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Prospects of endophytes in integrated pest management strategies for pesticide-free food production

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Abstract
The entire world is now facing with a serious issue with food contamination from pesticides. Since the beginning of civilization, agriculture has been severely impacted by the destructive infestation of various pests, including weeds, bacteria, viruses, and fungus, which has resulted in a sharp decline in production. We are polluting and disregarding the state of our natural resources. Farmers are also using numerous types of synthetic chemical pesticides, which are deteriorating the quality of the soil and water, to protect plants from various insect pests and diseases. Because synthetic chemical pesticides persist in the environment for extended periods of time, they are causing a variety of issues related to polluted water, soil, and air. Certain pesticide ingredients are absorbed by plants and build up in their tissues. Through the food chain, these chemicals are passed from one trophic level to another. The animals either die from the greater concentration or have their ability to function impaired. Chlorinated hydrocarbons are thought to be a major contributor to degenerative diseases including cancer and infertility in humans. Thus, we must pay attention to the issues surrounding pesticides and work to find a solution via the biological control of diseases and insect pests. This article will examine the characteristics of beneficial microbial endophytes used in integrated pest control to produce food without pesticides.

Keywords: Endophytes, pest management, pesticide-free food, agriculture

Introduction

The current agricultural landscape includes pressing concerns including population growth, food security, health risks from industrial pesticides, pesticide tolerance, devastation of the natural environment, and climate change. It is well recognized that chemicals are crucial to a country's attempts to meet its development goals and experience economic progress. Chemicals pesticides are used to control insect pests and diseases, especially in agriculture. Farmers use pesticides widely in agriculture to safeguard their plants. However, many pesticides remain in the ecosystem and affect both the environment and people [1]. Pesticide overuse in agriculture may have disastrous long-term effects. It could cause biological magnifications [2]. Certain pesticides are said to interfere with the reproductive systems and endocrine glands of living beings [3]. In the bodies of animals and humans, pesticides may accumulate via metabolic processes. Synthetic chemical pesticides have the potential to have harmful health consequences, such as those related to the skin, metabolism, psyche, heart, reproduction, and endocrine system [4]. Organo phosphorus pesticides, such as dimethoate, parathion, and malathion, have an impact on the development of mitochondria, cholinesterase enzyme function, insulin production, normal cell protein disorder, metabolism of fat and carbohydrates, genotoxic effects, and mitochondrial stress, which can affect to endocrine system, central nervous system [5]. Agricultural pesticides are absorbed into the soil via surface runoff from treated plants. Pesticide breakdown in soil is influenced by cropping strategies, irrigation methods, climate, and organic component composition [6]. Wild life and bees are among the other creatures that are negatively impacted by pesticide pollution in ecosystems [7]. In addition to endangering the environment, pesticides are also bad for human health. According to reports, pesticides are deposit in the colon, where they progressively contaminate the body. We must acknowledge that the apples we consume to maintain our healths are grown with toxic pesticides. Despite our belief that fruits and vegetables are pesticide-free after washing them, many pesticides is still present in them as pesticide residue [8]. Pesticides may contaminate food, mostly because they are used on crops [9]. Exposure to pesticides has been seen to be progressively increasingly associated with immunosuppression, hormone disruption, reduced IQ, problems in reproduction and cancer [10]. When pesticides are applied incorrectly, the residues go into the food chain, contaminating the ground, surface, and air, and ultimately affecting the whole ecosystem. Therefore, the only method for managing insect pests and diseases in sustainable agriculture is to produce food by using biological agents.

Biological Control of Insect Pests and Diseases

Since biological agents are naturally renewable, using them to manage pests is a sustainable approach (Figure 1). They are less tenacious in the environment and very specialized to their target. When it comes to controlling insect pests in sustainable agriculture, biopesticides show promising effects. Unlike synthetic pesticides, biological agents come from sustainable source materials [11]. These include:

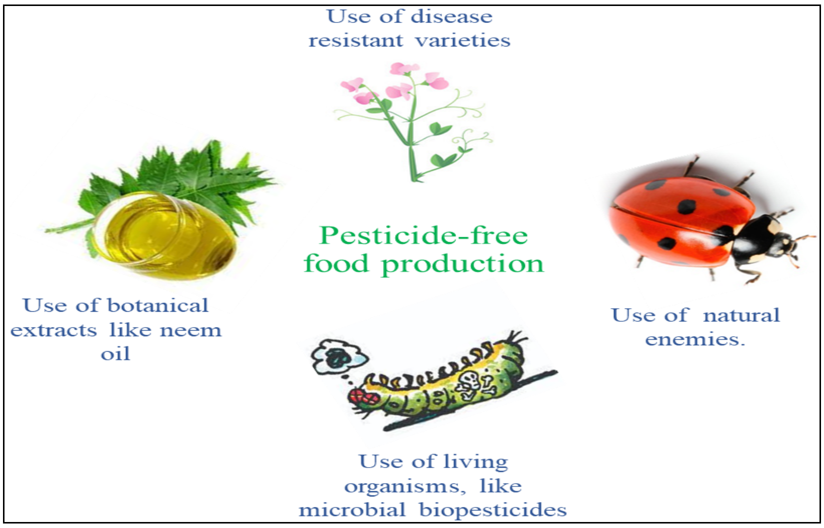

Fig 1: Different methods of pest control used in pesticide-free food production

Endophytes and other microbial biopesticides

According to Gill *et al*. (1992) [12], in contrast to traditional chemical pesticides, microbial pesticides have no toxicity and a superior selectivity. Microorganisms like *Bacillus thuringiensis* are often utilized to control insect infestations. The majority of insect pests belonging to the orders Lepidoptera, Coleoptera, and Diptera are controlled by *B. thuringiensis* [12]. According to Chandler *et al*. (2011), *B. thuringiensis* spores develop, the bacteria create protein crystals or toxins that, when eaten by certain insects may lyse gut cells. According to Samada *et al*. (2020) [13], *B. thuringiensis* works well to combat insect pests of several different lepidopterans and to lessen pest infestation in plants like potatoes and cabbage. Formulations based on *B. thuringiensis* decreased *Tuta absoluta* infestation of tomato leaves and fruit and results were almost as much as the traditional chemical treatment [13]. According to Basu (2009) [14], *Bacillus spp*. Bacteria are that promote plant development and operate as biological controllers. Potato producers utilize *Pseudomonas fluorescens* as a soil supplement and seed coating to control fatal diseases including common scab and bacterial wilt [14]. According to Wojda et al. (2009) [15], *Beauveria bassiana's* pathogenicity mechanism is predicated on the pest's heaemocoel colonizing the host insect's cuticle and penetrating it [15]. *Beauveria bassiana* and *Metarhizium brunneum* are said to be effective in controlling the infestation of thrips, beetles, weevils, aphids, whiteflies, and mites in ornamental crops, fruits, and vegetables [16]. *Metarhizium anisopliae*, an entomopathogenic fungus, is a common microbial pesticide used to reduce insect pests [17]. According to Douressamy *et al*. (2018) [18], it was discovered that *M. anisopliae* significantly contributed to the decline in the number of white grubs in sugarcane [18]. According to Natikar (2023) [19], *Verticillium lecanii* has shown the best percentage of protection against thrips and whiteflies in potato crops [19]. According to Wraight *et al*. (2005) [20], *B. thuringiensis* as well as *B. bassiana* has a lot of promise results for controlling *Colorado* potato beetle in integrated pest control [20]. According to Hussain *et al*. (2013) [21], biological therapy using *Aspergillus Niger* and *Trichoderma harzianum* as antagonists is successful in controlling the fungi that cause root rot in the chilli crop [21]. According to Arshi *et al*. (2021) [22], *T.viride* reduced the development of the pathogen *Fusarium oxysporum* to the greatest extent (83.56%) [22]. According to Girija *et al*. (2005), it has been shown that certain *Pseudomonas fluorescens* strains may function as biocontrol agents, suppressing plant diseases by shielding roots and seeds from fungal infection. According to Kaushik *et al*. (2000) [23], *P. fluorescens* outperformed than *B. subtilis* in terms of damping off tomato [23]. According to Bora *et al*. (2000) [24], the shoot fly *Atherigona varia soccata* and the stem borer *Chilo pertellus* are the primary pests that threaten sorghum and pearl millet [24]. Biredar and Sajjan (2018) reported that pearl millet shoot fly, *Atherigona approximate* is a regular insect pest of pearl millet in India [25]. According to Prasad *et al*., (2015) [26] severe infestation of hairy caterpillars, *Amsacta albistriga*, *Estigwene lactinea*, *Spilosoma obliqua* have been observed in north, south and western India. It ia reported in the study that S. *obliqua* infests young sorghum, maize, cotton, castor, cowpea and pearl millet. S. *obliqua* is a gregarious and voracious feeder, therefore, it takes a short period of time to completely defoliate the plant or destroy the seedling of millet. It is reported that grain yield reduced due to feeding of developing grains by common caterpillars e.g. *Heliothis armigera*, *Eublemma gayneri*, *Eublemma silicula* in millet. *E. silicula* has been found severely infesting the pearl millet in recent years [26]. According to Kishore (2000) [27], neem extract and *B. thuringiensis* are useful for reducing the insect pests of sorghum and pearl millet [27].

