent pathogen, or nonbiotic, such as chemical agents or plant extracts. Such resistance necessitates the use of signaling compounds such as JA and ET (Alexandersson et al. 2016). However, as many studies have shown, many chemical inducers can also activate the first type of resistance in plants (Lee et al. 2014, 2015; Zhao et al. 2019). Plant resistance inducers can have a systemic effect, as described above, or a local effect, such as changes in composition of the cell wall, hypersensitive response (HR), and producing antimicrobial protein and phytoalexins (Alexandersson et al. 2016). Many chemical inducers, such as SA, benzothiadiazole (BTH), 2,6-dichloroisonicotinic acid (INA), acetylsalicylic acid, β-aminobutyric acid (BABA), and trehalose. . . . etc., have been widely used to control wheat disease. For instance, in a three-year field trial, wheat plants treated with chemical inducers or some plant extracts exhibited long-term-induced resistance and a reduction in powdery mildew disease severity ranging from 2% to 53% (Vechet et al. 2009). In another study, although pretreatment of wheat plantlets with *N*-hydroxypipecolic acid moderately increases resistance to *Fusarium graminearum*, it improves immune response, allowing wheat plants to defend themselves against pathogens (Zhang et al. 2021). Furthermore, under greenhouse conditions, foliar treatments of wheat seedlings with saccharin, a metabolite derived from probenazole, caused a 77% decline in Septoria tritici blotch disease onset, and the protective effect of saccharin was attributed to induction and priming of lipoxygenase and PR gene-related defense pathways (Mejri et al. 2020).

Meanwhile, spray application of several chemical inducers under field conditions suppressed Septoria leaf blotch, particularly treatment with potassium silicate and sodium silicate; this positive effect was accompanied by an increase in grain yield in sprayed wheat plants that were sprayed (El-Gamal et al. 2021). Also, pretreatment of wheat seedlings with SA resulted in the induction of resistance against *Septoria tritici* blotch in wheat plants by significantly upregulating the phenylalanine ammonia-lyase (*PAL*) and β-1,3-glucanase (*PR2*) genes in wheat-treated plants compared to untreated ones (Mahmoudi et al. 2021). Table 10.1 summarizes the preliminary findings concerning the function of plant resistance inducers in the reduction of wheat diseases.

10.2.6 Biofumigation for the Safe Management of Wheat Diseases

Biofumigation is the suppression of soilborne pathogens through the decomposition of organic material, such as agricultural by-products or manure, which releases volatile chemicals that have the ability to reduce different types of phytopathogens including bacteria, fungi, and nematodes (Baysal-Gurel et al. 2020; Madhavi Gopireddy et al. 2019; Matthiessen and Kirkegaard 2006). Biofumigation can be accomplished by including green manure, seed meals, or dried plant matter that has been treated to retain isothiocyanate activity into the soil (Lu et al. 2010; Matthiessen and Kirkegaard 2006). Plants in the *Brassicaceae* family are more appropriate for biofumigation because their tissues contain a high concentration of glucosinolates and other sulfur-containing compounds (Campanella et al. 2020). As a result of the hydrolysis of glucosinolates by the action of the myrosinase enzyme, these plants emit toxic substances such as nitriles, thiocyanates, isothiocyanates, oxazolidine, methanethiol, and dimethyl sulfide (Fahey et al. 2001).

The hydrolyzation process happens when plant tissues are injured or chopped. Consequently, fresh Brassicaceae plants or seed meals are chopped and mixed into the soil to perform biofumigation (Ziedan 2022). Because of their exposure to the slowly released toxic substances, many harmful soilborne phytopathogens, weeds, and insects are effectively suppressed (Madhavi Gopireddy et al. 2019). Furthermore, these substances can boost the activity of beneficial soil microorganisms and increase their competitiveness against non-beneficial microorganisms (Galletti et al. 2008; Gimsing and Kirkegaard 2009). Additionally, this process can help improve soil fertility by increasing available nutrients, enhancing soil properties, and enriching soil organic matter (Galletti et al. 2008; Gimsing and Kirkegaard 2009; Matthiessen and Kirkegaard 2006). Biofumigation with brassica plant materials has proven to be an operative method for controlling wheat soilborne pathogens, either alone or in combination with other methods. In this regard, using *Brassica carinata* as a break crop with durum wheat reduced the occurrence and intensity of Fusarium foot rot by 40.6% and 56.3%, respectively, as well as no symptoms of common root rot on wheat plants cultivated after *B. carinata* break crop. These positive results were accompanied by a significant boost in wheat yield when compared to wheat monoculture (Campanella et al. 2020). Moreover, using white mustard meal as a wheat seed wet dressing reduced *Fusarium culmorum* Sacc. infection by 38 to 44% in a greenhouse trial and improved wheat growth and grain quality parameters in a field trial (Kowalska et al. 2021). Similarly, mulch layer and botanical extract treatments of *Sinapis alba*, *Brassica juncea*, or *Trifolium alexandrinum* on top of the maize remains infected with *Fusarium graminearum* after wheat planting demonstrated consistent suppression of fusarium head blight and remarkable reduction of mycotoxins contents in wheat grains over 2 years of field experiments (Drakopoulos et al. 2020). Additionally, Ashiq et al. (2021) found that isothiocyanates, allyl, and methyl isothiocyanates have greater inhibition abilities against conidial germination and mycelium radial growth than the other isothiocyanates compounds during in vitro evaluation of antifungal activity against *Fusarium graminearum*. Table 10.2 illustrates the initial findings regarding the role of biofumigation as an effective means of suppressing soilborne wheat diseases.

