Chapter

Microbiological Control: A New Age of Maize Production

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Abstract

Maize is one of the world's most widely grown and consumed cereal. It is known for its multipurpose use; it provides food and fuel to humans, feeds to animals and used as raw material in manufacturing industries. Globally, maize production is a large and significant market which produced 1,116.41 million tons in year 2020 and it's expected to increase by 1.57% in year 2021. Pests and disease of maize cause significant damage to maize thereby reducing its's yield and quality. There are many methods of controlling maize disease and pests; they include cultural, biological and chemical methods etc. Recent research studies have discovered an alternative agricultural practices that are sustainable and safe as compared to chemical control of pests and disease. However, biological control has gained large acceptance and its believed to yield positive outcome as compared to chemical control. Various microorganisms are used to control pathogens of maize and thus, there is a need to understand better their interactions with plants. Furthermore, microorganism known as entomopathogens are used to control arthropods. They are biopesticides that play integral role in Pest Management. This section focuses on microbiological control of pathogens and arthropods, their mechanisms of action, applications and the future of entomopathogenic microorganisms and microbiological control of pathogens.

Keywords: maize, pathogens, pests, microbiological control, entomopathogens

1. Introduction

Corn, also referred to as Maize, *Zea mays*, is an annual grass in the family Poaceae and is the third most widely grown cereal after wheat and rice throughout the world [1]. It is a staple food crop which has a total production of 1.09 billion metric tons achieved in 2018/2019, [2] and still a vital source of energy and protein in humans' diet and animals, hence ensuring food security globally [3]. The United States was recorded to be the largest corn producer in the world with an estimated volume of 345 million metric tons in 2019/20 which is approximately one third of corn produced globally. In that year, China and Brazil were the next top corn producing countries after the United States [4].

The origin of corn is quite unknown but history revealed that corn was first domesticated in Mexico's Tehuacan Valley. There are several types of corn which include sweet corn, popcorn, pod corn, flint corn, flour corn, waxy corn and dent corn. In the United States corn is known to be an important crop and in the past few years, the country's corn farmers experienced constant increases in annual revenues [4].

However, during preharvest and postharvest operations, insect pests and microorganisms attack maize, thereby reducing both the qualitative and quantitative value of maize [5]. In addition to the reduction of production yield, some pathogens produce toxins that are detrimental to both man and animals' health, they also reduce the nutritive value of maize and thus negatively impacting world food security [6]. A vast number of pathogenic microorganisms (fungi, bacteria, virus) and insects damage maize grains and plant; leading to worldwide annual losses of 9.4%. Insects are known to the the most important cause of deterioration and low yield of maize followed by fungi [7, 8]. Maize pests happens to be one of the major challenges of growing maize and some of the major threat to maize mainly include insect pests (stalk borers and armyworms) and soil pests (wireworms and rootworms). The damaged caused by the western corn rootworm (*Diabrotica virgifera virgifera*) in Europe and in USA is estimated to be more than $1 billion annually [9]. Roberts et al. [10] also reported the annual losses attributed to plant diseases to be about 40 billion dollars worldwide either directly or indirectly.

There are three significant and most noxious soil-borne pathogens that infest maize in the field namely; *Fusarium* species, *Rhizoctonia* spp. and *Verticillium* spp. [11, 12]. Furthermore, three fungal pathogens that are mostly found in stored grains are *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp. [13, 14] and some xerophytic species, a number of them are known to produce toxins that causes adverse health problems including death [14–16]. The control of these microorganisms are difficult to quell due to their ability to utilize various infection modes to overcome maize immune system, possession of important structures for pathogenesis that are resistance to adverse conditions and the development of some resistance genes that ae understudied [17]. Over the years, pests and diseases management have depended majorly on the use of pesticides and agricultural practices such as crop rotation and irrigation for control of pests and diseases [18, 19]. However, the potency and environmental concerns such as its possibility of destroying beneficial microorganism and insects that promote plant growth and health, bioaccumulation of the chemicals on crops and their harvest, as well as pathogen resistance to some pesticides, have encouraged the pursuit for an alternative that is ecofriendly, less expensive, more sustainable in the management of pests and diseases [20, 21]. Amidst these alternatives, biological control method seems to be the preferable and acceptable option. Biological control using microorganism is an important tool for controlling and managing plant pests and diseases in sustainable agriculture [22].

