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Biological Control for Insect Pests: A Review

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Abstract: The continuous and enhanced use of chemical pesticides for eliminating the insect pests effected the crops quality, market value and yield significantly. These pesticides are also harmful for some beneficial microorganisms, human health and the environment. The biopesticides is a better alternative to these chemical pesticides. The biopesticides arederived from the microorganisms like bacteria (Bacillus thuringiensis, Bacillus subtilis), virus (Baculovirus), fungi (Acremonium cephalosporium, Aspergillus niger, Trichoderma viridae, Penicillium chrysogenum and Verticillumalbo-atrum) and some nematode (genera Heterorhabditis and Steinernema). The biological control of insect pests has various advantages over the use of chemical pesticides. Biopesticides are eco-friendly, cost-effective, specific to target pests and do not harm the human health. Although biocontrol methods give rise to some ethical issue but by doing more research and experimental studies on biological control of pests, biopesticides can be a potential method of controlling the pest population.

Keywords: Chemical insecticides, insects, pests, biological control, bacteria, fungi

1. Introduction

Undoubtedly, the green revolution has fulfilled the demand of food supplies at higher rate, but simultaneously it has also become the reason of some ecological, environmental and semi-economic problems. The green revolution technology was based on the practice of dwarf and semi-dwarf high yielding varieties of crops, enhanced use of agricultural chemicals and irrigation and due to these practices crop pests started buildingbuilding-up, resulting in the increased several pests. The improper and overutilization of pesticides has led to the problems like pesticide resistance and polluted the different components of the environment. Crop losses keeps on increasing even after the use of various control methods against pests (Dhaliwal and Koul,2010). It should also be noted that the climate change also has great impact on the magnitude of the pest problems (Ramamurthy et al. 2009). More than 10,000 species of insects, 30,000 species of weeds and 10,000 species of nematodes are the reasons of the injuries caused to the food plants all over the world (Hall,1995; Dhaliwal et al. 2007). But the major pest species are only less than 10 per cent. The intensity of problems associated with pests keeps on changing with the changes in the farming practices and development in agricultural techniques (G.S, Dhaliwal et al. 2010).

Insect pests are massive challenge to all the agricultural systems that are present worldwide, causing damage to the yield of crops and interfering the food security(Barbosa P et al. 1991). There is persistent pressure to develop efficient approaches to control pests in order to decrease the environmental impact and reliance on chemical pesticides (Gurr GM et al. 2004). Integrated Pest Management (IPM) appears to be an integral method that combine different techniques to manage the pest population and encouraging the supportable agricultural operations (Awanindra Kumar Tiwari, 2024). Insect pests can harm the crops by different mechanisms like eating the plant tissues, transmission of diseases and disturbing the overall growth and development of plant (Flint ML et al. 1981). Several pests like aphids and caterpillars straightway feed on plant tissues and cause evident harm to leaves, stems and fruits. Some pests also act as vectors for plant pathogens in the transmission of diseases that can destroy whole crop fields (Horowitz AR et al. 2004). Generally, insect pests have very high reproduction rate that allows them to grow faster and the ability to cause worldwide infections (Mahr DL et al. 2008). With the time, the pests become resistant to pesticides which gives rise to various challenges in order to control their population(Shelton AM et al. 2003).

Pesticides, fertilizers and the crop varieties having high yield, proved beneficial for the farmers to attain considerable enhancement in agricultural productivity but the continuous use of pesticides has become the reason of pest resistance along with the threats to ecology and health of the humans (Pratap S. Birthal et al. 2000). The regular utilization of pesticides results in the pre-harvest (40 per cent) and post-harvest losses (10-20 per cent) (Cramer, 1967; Pimental, 1992; Oerke et al. 1995). When the population of pest reaches beyond a fixed level of economic injury, then it impacts human health, yield and profits (Fiza Khan et al. 2014). A pest can be called as an economic pest only when it causes loss in yield more than 5 percent level (Edward and Heath, 1964). The population density at which practices should be initiated to control the increasing population of pests and preventing them from reaching the economic injury level, this is termed as economic threshold (Stern et al. 1956). Once it is analyzed that an insect is becoming the reason of economic loss, then it is important to bring their population under control. Feeding capability, host plant relationship, nature of the injuries and the vulnerability of the plant to attack, are some factors that decide the seriousness of the attack(Fiza Khan et al. 2014). The insects cause damage to the one-fifth of the production (in tons) every year(Banerji, 1985). So, it becomes necessary to bring down the damages level caused by insect pests (Fiza Khan et al. 2014).