10.3 Conclusions and Prospects for the Future

The uncontrolled use of agrochemicals has caused significant damage to resource-poor ecosystems with low biodiversity. The severity of these damages has reached an unprecedented level in recent years, particularly in developing countries. For example, the accumulation of high concentrations of agrochemicals in agricultural soils has negatively impacted the positive role of their beneficial microorganisms and significantly reduced their organic matter content, significantly reducing their ability to retain moisture content and negatively affecting their other physical properties. Such that if these irresponsible behaviors of random and excessive use of these chemicals are not remedied, this may result in irreversible damage to these poor ecosystems' vitality, components, and natural resources. This is in addition to the significant health consequences for humans and animals. As a result, it is critical that we use safe environmental alternatives to achieve environmentally friendly pest management of agricultural pests in order to restore and repair damaged ecosystems. The continued use of these alternatives will allow us to sustain our ecosystems' limited natural resources. This is accomplished practically by incorporating these alternatives into integrated pest management programs for cereal crops, particularly wheat, either individually or in combination with the other available alternatives. Furthermore, such incorporation should be carried out in a way that does not negatively impact the performance of currently used methods, as well as the components and resources of existing ecosystems, and is also compatible with the limited material capabilities of low-income farmers. This will contribute to the gradual disappearance of pollution challenges caused by the accumulation of high levels of agrochemical concentrations in soil and other ecosystem components. Figure 10.2 depicts a number of anticipated benefits from the use of environmentally friendly approaches in the control of wheat diseases.

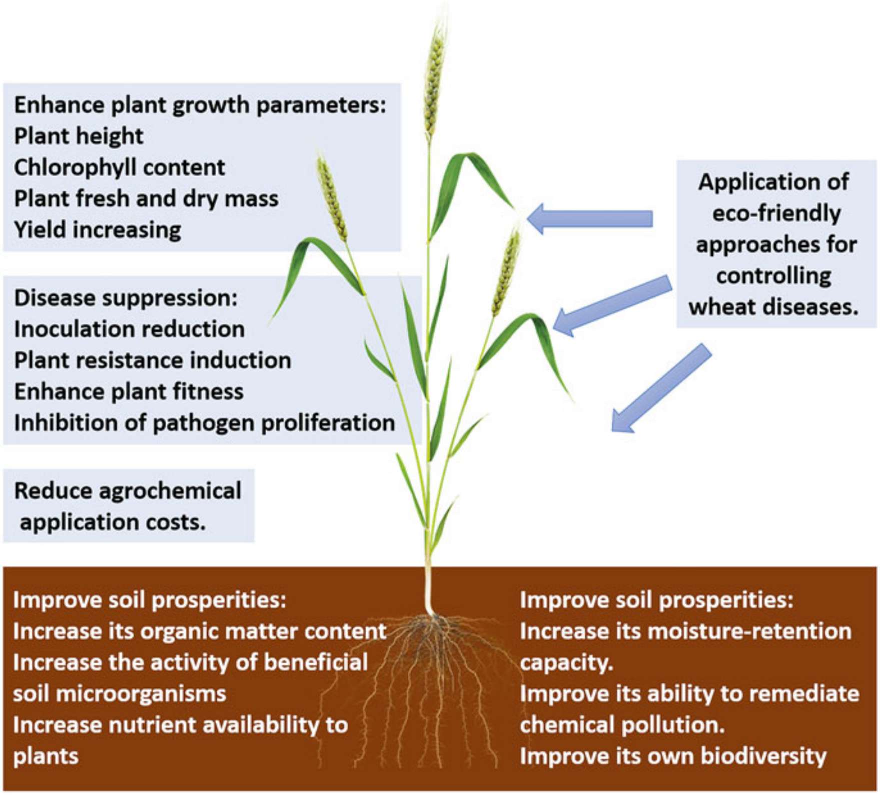

Fig. 10.2 The anticipated advantages of using eco-friendly alternatives for the safe management of wheat diseases are many

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