Microbial biological control agents (MBCAs) are applied to crops for biological control of plant pathogens, they use various modes of action. Their mode of action may include nutrient competition, antagonist relationship (hyperparasitism and antibiosis) against the pathogen or by inducing resistance or priming plants without any direct interaction with the targeted pathogen [23]. In addition to using microorganism as biocontrol of pathogens, microorganisms known as entomopathogens are used in the control arthropods such as insects, mites, and ticks that infest and deteriorate maize. Diverse species of bacteria, fungi, nematodes, and viruses are used in pest management. The use of entomopathogens as biopesticides in pest management is referred to as microbial control, which can be an integral part of integrated pest management (IPM) [24].

In rhizosphere of plants, microorganisms do interact and display different associations, some may be mutualistic, commensal or even pathogenic [25–27]. Interestingly, maize' rhizosphere contains some specific microorganisms that are beneficial to its growth [28, 29]. Positive interactions in rhizospheres are known to be of importance all through the plant's life-cycle [30]. In recent years, there have been an increased interest on the issue of inoculating rhizobacteria into the agricultural soil because they are known to increase productivity and quality of agriculturally important crops and help to the stabilize agroecosystems [31]. Inoculation of maize with various plant growth-promoting rhizobacteria (PGPR) strains, however could result in significant increases in plant biomass, root and shoot length and uptake of essential plant nutrients. The use of plant growth-promoting rhizobacteria (PGPR) is a promising alternative method to external chemical inputs to improve crop yield in sustainable agricultural systems [32]. PGPR's modes of action include nutrient uptake, stress protection, induced resistance and plant growth promotion by production of phytohormones [33–35].

With respect to the severe maize' annual losses, and threat to food security caused by pathogens and insect pests, thus the need for Microbiological control methods to minimize losses caused by pathogens and insect pests. This scope of this chapter concentrates on the use of microbiological agents; an alternative, safe, less toxic, and less disruptive method of controlling the growth and development of pathogens and insect pests of maize, and optimizing maize production.

2. Maize

2.1 Maize production

Maize is known to be one of the world's most important cereal crops. It has a wide genetic diversity and diverse uses which accounts for its cultivation in a vast range of agro-ecological environments. Apart from the consumption of maize by man and animals, maize is also used to produce corn ethanol and other maize products, such as corn starch and corn syrup [36].

Andean countries of South America, Mexico, Central America and the Caribbean, Africa and South and Southeast Asia are known to consume maize as human food much higher than half of its maize production. Interestingly, maize accounts for at least 15 percent of the total calories daily intake in almost all the countries in Africa and Latin America. The economy of the developed and developing countries is significantly impacted by maize production. [37]. The world market has recorded an enormous growth in maize production in the most especially in countries with temperate environment where hybrids and high yielding agronomic practices are used. The main maize exporters are: United States, Argentina, France, China P.R., Hungary, Canada, South Africa. China is a relatively new exporter being the main suppliers of Asian neighbor countries. There was a prediction for developing countries by Ortiz et al. [13] that there will be a growing demand for maize alone as food to increase by around 1.3% per annum until 2020. Furthermore, another prediction by Rosegrant et al. [38] stated a double demand for maize by 2050 in the developing world, and maize is predicted to become the crop with the greatest production globally, and in the developing world by 2025.

2.2 Maize losses

Abiotic and Biotic factors (pests, pathogens and weeds) significantly contribute to grain loses and thus affects food supply. About one-third of potential crop yield is lost to pre-harvest pests, pathogens and weeds [39]. Coupled with pre-harvest losses, the losses occurring during transport, pre-processing, storage, processing, packaging, marketing and plate waste are also important. An average of 35% of potential crop yield is lost to pre-harvest pests worldwide [40].

There are different number of ways pests reduce crops productivity; their effects include, stand reducers (damping-off pathogens), photosynthetic rate reducers (fungi, bacteria, viruses), leaf senescence accelerators (pathogens), light stealers (weeds, some pathogens), assimilate sappers (nematodes, pathogens, sucking arthropods), and tissue consumers (chewing animals, necrotrophic pathogens) [41].