Rice,the rice plant is one of the most common hosts for many species of insects. Every part of the rice plant is prone to attack during the time from sowing till harvest. More than 800 species of insects cause damage to rice plant but many of them do very minute harm. There are numerous insects that consume the root and stem of rice plants. White grubs and root aphids, feed only on the roots, mealybug,

gall midge and rice stem maggot cause damages specifically to the stems and some pests like mole crickets cause harm to both roots and stems (D. Dale, 1994).
Cotton, Pink bollworm Pectinophoragossypiella (Saunders), spotted bollwormEariasvittella (Fab.), tobacco caterpillar Spodopteralitura (Fab.) and the whitefly Bemisiatabaci (Genn.) are some of the crucial pests of cotton that can decrease the production by 20-80% (Mukherjee, 1982). The red cotton bug (Dyscdercus spp.) is also an important pest of cotton because of its ability to cause discoloration of fluff (Ashfaq et al., 2011). In India, cotton growing states, specifically Andhra Pradesh, Maharashtra and the Punjab, suffered major economic losses during the year 1987 and 1997 due to the infection of cotton crop (K.R. Kranthi et al. 2002).
Wheat,wheat (Triticum spp.) is very beneficial food for the human race and is most crucial cereal in the crop field. There are several arthropods that harms to wheat (Triticum aestivum) plants during their whole life and every stage of the crop is susceptible to damage. Wheat pests can be polyphagous (cause injuries in broad range of plants) or can be oligophagous (effect only small no. of plant species) and rarely any insect would be monophagous to wheat crop (Umer Bin Farook et al. 2019).Wheat crop is damaged by various insect pests such as Termites, aphid species, Schizaphisgraminum, Rhopalosiphummaidis, Sitobionavenae and Rhopalosiphumpadi(Dilbar Hussain et al., 2022) and wheat midges Sitodiplosismosellana(Jacquemin et al., 2014). Prior to the green revolution, the worldwide yield loss was about 5.1 per cent but the losses reached to 9.3 per cent after the green revolution in 1990s (Dhaliwal et al. 2010).
Tomato, tomato (Solanum lycopersicum) is one of the most important vegetable crops(Sultana Afreen et al. 2017). Along with the calcium and carotene, vitamin A, B and C are found in the abundant amount in tomato due to which the food value of tomato is very high(Bose and Som, 1990). There are various insect pests of tomato, such as Tomato fruit worm, Potato aphid, Stink bugs and Leaf footed bugs, Hornworms, Silverleaf, Whitefly etc. But the main pest of tomato is Tomato fruit borer, Heliothisarmigera (Hub.) which causes damage that ranges in between 85-93.7% (Haque,1995). Every plant part of tomato is prone to the attack of pests (Sultana Afreen et al. 2017).

2. Different types of pests

2.1 Pests that infectthe rice plants

White Grubs (Larvae of scarab beetles), in many regions of the world, white grubs are very crucial pasts of upland rice. Most of them polyphagous, hence they also harm the other crops. White grub species consists of two groups: One is chafers, the adults belonging to this group feed on the leaves, flowers and branches of rice plant and the root of living rice crops is attacked by larvae, another group is Black beetles, adults infect roots and larvae feed on organic matter but not cause injury on living roots.The larvae of chafers attack on roots and other parts of the plant that are present under the surface of the earth. The rowing grubs ultimately becomes uncontrolled feeders that harm the crops at higher rate. If the injury is severe to the roots, then the impact can be seen on the whole plant while the limited injury only effects the growth of the host plant (D. Dale, 1994).Heteronychuslioderes, it is a black beetle and cause damage to the rice plant particularly in Uttar Pradesh, India (Garg and Shah, 1983).Rice stem maggots,the maggots are found in the nearby areas of the growing rice plants and eat the leaf blades. Stunting and reduced tillering are the consequences of early attack of the maggots. Later generations of larvae attack on the growing flowers that bring down the yield greatly (D. Dale, 1994).Molecrickets, these fall under the category of polyphagous insects. Mostly the infect the upland rice in the damp fields. The nymphs and adults infect the subterranean stems and nearby to the roots. The considerable damage is seen in the dried tillers. If there is severe attack, then the death of the whole plant occurs. The plants that got dried are visible in the form of patches in rice field. The seedlings that are young and planted newly, are generally attacked in the starting of the season. Commonly, around the borders of the field, damage is severe (D. Dale, 1994). Field crickets carries the cut tillers till their burrows but it is not seen in the case of mole crickets (Tripathi and Shri Ram, 1968).