According to Aamir *et al*. (2020) [28], endophytic fungi have a significant role in strengthening stress tolerance, changing metabolism, forming mutualistic connections with host plants, and preventing harm from insect pests [28]. According to Prasad *et al*., (2015) [26] severe infestation of hairy caterpillars, *Amsacta albistriga*, *Estigwene lactinea*, *Spilosoma obliqua* have been recorded in north, south and western India. *S. obliqua* infests young sorghum, maize, cotton, castor, cowpea and pearl millet. It is a gregarious and voracious feeder, therefore, it takes a short period of time to completely defoliate the plant or destroy the seedling of millet. It is reported that grain yield reduced due to feeding of developing grains by common caterpillars e.g. *Heliothis armigera*, *Eublemma gayneri*, *Eublemma silicula* in millet. *E. silicula* has been found severely infesting the pearl millet in recent years [26]. Kishore (2000) [27] has reported that neem extract and *B. thuringiensis* are useful for suppressing insect pests of sorghum and pearl millet [27].

Aamir *et al*. (2020) [28] reported that endophytic fungi show important role increase ability to form mutualistic relationships with host plants, alter metabolism, strengthen stress tolerance, and protect against insect pest damage [28]. Sui L et.al. (2023) [29] reported that the use of *B. bassiana* was effective in reducing the damage caused by *H. armigera* in tomato crop. *B. bassiana* improve resistance of tomato plants to gray mold caused by *B. cinerea* [29]. Ownley *et al*. (2004) [30] observed that *B. bassiana* strain 11–98 colonization might suppress damping-off in potato caused by soil-borne pathogens, *R. solani* and *P. myriotylum* [30]. Klieber and Reineke, (2016) [31] reported a similar reduction in damage caused by bean stem maggot *Ophiomyia phaseoli* was observed in common bean, *Phaseolus vulgaris* when *M. anisopliae* was used as a potential Entomopathogenic Fungi. Similarly, *B. bassiana* colonizing tomato leaves also resulted in a reduction in the longevity of *T. absoluta* larvae and caused 50% mortality of all larval instars [31]. Fasusi *et al*. (2021) [32] reported that use of endophyte as biofertilizers may be a better way to improve soil microbial environment for influencing nutrient convenience and decomposition of organic matter [32]. Gajero *et al*., (2013) [33] reported that growth promoting species of endophytes found in soil but they colonize in plants under favourable conditions [33]. Mona *et al*. (2024) [34] reported that endophytic bacteria shows potential for use in agriculture, as an effective biological agent against *Rhizoctonia* root-rot of tomato plants [34]. According to Jensen *et al*., (2019) [35], Entomopathogenic fungi, *B. bassiana*, were reported to colonize many crops, such as corn, wheat, cotton, soybean, tomato, grapevine, sorghum, and citrus, and to reduce infestation by serious pests, mainly moth larvae and aphids. It is found during the different studies that the presence of endophytic EPF resulted in the significant lessening of both pest population and plant damage [35].