Post-harvest loss occurs between harvest and consumptions. The major physiological, physical and environmental causes of post-harvest losses are high crop perishability; mechanical damage; excessive exposure to high ambient temperature, relative humidity and rain; contamination by spoilage fungal and bacteria; invasion by birds, rodents, insects and other pests; and inappropriate handling, storage and processing techniques [42]. Post-harvest losses lead to high food prices thus reducing food in the market. Reducing post-harvest losses in maize is an important element in any strategic planning to make more food available without increasing the burden on the natural environment.

2.3 Major pathogens of maize

Fusarium species are among the most common fungal pathogens causing diseases in maize. This genus is ubiquitous in nature and contains various toxigenic species, with *F. graminearum* and *F. verticillioides* being the most commonly found pathogens in maize. They infect several parts of maize at any stage of development, processing and storage thereby reducing maize quality and production yields. They do produce mycotoxins (fumonisin, deoxynivalenol, and zearalenone.) that are poisonous to man when consumed [43, 44].

2.3.1 F. verticillioides

F. verticillioides causes Fusarium ear (characterized by discolored and a reduced number of grains), and stalk rot which leads to global significant losses of maize [45]. It is one of the most prevalent disease causing agent in maize (*Zea mays* L.). Fusarium ear/stalk rot is common during hot and dry weather, both pre and post-harvest conditions. Fumonisins are carcinogenic [46, 47], and are produced in large amounts in maize and contaminates maize based food and feed, therefore they are of high importance to farmers [43, 44].

2.3.2 F. graminearum

Maize kernels contaminated with *F. graminearum* results in a moldy kernels called Gibberella ear rot. This organism also produces mycotoxin (deoxynivalenol and zearalenone), toxic to humans and farm animals when consumed. This fungus often starts infecting the tip of an ear when it starts silking during the cool and wet weather, [48].

2.3.3 Aspergillus flavus

A. flavus is a phytopathogenic fungus that causes diseases in several agricultural crops and at the same time producing aflatoxins which is a toxic metabolite produced during its secondary metabolism [49, 50]. *A. flavus* is the disease causing agent of Aspergillus ear rot; a global disease of maize. Aflatoxins are hazardous to both humans and animal' health if ingested via contaminated food and feed. In humans, aflatoxins have been directly linked to hepatocellular carcinoma, since they are metabolized in the liver [51].

2.3.4 Curvularia lunata

C. lunata is a foliar fungal pathogen that causes Curvularia leaf spot of maize, especially during the hot and humid seasons [52]. *C. lunata* produces a furanoid type toxin, both *in vitro* and *in planta*, which can possibly lead to leaf lesions which invariably lead to a reduction in maize yields [53].

2.3.5 Other pathogens of maize

Some other economically important pathogens that infest maize and their corresponding diseases are listed as follows: *Pythium* spp., *Rhizoctonia* spp., and *Acremonium* spp. (Root and Stalk rot), *Puccinia sorghi* and *P. polysora* (Leaf rusts), *Helminthosporium turcicum* or *Setosphaeria turcica* (Leaf blights), *H. maydis* (Maydis leaf blight), *Cercospora zaeamaydis* (Gray leaf spot (GLS)) [54]. *Sclerophthora macrospora* (Downy mildew/Yellow tuft), *Sphacelotheca* reiliana (Head smut of maize), *S. macrospora* (Downy mildew/ Yellow tuft), *Trichometasphaeria turcica* Luttr. (Northern Leaf Blight), *Ustilago maydis* (Corn smut), *P. coronata* (Crown crust), Maize streak virus (Maize streak disease), Sugarcane Mosaic Virus (SCMV) is another viral pathogen and causal agent of mosaic disease in maize and other graminaceous plants [55].