2.2 Pests that infect the cotton plants

Pectinophoragossypiella (Saunders), pink bollworm, an infamous pest that infects cotton. It infects only cotton crops and hence called monophagous. It is found in every part of the world, where cotton is grown. It spreads serious infections and also the reason of yield loss. The larva of P. gossypiella pierce into the buds and bolls and feed on the content that are present inside the buds and seeds in the bolls (Unsar Naeem-Ullah et al., 2020). The most vulnerableare those cotton bolls that are 10-24 days old, causing loss of seed, fluff damage and shedding of fruits (Sarwar, 2017). Spodopteralitura (Armyworm), a devastating pest of cotton in all cotton growing countries. This pest has over 120 host plants. It also infects pulses, amaranthus, chilies, groundnut, sunflower, tobacco and castor (Xian-lin et al., 2011). It is seen in countries like India, Afghanistan, China, Pakistan, Korea, Indonesia, Japan, Taiwan, Sri Lanka, Burma and Thailand (Luo et al., 2000). The whitefly, Bemisiatabaci (Gennadius) is a global pest. It is polyphagous in nature. It produces severe infections in cotton plants by means of sap-sucking and evacuating honeydew, as a result of which smutty mould grow on leaves that lowers the photosynthetic activity. Cotton leaf curl virus disease (CLCV) and honeydew harms indirectly that reduces the quality of fluff. A decrease in the yield can be seen by direct attacking on the crop (Unsar Naeem-Ullah et al., 2020). Red cotton bug (Dysdercus spp.) is an important pest of cotton because of its ability to cause discoloration of fluff (Ashfaq et al., 2011). Cotton seeds and cotton bolls are attacked by both nymphs and adults of red cotton bug. The mouthparts of red cotton bug are drilling and sucking type that helps in sucking the sap of the cell and eat the contents that are present on and inside the bolls (Unsar Naeem-Ullah et al., 2020).

2.3 Pests that infect the wheat plants

Aphids are devastating pests of all the crops that are cultivated globally. Rhopalosiphumpadi and Schizaphisgraminum are the two aphid species that cause evident harm to all the wheat crops worldwide (Hamid, 1983; Inayatullah et al., 1993). Aphids also cause viral diseases in wheat plant by phloem sap sucking and have negative impact on its development. Aphids infect stem, kernals, tillars and the leaves that are attached on wheat. Aphid species such as Schizaphisgraminum, Rhopalosiphummaidis, Sitobionavenae and Rhopalosiphumpadiareimportant pests of wheat plant. Serious injuries by aphids on wheat crop is mainly caused by feeding on its leaves (Dilbar Hussain et al., 2022). Wheat midges, Sitodiplosismosellana (Gehin) is an orange-colored wheat blossom midge (OWBM). It is polyphagous and cause high and significant reduction in the crops, particularly wheat plants (Jacquemin et al., 2014). Termites are severe pests of several agricultural crops that eat cellulose and harm woody plants (Rashmi and Sundararaj, 2013). During the growing and final stage in the Triticum aestivum crop, there is 43-80% loss in the yield caused by termites (Chhillar et al., 2006).