Parasitoids as Biological Control Agents in Agriculture

According to Wyckhuys *et al*. (2009), the use of parasitoids as a natural enemy has shown encouraging outcomes in the control of insect pests. For effective pest control, timely release at the right density is essential [36]. Lou *et al*. (2014) reported that the biology and effectiveness of natural enemies as biocontrol agents. These natural enemies include four parasitoid wasps: *Apanteles cypris, Cotesia chilonis, Anagrusnila parvatae*, and *Trichogramma japonicum* [37]. According to reports, *Cotesia glomerata* is an effective biological control agent that may be used as the main parasitoid to inhibit *Pierre brassicae* [38]. According to Dabhi *et al*. (2011) [39], *Bracon brevicornis* consumes the hemolymph of its host before laying eggs. They also feed on it after paralyzing the larvae in their third instar, killing the host in the process. subsequently, it is evident that *B. Brevicornis* may also regulate larvae in their third instar. Its ability to generate a large number of offspring on a variety of lepidopteron pests, such as *Corcyra cephalonica*. As a generalist this parasitoid makes it a valuable tool for the biological control of insect pests in sustainable agriculture [39]. It is suggested that *Trichogramma chilonis* can be used as a possible biological control agent for controlling *H. armigera*. When a biological control agent like *T. pretiosum* is released, the combined impact of several natural enemies on the pest population in an agro-ecosystem cannot be understated [40]. It is evident that parasitoids are very successful in controlling insect pests at all phases of their life cycles.

Biochemical pesticides

These are naturally occurring compounds that use non-toxic means to manage pests, such fatty acids, plant extracts, and pheromones. Biochemical pesticides include compounds like plant growth regulators that prevent pests from growing or reproducing, or compounds like pheromones that either attract or repel pests. According to Thacker *et al*. (2002) [41], Asia and the Middle East have been using plant based pesticides in agriculture for at least 2,000 years ago [41]. Novel botanical compounds with the potential to manage pests are of interest due to their physiological activity, biodegradability, and bioefficiency. Plant-based treatments are less harmful to creatures that are not their intended targets, less invasive in the environment, and work well with other control methods in an integrated pest management system. Numerous plant extracts together with their essential oils are said to be a rich source of bio-pesticides [42]. The neem (*Azadirachta indica*) and Chinese neem (*Melia azedarach*) have been found significant insecticidal qualities. The bio efficacy of *M. Azedarach.* have been reported of working against some insect pests [43]. Ibrahim *et al*. (2019) [44] reported that the neem seed extracts followed by tobacco are as effective as the chemical pesticide in reducing the target pests e.g. citrus leaf miner, armored scale and citrus whitefly [44]. It is reported by Chaudhary *et al*. (2017) that there are many herbs in which Neem plant based insecticides has been found most effective bio-pesticide because many limonoids are present in Neem plant extracts which control pests and increases plant disease resistance, from various synthetic insecticides. The use of Neem based insecticides may increase the productivity and yield of crops. Singh *et al*. (2003) [45] reported that Neem Seed Kernel Extract based bio-chemical was found the most effective in controlling the white fly and jassid [45]. According to Bhushan, *et al*., (2011) [46] NSKE was most effective in reducing the larval population of *Helicoverpa armigera* in chickpea [46]. It is reported by Kumawat, *et al*., (2014) [47] that garlic and chilli extracts are found useful to manage bacterial and fungal infection. Chilli has the property to avoid fungal and bacterial infection due to its preservative property [47].

Varietal Resistance and Crop Rotation

The most crucial thing is to plant tolerant and healthy varieties of crops because resistant variety plants are less susceptible to assault by insect pests and diseases within a specific group, resistant variations are essential to the production of pesticide-free food. According to Lupton *et al*. (1968) [48], resistant variety seeds are an economical and eco- friendly method for protection of the crop from pests and diseases, [48]. Thompson's (2005) [49] stated that there are some significant varieties of crops which have defense system against pests [49]. Kollner *et al*., (2008) [50] reported that Maize variety resulted in the production of the volatile compound (E)-b-caryophyllene that caused a stronger attraction of the natural enemies of the herbivore proportionate to a maize variety that did not induce TPS23 expression [50].

Conclusion

From the above analysis, it is obvious that bio agents, biochemicals and resistant varieties of crops play a vital role in management of insect pests and diseases to grow pesticide free food. Biological agents do not have residue problem in agriculture produce which is a matter of significant concern for consumers. Advantages associated with biological control are their host specificity, effective in very small quantity, biodegradable in nature, no problem of toxic residue and these are ecofriendly in nature. The use of endophytes as biological agents is a promising technology for producing pesticide free food through integrated nutrient, pest and disease management.

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