2.4 Major insect pests of maize

Globally, insect pests are categorized into two classes; (1) field pests such as stalk borer (*Busseola fusca*), maize leafhoppers (*Cicadulina mbila*) and mole crickets (*Gryllotalpidae*), African bollworm (*Helicoverpa armigera*), African armyworm (*Spodoptera exempta*) and black cutworms (*Agrotis ipsilon*) and (2) storage pests like the maize weevil (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus*) (Hon), red flour beetle (*Tribolium castaneum*) and dried bean beetles (*Callosobruchus maculatus*) and Indianmeal moth (*Plodia interpunctella*) [54].

The most important arthropod pests of maize in Europe is known as European corn borer, *Ostrinia nubilalis* (Hbn., Lepidoptera: Crambidae). The lepidopteran larvae (i.e., caterpillars) known as stalk borers, ear or leaf feeders, and coleopteran larvae (i.e., beetle grubs) that feed on roots. The European corn borer is a nicknamed the "billion dollar bug" because it cost growers over a billion dollars annually in insecticides and lowers crop yields [56, 57]. It is known globally to cause enormous economic damage. While in America the borer mostly found include the genera Zeadiatraea, Diatraea and Elasmopalpus. The western corn rootworm (*Diabrotica virgifera virgifera* LeConte), a chrysomelid beetle is known to be the most destructive for maize production in the USA, Hungary and other central and eastern European countries [58]. While in Africa the following pests are associated to this region; *Chilo*, *Sesamia*, and *Busseola*, and in Southeast Asia *Chilo*, *Sesamia* and *Ostrinia furnicalis* are present in their maize fields. While damage is mainly caused by the larvae feeding on roots, adults feeding on silk and ears may cause additional losses, particularly in maize production for grain, seed or food (sweet maize). Sap sucking pests, like aphids (Aphididae) and leafhoppers (Cicadellidae), as well as the frit fly (*Oscinella frit* L.) cause limited economic damage as compared to the european corn borer. Other pests of regional importance include armyworms such as *Pseudaletia unipuncta* (Haworth, Lepidoptera: Noctuidae), Diptera species such as *Delia platura* (Meig.), *Geomyza* spp. and *Tipula* spp., Coleoptera species such as *Oulema melanopus* L., *Glischrochilus quadrisignatus* (Say), *Tanymecus dilaticollis* Gyll. and *Melolontha melolontha* L., spider mites (*Tetranychus* spp.) and thrips (Thysanoptera) [59].

2.5 Maize disease and Pest management

2.5.1 Planting resistant varieties

One of the most reliable method of controlling plant disease is planting of resistant varieties. [60]. It is one of the most attractive approaches and can be considered as an ideal method if good quality plants are adapted to the growing regions with sufficient levels of tolerance and durable resistance This method is considered ideal and mostly used in many crops because its less expensive as compared to pesticides cost and residual effects on man, animals and the environment. Although its economical as compared to pesticides, these resistant varieties often take decades to develop and GM-plants suffer from extremely high regulatory approval cost and consumer acceptance. Its ultimately used by farmers provided quality plants are selected and adapted to exhibit adequate levels of tolerance and substantial resistance to pathogens [61]. Inspite of its advantages, it is faced with some backlash as regards the time in developing Genetically Modified (GM) plants, cost of approval and acceptance rate by customers. There have been also cases where resistance breakdown was recorded in several crops coupled with pathogens mutating their virulence gene, inconsistent uniformity in the genetics of the plants. Such cases were observed in cotton leaf curl disease [62].

2.5.2 Chemical control

Agrochemicals have been adapted over the years to secure food production and improve crop yield thus protecting crops from pests and pathogens. Since the 1960s, there have been an increase in pesticides use. They help in preventing losses and damages of crops; it has now become an integral component in Integrated Pest Management (IPM) [63]. It cannot be overemphasized the advancement that pesticides have brought to the agricultural sector as regards improving crop quality and annual agricultural output [64]. Nevertheless, the development of resistance genes by pathogens and pests coupled with the growing concern of accumulation off these chemicals in feeds and the ecosystem has been a great concern to farmers [65, 66].