2.4 Pests that infect the tomato plants

Tomato fruit worm, Helicoverpaarmigera is an important pest that infects several crops such as tomato, cotton, chickpea and cotton pea. The larvainvades and cause potential harm to the fruit of tomato and lowers the yield. The larva infects both the leaves and fruit of the tomato (Numan Nisar et al., 2020). The market value of the tomato decreased due to the infection caused by the larva of H. armigera (Hussain B and Bilal S, 2007). The whitefly, Bemisiatabaci directly harms to tomato plants and transmit several viruses, such as begomoviruses (Pedro Henrique Brum Tongi et al., 2018). Direct damage is caused by sap sucking that brings about physiological disorders in plant and by evacuating honeydew that pile upon various plant parts (Gilberston, Batuman, Webster and Adkins, 2015). Over 110 species of viruses are transmitted by this insect, mostly belonging to genus Begomovirus (Gilberston et al., 2015; Jones, 2003; Navas-Castillo, Fiallo-Olive and Sanchez-Campos, 2011). The symptoms induced by this virus includes, curling of leaves, chlorosis, mosaic and stunting in several crucial crops (Diaz-Pendon et al., 2010). Silverleaf Whitefly (SLW) that feeds on tomato plants transmit a disorder causing irregular ripening of the fruit (T.G. McCollum et al., 2004). SLW, Bemisiaargentifolii Bellows and Perring, is an important pest of many vegetable crops that are produced commercially. Due to the attack of SLW, several physiological disorders re observed that includes, squash silvering (Maynard and Cantliffe, 1989;Yokomi et al., 1990), chlorotic streak pf bell peppers (Summers and Estrada, 1996) and non-uniform ripening of tomatoes (Maynard and Cantliffe, 1989; Schuster et al., 1990; Schuster, 2001). Hindrance in softening of fruits is also observed in the plants infected from SLW (Hanif-Khan et al., 1999).

3. Impact on Agriculture and Economy

There are several ways by which pests reduce the productivity of the crop: According to Boote et al., 1983, on the basis of their impact, pests can be classified into stand reducers (damping-off pathogens), lower photosynthetic rates (fungi, viruses, bacteria), hasten the senescence of leaf (pathogens), assimilate sappers (nematodes, sucking arthropods, pathogens), tissue feeders (chewing animals, necrotrophic pathogens). Crop losses can be described as quantitative and qualitative. The reduction in the productivity is a result of quantitative losses that leads to a low yield per unit area. Qualitative losses due to the pests may arise because of the reduction in the content of important ingredients, diminished market quality, e.g. because of the aesthetic features (pigmentation), reduced storage features, harvested products contaminated with the pests or products having toxicity of pests (e.g. mycotoxins) (E.-C. Oerke, 2005). The loss in Indian agriculture because of insect pests are estimated regularly (Pradhan, 1964; Krishnamurthy and Murty, 1983; Atwal, 1986; Jayaraj, 1993; Lal, 1996; Dhaliwal and Arora, 1996, 2002; Dhaliwal et al., 2003, 2004). Feeding on plant leaves, penetration into fruits, stems and roots are some ways through which insect pests cause direct damage to the crops. In direct damage, the destruction to crops caused by the pests is observable. But the extent and potency of damage varies. Various insects that come under the order lepidoptera, orthoptera, heteropteran, homoptera, coleoptera and diptera are the reasons of direct damage to the crops. There are also several insects that do not harm the crops but spread infections (bacterial, fungal and viral) to crops. This type of damage is called as indirect damage. For ex. the viraldiseases of potato and sugar beet is spread by the aphids that falls under the order hemiptera. These infestations of pests lower the crop quality and market value (Enock Asante Osei et al., 2021).
The economy is also affected up to a great extent because of these pests.In early 1960s, the losses were 7.2 per cent but it reached to 23.3 per cent in the early 2000s (G.S. Dhaliwal et al., 2010). In India, the output loss because of these pests is approximately, 5 per cent for wheat, 20 per cent for sugarcane, 25 per cent for rice, 30 per cent for pulses, 35 per cent for rapeseed-mustard and 50 per cent in case of cotton (Dhaliwal and Arora, 1993). Therefore, the use of pesticides without proper technical methods can decrease the crop-yields, food and fiber supplies and elevation in output prices (Pratap S. Birthal et al. 2000). On regular basis, India has witnessed a major loss due to the infestation of insect pests both in field and storage (Mamgain et al. 2013).