2.5.3 Biological control of pathogens

Heimpel and Mills [67] defined biological control of plant diseases to be the suppression of the populations of plant pathogens by the use of living organisms. In plant pathology, beneficial organisms (crops, insects and microorganisms) are selected to diminish the effects of pathogenic organisms and improve the crop yield microorganisms. Other examples of biological control include the application of natural products and chemical compounds extracted from different sources, such as plant extracts, natural or modified organisms or gene products control [68]. This method was developed to minimize the dependence on agrochemical use and the risks for human health and the environment [69].

There are various interactions between plants, biological control agent and pathogens, they include mutualism, commensalism, neutralism, competition, amensalism, parasitism, protocooperation and predation [70–72]. The interactions between the microbes and plants occurs naturally at both macroscopic and microscopic level [68].

2.5.4 Cultural/traditional insect Pest control

Timely harvesting, proper harvesting and processing methods are the best strategy for controlling insect pest in maize. Proper sanitation, removal of old stock, avoid storing infected crops inside the storage facility. Other methods used by farmers to reduce infestation of maize by insect pest include the use of material such as ashes (it is known to abrasive and lethal effect on the insects' cuticle), sand, crushed limestone, mineral and oil in which physical barrier effects are responsible for the control of insects, storing dried maize that are properly dried or re-drying when infestation is detected, the use of sheaths in storing maize for protection by the husk, the use of repulsive local herbs and plants to scare off the pests (Nim ground seed, leaves of acanthaceae, acardiaceas, annonaceae, myrtaceae, other plants extract [73].

2.6 Microbiological control of pathogens

In modern agriculture, biological control of pathogens using microorganism is playing a major role in disease control of crops. Beneficial microorganisms are used as biopesticides and is known to be the most effective methods for safe crop-management practices [74].

The rhizosphere was discovered by Hiltner [75] to be the layer of soil dominated by the root, and is much richer in bacteria than the surrounding bulk soil. The plant rhizosphere is regulated by the synergistic relationship between the soil, plant root, and the microbes present and is controlled by the soil pH, texture, complexity and plant roots exudates mainly composed of sugars, amino acids and various nutrients [27]. The rhizosphere is a zone of soil that surrounds the plant root, is a niche colonized by numerous organisms and is considered as one of the most complex ecosystem on Earth [76].

There are some heterogeneous group of bacteria known as Plant growth-promoting rhizobacteria (PGPR), they are free-living soil bacteria mostly found in the rhizosphere, at the rhizoplane or in association with roots. They are used as biocontrol agent for the control of plant pests and disease by suppressing the activity and growth of phytopathogenic organisms, and also help to improve the extent or quality of plant growth directly or indirectly [77] by providing nutrients, synthesizing phytohormones, solubilizing phosphate, reducing stress, alleviating soil contamination with heavy metals [78–83] or improving the microbial community structure of the rhizosphere [84, 85]. The following genera of bacteria have been reported as PGPR: *Agrobacterium*, *Arthrobacter*, *Azoarcus*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Caulobacter*, *Chromobacterium*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *Klebsiella*, *Micrococcous*, *Rhizobium*, *Pantoea*, *Pseudomonas* and *Serratia* [86, 87] which have shown prospect as biocontrol agents against various fungal pathogens [87].

2.7 Relationships that promotes biocontrol

2.7.1 Microbial antagonisms

Microorganisms that have the ability to grow in plant rhizophere are considered to be ideal for use as biological control agents. The rhizophere provides a leading edge defense for plants roots against disease causing microorganisms by suppressing pathogens growth and infestation. Pathogen-antagonizing metabolites produced by beneficial microbes that colonize the plant root, help to suppress phytopathogens' growth and thus preventing them from penetrating the root system [87]. Furthermore, this antagonistic relationship displayed between the beneficial microbes and pathogens often results to significant disease control, in which the established metabolites produced by active beneficial microbes protects plants either by directly antagonizing pathogen activity directly, by outcompeting pathogens or by stimulation of host plant defenses (priming) [88], also displays its antagonism against pathogens by antibiosis which is the secretion of diffusible antibiotics, volatile organic compounds, and toxins, as well as the development of extracellular cell wall degrading enzymes such as chitinase, β-1,3-glucanase, beta-xylosidase, pectin methylesterase and many more [87, 89].