4. Preventions

4.1 Chemical insecticides

Chemical insecticides are the noxious substances which are used to eliminate or kill and control the population of insect pests, for example ovicides are used to kill eggs and larvicides eradicate the larvae (Maria F. Araujo et al., 2023). Earlier, the insecticides consist of substances like sulfur, heavy metals, salts and sometimes even plant extract also (e.g. Chrysanthemumcinerariifolium earlier known as Dalmatian pyrethrum) (Wang, C et al., 2019; Oberemok, V.V et al., 2015; Corso, I.C. et al., 1998; McLaughlin, G.A. et al., 1973). The first-time insecticide was used by the Sumerian people around 4500 years ago, they used insecticide containing sulfur compounds to eradicate insects and mites (Maria F. Araujo et al., 2023).The insecticides attack the PNS and CNS of the insects and also alter their normal metabolism. When insecticides are spread in the crop fields, most of it outstretch to the soil and pollute the groundwater reserves. Additionally, the improper use of insecticides create resistance among pest population. The insecticides not only kill the insects but also contaminates the environment that can be harmful to other organisms along with the humans.The use of insecticides helps in controlling population of pests but the use insecticides on regular basis effects the crop production significantly, for ex, it may interfere the rate of decomposition of soil organic matter (D. Pimentel et al., 1984). Due to this, the carrying capacity of crop fields and soil productivity gets effected (A.K. Misra et al., 2021). Chemical insecticides harm agricultural land by altering the growth of useful insect species and soil microorganisms that are important for maintaining the soil health. Plant root and immune systems are also affected by the use of chemicals as result of which there is decrease in the nitrogen and phosphorus concentrations in the soil which are considered as important plants nutrients (L Holmes et al., 2016). Some examples of most used chemical insecticides in the world are Imidacloprid, Chlorpyrifos, Carbaryl, Acephate, Dimethoate, Thiamethoxam, Malathion and Bifenthrin (A.K. Misra et al., 2021).

4.2 Biological insecticides

Biological insecticides are those pesticides that are obtained from the natural materials such as bacteria, plants, animals and some minerals (Ukoroije, Rosemary and Otayor, Richard Abalis, 2020). The application of biological insecticides is same as of chemical insecticides but the management of pests is done in environmentallyfriendly manner (Kumar S, 2012). Biological insecticides act slowly and human friendly having very fewer residual effects on the environment in comparison with the use of conventional insecticides (Adebayo TA et al., 1999). Biological insecticides that are derived from the plants can alter the growth, feeding and pest reproduction (Adeyemi MMH, 2010). Plants like Azadirachtaindica, Dracaena arborea etc. are important for the individual’s health & the environment (Ukoroije, Rosemary and Otayor, Richard Abalis, 2010). The insecticidal effects of plants are found in the chemical substances, termed as active ingredients that show specific physiological activity on the body of the insects (Okwu DE, 2001). The application of the products that are derived from the plants have beneficial effects as they are biodegradable, specific to target, eco-friendly, economical, available locally and safe, thus very effective in controlling pest population without hampering the quality (Srijita D, 2015; Mondal T, Mondal D, 2012; Montasser SA et al., 2011; Rembold H, 1994). More than 550 insect pests belonging to order Orthoptera, Homoptera, Diptera, Heteroptera, Isoptera, Coleoptera and Dictyoptera and others are well controlled with the help of active ingredients that are extracted from more than 200 agricultural plants of different families ((Ukoroije, Rosemary and Otayor, Richard Abalis, 2020).Some examples of biological insecticides are Bacillus thuringiensis, Bacillus subtilis, Trichoderma spp., entomopathogenic nematodes etc. (Coombs A, 2013; David C, 2018).