2.7.2 Plant-microbe mutualistic interaction

Microbes that inhabit plant rhizophere are nourished with nutrients obtained from plant roots in the form of root exudate and lysates. The plant-microbe interaction is not only beneficial to the microbe but it also improves plant nutrition, growth and proliferation and do enhances plant's ability to prevail over biotic and abiotic stress. This associoation gives the plant a good competitive advantage due to the presence of rhizophere [90]. Various endophytic bacteria and free-living rhizobacteria that inhabit the root surface and rhizosphere secrete metabolite substances that suppress deleterious pathogen growth and activity which invariably leads to the control plant diseases caused by fungi or bacteria [91–94].

Furthermore, microorganisms can be directly involved in plant growth promotion, by acting as agents for stimulation of plant growth and management of soil fitness, for example through the production of auxin [95].

2.7.3 Production of allelochemicals/antimicrobial compounds

Allelochemicals/antimicrobial compounds produced biological control bacteria helps improve the plant-microbe rhizophere niche. Example of such compounds include iron-chelating siderophores, antibiotics, biocidal volatiles, lytic enzymes (chitinases and glucanases), and detoxification enzymes. These chemical may have detrimental effect on target pathogens, some help the plant to induce resistance against pathogen infestation and attack while some assist in nutrient absorption which promotes plant growth [96–98]. For example, rhizobacteria include antibiotic-producing strains such as *Bacillus* sp. producing iturin A and surfactin, *Agrobacterium* spp. producing agrocin 84, *Pseudomonas* spp. producing phenazine derivatives, pyoleutorin and pyrrolnitrin, and *Erwinia* sp. producing herbicolin A [99, 100], that are tenacious in the rhizosphere [101, 102]. The mycoparasitism of phytopathogenic fungi of the Trichoderma and Streptomyces genera have important roles in secretion of chitinases and glucanases [103]. A common feature of successful biocontrol strains and a crucial factor for plant root pathogen suppression is the production of antibiotic compounds and fluorescent siderophores that enable effective competition for iron [104].

Trichoderma spp., are universally known as BCAs and used to prevent plant pathogens and increase plant immunity in field and greenhouse conditions [105]. This is due to its ability to interact with plants (maize, cotton, cucumber) through production of auxin like compounds and secondary metabolites [106–108]. BCAs of *Trichoderma* spp. have ultimate functions in promoting the plant beneficial microbial community and decreasing the pathogen attack through the specific interactions with host-pathogen. In maize, growth-promoting and antifungal compounds-producing bacteria have been shown to have inhibitory effects on southern leaf blight disease caused by the fungus *Cochliobolus heterostrophus* [109, 110].

2.7.4 Induced systemic resistance (ISR)

Van Peer et al. [111] first discovered rhizobacteria-induced systemic resistance or ISR, also referred to in its early stage as priming. It is as an enhanced defensive capacity of the whole plant to multiple pathogens induced by beneficial microbes in the rhizosphere [112] or elicited by specific environmental stimuli which lead to potentiation of the plant's innate defense against biotic challenges [113]. Non-pathogenic rhizobacteria are capable of activating defense mechanisms in plants in a similar way to pathogenic microorganisms, including reinforcement of plant cell walls, production of phytoalexins, synthesis of PR proteins and priming/ISR [112]. Plants that possess ISR displays stronger and/or faster activation of defense mechanisms after a subsequent pathogen or insect attack or as a response to abiotic stress, when inoculated with rhizobacteria [114].

2.8 Entomopathogens

Entomopathogens are microorganisms that are pathogenic to arthropods such as insects, mites, and ticks. Various species of naturally occurring bacteria, fungi, nematodes, and viruses infect a several arthropod pests and play an important role pest management. Some entomopathogens are produced in large scale as in vitro (bacteria, fungi, and nematodes) or in vivo (nematodes and viruses) and sold commercially. In some scenario, they are also produced on small scale for non-commercial local use. The use of entomopathogens as biopesticides is an alternative method to chemical control and a novel approach pest management, which can be a profound part of integrated pest management (IPM) against several pests [24].