5. Species used as biological control

5.1 Bacterialbiopesticides

Most of the microorganisms based biopesticides are consist of the bacterial products (Shoresh et al., 2010) in which Bacillus thuringiensis contributes more than 70% of the total bacterial biocontrol agents. Basically B. thuringiensisis used to bring down the insect pest population. There are also several other isolates of bacterial genera that are used to protect the crops (Helene Cawoy et al., 2011). B. thuringiensis is the most used species as a biopesticide. Cry and Cyt are the two proteins that are produced by this bacterium. These proteins are very poisonous to insects but do not harm mammals and the environment. In 1938 this biopesticide was used for the first time (Sanahuja et al., 2011). Cry toxins are the structural part of the spores of B. thuringiensis. When any insect feed on these bacterial spores, the cry proteins make pores in the gut wall of the insect and enables the bacteria that comes out from the spores to feed on the materials that are present inside the body cavity of the insect (Helene Cawoy et al., 2011). This gives rise to the new population of bacteria and consequently new origin of spores after the insect's death (Sanahuja et al., 2011). Insect families belonging to order Coleoptera, Lepidoptera and Diptera can be brought under control by using Cry/Cyt toxins (Helene Cawoy et al., 2011). Bacteria like Brevibacilluslaterosporus is used as a biocontrol against S. avenae (wheat) (Khadija Javed et al., 2022).

5.2 Fungal biopesticides

Fungal biopesticides are those in which fungi are used as a method of controlling insect population in order to prevent infestation and crop damage (Chet et al., 1983). It is an environmental-friendly and effective method of controlling pest population (Sardul Singh Sandhu et al., 2017). The explorationuse of fungi as a biopesticide is increasing because they possess rich biodiversity, ease in engineering and delivery techniques etc. (Butt et al., 2001; St Legerand Wang, 2009). Globally, fungi are used as biocontrol agents because of their ability to maintain yield and controlling disease efficiently (Pandya and Saraf, 2010). Fungi has huge biodiversity of 1.5 million species out of which 70,000 species are discovered (Zain et al., 2013). Their complicated metabolic pathways, varieties in the enzymes secreted by them and secondary metabolites have been utilized since many years in making various natural products (Moore et al., 2011; Hawksworth, 2001; Turner, 2000). The genes that are responsible for the formation of secondary metabolites and the biological activity of these metabolites has grabbed the attention of the several pharmacologists and microbiologists (Yu and Keller, 2005; Zain et al., 2009; Awaad et al., 2012). There are some strains of fungi in which insecticidal activity was tested against the housefly, Musca domesticaand these strains were of Acremonium cephalosporium, Aspergillus niger, Trichoderma viridae, Penicilliumchrysogenum and Verticillumalbo-atrum(Al-Olayan, 2013).Fungi like B. bassiana is found effective biocontrol agent against P. gossypiella (cotton) (Emam M. Abd-ElAzeem et al., 2020), S. litura (cotton) (Shah Mohammad Naimul Islam et al., 2023),R. padi (wheat) (Iqra Saif et al., 2024), S. graminum (wheat) (Entesar N.S. Haron et al., 2020), R. maidis (wheat) (El-Heneidy et al., 2012), H. armigera (tomato) (M. Phukon et al., 2014),B. tabaci (tomato) (Martina Sinno et al., 2021), Aspergillus niger against Dysdercus spp. (cotton) (S Kumari et al., 2019),Metarhiziumanisopliae against R. padi (wheat) (Iqra Saif et al., 2024) and White grubs (rice) (Ravinder S. Chandel et al., 2019),Paecilomycesfumososroseusagainst R. maidis (wheat) (El-Heneidy et al., 2012).

5.3Viral biopesticides

Most of the viral agents that are prepared to protect the plants are derived from the baculoviruses (Bahvalov, 2001; Szewczyk et al., 2006). The making of viral biopesticides is costly and selective, act slowly but efficiently (Rosell et al., 2008). There is a latent period in the life cycle of baculoviruses which is the reason of their slow action on pests (VolodymrVolodymyrovychOberemok et al., 2015). There are two phenotypes of baculoviruses, budded-virus and occlusion-derived virus. The budded virus passes on infection from one cell to another cell while occlusion-derived virus passes on infection from one insect to another insect (Jehle et al., 2006). The preparations of baculovirus agents are based on the viral polyhedra resulting in the oral infection of insects that feed on green plants (VolodymrVolodymyrovychOberemok et al., 2015). The polyhedra formation completes when the nucleus of the cell gets fully filled with them, as result there is formation of around 10^{10}polyhedra, exceeding 30% of the insect's dried biomass (Miller et al., 1983). In viral polyhedra, virions are present in the ground substance of polyhedrin protein, extremely resistant to environmental factors (Chiu et al., 2012). The baculoviral preparations are way behind than the preparations based on the Bacillus thuringiensis (Moscardi et al., 2011).