2.8.1 Entomopathogenic fungi

They typically cause infection when spores come in contact with the arthropod host. Fungal spores germinate and breach the insect cuticle through enzymatic degradation and mechanical pressure to gain entry into the insect body provided the environmental conditions such as moderate temperatures and high relative humidity are in place. Once inside the body of the insect, the fungi multiply, invade the insect tissues, emerge from the dead insect, and produce more spores [24]. Fungal pathogens have an eclectic host range and are especially suitable for controlling pests that have piercing and sucking mouthparts reason being that spores do not have to be ingested. However, entomopathogenic fungi are also effective against a variety of pests such as wireworms and borers that have chewing mouthparts [24].

The potential use entomopathogenic fungus has been reported by some researchers. For example, *Beauveria bassiana* (Bal.) Vuillemin (Deuteromycotina: Hyphomycetes) can be used against the following stored-grain insects: rice weevil (*Sitophilus oryzae*), corn weevil (*S. zeamais*), granary weevil (*S. granarius*), lesser grain borer (*Rhyzopertha dominica*), red and confused flour beetles (*Tribolium castaneum* and *T. confusum*), *Oryzaephilus surinamensis*, and *Prostephanus truncatus* [115–121], and for another entomopathogenic fungus *Metarhizium anisopliae* (Metch.) Sorokin (Deuteromycotina: Hyphomycetes) against the following stored-grain insects: rice weevil (*S. oryzae*), lesser grain borer (*Rhyzopertha dominica*), and red flour beetle (*Tribolium castaneum*) [120–125].

2.8.2 Entomopathogenic bacteria

Entomopathogenic bacteria are well known for their ability to produce a plethora of protein insecticidal toxins [126]. Bacterial toxins acting as virulence factors have been shown to range from very specific to broad insecticidal spectrum ever since it was first discovered in the 19th century. When compared with chemical insecticides, bacterial toxins displayed high diversity of simultaneous action, contributing to the sustainability of bacteria-based bio-pesticides by limiting insect resistances. *Bacillus thuringiensis* (Bt) has been profoundly used in biocontrol of insects and it represents approximately 95% of microorganisms used in biocontrol [127].

B. thuringiensis produces protein-based δ-endotoxins known as "Cry", which are lethal for several species of various insect orders [128]. Presently, about 170 different "Cry" toxins have been identified, which are effective against several coleoptera, lepidoptera, and diptera species [129]. These proteins are produced upon sporulation, and are contained in crystal inclusions. Once ingested, crystals inclusions are solubilized by the insect proteases in the midgut, inadvertently activating the "Cry" proteins [130]. A vast number of research work has produced various of Bt-based insecticides, ranging from wettable powder or liquid formulation to transgenic crops, thereby facilitating their use in organic farming and integrated pest management (IPM) programs.

2.8.3 Entomopathogenic viruses

As compared to entomopathogenic bacteria, entomopathogenic viruses are also required to be ingested by the insect host and are therefore ultimate in controlling pests that have chewing mouthparts. Diverse lepidopteran pests are important hosts of baculoviruses including nucleopolyhedroviruses (NPV) and granuloviruses (GV). These related viruses have various types of inclusion bodies in which the virus particles (virions) are implanted. Virus particles attack the nucleus of the midgut, fat body or other tissue cells, compromising the integrity of the tissues and liquefying the cadavers. Before the insect pathogen dies, infected larvae climb higher in the plant canopy, which helps in dispersing virus particles from the cadavers to the lower parts of the canopy. This conduct assists in the proliferation of the virus to cause infection in healthy larvae. Viruses are host specific and can cause remarkable reduction of host populations. Examples of some commercially available viruses include *Helicoverpa zea* single-enveloped nucleopolyhedrovirus (HzSNVP), *Spodoptera exigua* -enveloped nucleopolyhedrovirus (SeMNPV), and *Cydia pomonella* granulovirus (CpGV) [24, 131].

2.8.4 Entomopathogenic nematodes

They are microscopic, soil-inhabiting worms that are detrimental to insects. Diverse species of *Heterorhabditis* and *Steinernema* are obtainable in multiple commercial formulations, majorly for managing soil insect pests. Infective juveniles of entomopathogenic nematodes actively explore their hosts and penetrate through natural openings such as the mouth, spiracles, and anus or the intersegmental membrane. Immeddiately the get into the host body, the nematodes extricate symbiotic bacteria that kill the host through bacterial septicemia. *Heterorhabditis* spp. carry *Photorhabdus* spp. bacteria and *Steinernema* spp. carry *Xenorhabdus* spp. bacteria. *Phasmarhabditis hermaphrodita* is also available for controlling slugs in Europe, but not in the USA [24].

2.9 Application of biocontrol

2.9.1 Seed dressing

A suitable method for suppressing plant pathogens in the spermosphere and rhizosphere is dressing seeds with biocontrol agents [132]. Recently, bacterial inoculants have been used to antagonize soil-borne plant pathogens such as *Fusarium verticillioides (Fv)* and to promote plant growth. *Bacillus subtilis* and *Pseudomonas cepacia* have been used to control root rot caused by *Fv* in Argentina [133]. *Bacillus amyloliquefaciens* or *Microbacterium oleovorans* can reduce the fumonisin content in harvest grains during three evaluated seasons [134]. *Burkholderia* spp. stimulate plant growth and suppress disease caused by *Fv* in maize [45], and species like *Bacillus amyloliquefaciens* and *Enterobacter hormaechei* reduce the *Fv* infection and fumonisin accumulation in maize kernels [135]. Another example, is the application of *Gliocladium virens* and *Trichoderma viride* isolates on corn seeds for the reduction of Pythium and Fusarium-induced damping-off [136].

2.9.2 Rhizophere inoculation

Inoculation of rhizophere with biocontrol agents by alters the rhizosphere microbiota, thereby antagonizing soil-borne plant pathogens and promote plant growth. *Bacillus subtilis* and *Pseudomonas cepacia* have been used to control root rot caused by Fv in Argentina [133].

2.9.3 Conventional spraying

Entomopathogens viz., fungi, bacteria, virus and nematodes have an important place in the biological control because they have a wide host range, are harmless to the environment and human, and could be applied with conventional sprayers. They can be used more against stored product pests with the development of new biotechnical methods such as collecting pests in some stations to meet them with entomopathogens [137].

2.10 Advantages of microbiological control

2.10.1 Reduced use of Insecticides

Many farmers have adopted the use of microbiological control agents (MCAs). Bt maize is an example of MCA, it has provided maize farmers testimonies coupled with both economic and environmental advantages. Many farmers quote unique opportunities to protect yield and reduce handling (and use) of insecticides to explain their rapid adoption of Bt maize [138].

2.10.2 Protected yields

Over the years, maize farmers had challenges in controlling corn borers because insecticides are not successful after larvae have tunneled into the stalk. In 1990, entomologists experimented the use of Bt maize and found out the "bullet proof" effect it gave to corn borer. Until then, plant breeders were able to increase host plant resistance, but none of these plants were "bullet proof". That has been the reason why farmers chose to use Bt maize which resulted in higher yields due to this reduced insect injury [139].

2.10.3 Improved grain quality

The use of Bt maize also helps to reduce the occurrence of ear mold on the field. This is as a result of the reduction of insect attacks that provides a site for infection by molds, Bt-protected maize can have lower levels of toxins produced by molds (i.e., mycotoxins), especially fumonisin and deoxynivalenol [140, 141]. Consequences of contamination with mold may be serious, as fumonisins can cause fatal leukoencephalomalacia in horses, pulmonary edema in swine, and cancer in laboratory rats. Economic analysis suggests that USA farmers save $23 million annually through reduced mycotoxins [142] and mycotoxin reduction also could be a significant health benefit in other parts of the world where maize is a diet staple [143].

3. Conclusion

The presented chapter outlines the use microbiological control, an ecofriendly, non-toxic, effective and biodegradable alternative to chemical pesticides. It is also an effective strategy for pest and disease management but it requires developing beneficial microorganisms that are native to the soils where maize is grown [144]. However, for biological methods to reach their full potential, an increased research effort is required. Future functional studies are still needed to fully unravel this intricate alternative approach to pest and disease management of maize and thus help boost maize yield and improve food security.

Conflicts of interest

All authors declare no conflict of interest.

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