5.4 Nematode biopesticides

Nematodes that kill the insect belong from the genera Heterorhabditis and Steinernemaare applied to control beetles, leaf-mining flies, shore flies, sciarid and lepidopterans since 1980s. The infection of nematodes results in the release of bacteria into the body of the insects that kill them (Joop C, van Lenteren et al., 2020). The juvenile stage is infective and free living (D Kachhawa, 2017), penetrates the host insect through mouth, spiracles and anus and then into the hemocoel (BeddingR, 1982). After the host being killed, nematode keeps on feeding on host tissue, mature and reproduce (Joop C, van Lenteren et al., 2020). Entomopathogenic nematodes are target specific and non-poisonous to humans due which these are considered as suitable way to control insect pests (Shapiro-Il DI et al., 2006).

Nematode such as Serangiumparcesetosum is a potential biological control agent against B.argentifolii(tomato) (RL Meagher JR et al., 1996).

S.No.	Crops	Target pathogens	Biocontrol agent	References
1.	Rice	White grubs	Metarhizium anisopliae	Ravinder S. Chandel et al., 2019
2.	Cotton	P. Gossypiella S. litura Dysdercus spp.	B. bassiana B. bassiana Aspergillus niger	Emam M. Abd-ElAzeem et al., 2020 Shah Mohammad Naimul Islam et al., 2023 S Kumari et al., 2019
3.	Wheat	R. padi S. graminum R. maidis S. avenae	B. bassiana, M. anisopliae B. bassiana Paecilomycesfumososroseus, B.bassiana Brevibacilluslaterosporus	Iqra Saif et al., 2024 EntesarN.S. Haron et al., 2020 El-Heneidy et al., 2012 Khadija Javed et al., 2022

4.	Tomato	H. armigera B. argentifolii B. tabaci	B. bassiana Seragiumparcesetosum B. bassiana	M. Phukon et al., 2014 RL Meagher JR et al., 1996 Martina Sinno et al., 2021

6. Limitations and future prospects

Still there is lack of studies in controlling the insect pests biologicallythat do not harm the quality and yield of crops. Moreresearch work is required in the field of biological control of pest infestations.With the increase in crop production, the pest infestation is also increased, so instead of chemical control of these pests, more experimental studies can be done on different and various biocontrol agents in order to control the insect pest population without harming the environment, non-target pests, quality, market value and yield of the crops.The use of microorganisms for the crop protection, especially the edible ones result in the rise of ethical issues for many people, hence it's also a challenge to bring those crops into the market that are being treated with the biological agents. There is a high need to assemble a regulatory authority which will make sure that the crops treated with the microorganisms are completely safe and do not interfere with the health of the humans. For this, some preliminary tests can be done before making these crops available for the human consumptions. Proper safety and quality testing can be the key of success in resolving the ethical and health related issues.

7. Conclusion

Theincreased rate of crop production has fulfilled the requirement of food supplies at higher rates but simultaneously the pest infestation has been also increased. There is no doubt that chemical pesticides control pest population from causing damage to crops but the regular use of these chemical pesticides harms the environment, human health,soil health and the other microorganisms that are beneficial for maintaining the ecological balance. Instead of relying on chemical control of pests, we can shift to biocontrol agents to prevent the crops from damage and maintaining the yield. Biocontrol agents have many benefits over chemical pesticides like, these are cost-effective, eco-friendly, do not cause harm to environment and other beneficial microorganisms. Several experimental studies have shown that biocontrol agents are effective way of controlling pests. Microorganisms like bacteria, fungi, viruses and even nematodes can also be used as biocontrol agents in eradicating the pest and helpful in sustainable agricultural practices.

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