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RESEARCH ARTICLE

Bio-Pesticides: Natural Strategies for Agricultural Sustainability in the Developing Countries

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ABSTRACT

The basic goal of sustainable development was to create a nexus between socially acceptable economic growth and environmental management. Within this framework, agriculture would be created to achieve profitability, community well-being, and environmental safety. Agricultural sustainability is targeted at increasing the yield of food and fiber crops thereby reducing the incidence of pests and diseases to such a degree that they do not cause extensive damage to crops and environments. Overdependence on chemical pesticides for food production has caused serious health and environmental problems and these propelled researchers to look for better alternatives to synthetic pesticides. Bio-pesticides are materials with pesticidal properties that originate from natural living organisms, including microorganisms, plants, and animals. Bio-pesticides can make important contribution to sustainable agriculture and help to reduce over reliance on chemical pesticides that impose environmental pollution and health hazard at the detriment of mankind. To highlight the needs of bio-pesticides for the interest of man and his environment, this paper used analytical approach to review the followings: Bio-pesticide as a concept, potentials of bio-pesticides, categories of bio-pesticides, and agricultural sustainability as regard to bio-pesticides application.

Key words: Bio-pesticides, agriculture, environment, sustainable development, crop protections

INTRODUCTION

Agriculture still remains important tools for nation building due its ability to ensure food security, poverty alleviation and conservation of the vital natural resource on which the world's present and future generation will be entirely dependent on for their survival and well-being. Food and Agricultural Organization of the United Nations highlighted the need to increase world food production by 70% as to meet up with the growing demand of food caused by the over growing global population (Kumar, 2013). Increasing food production should be the primary objective of all the countries, as the global population is expected to reach 10 billion by 2050.[1-10]

Before 19th century, most food in the world was organically produced using organic manure, human, and animal power. Thereafter, the tremendous increase in the human population necessitated the use of modern technologies in agriculture production system to balance the need of food for human consumptions as well as commercial purposes. Improving crop yield to an industrial scale requires the deliberate application of conventional fertilizers and pesticides. Modern agriculture which mainly relies on extensive use of external inputs such as hybrid seeds, fertilizers, and pesticides for better production has been of great help in alleviating hunger from the world in the last century, but this

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has not benefited modern agriculture, since it has led to the emergence of several pests and diseases.

Pests are any species of living agents that cause damage to crops and their stored products. Some of these agents include fungi, bacteria, nematodes, weeds, rodents, and insects. According to Pandya (2018), pests account for 30% loss of potential yield (with major loss from developing countries) and 14% damage in storage pests (Jankielsohn, 2018). This has later raised concern about sustainable development, considered as the judicious exploitation of the environment for the benefit of both the present and future generations.[11-29]

The central message of sustainable development was to create a nexus between socially acceptable economic growth and environmental management. Within this framework, agriculture would be tied to achieve profitability, community well-being, and environmental safety (Emmanuel *et al*., 2020). Agricultural sustainability is targeted at increasing the yield of food and fiber crops thereby reducing the incidence of pests and diseases to such a degree that they do not cause extensive damage to crops. Overdependence on chemical pesticides for food production has caused serious health and environmental problems. This prompted researchers to look for better alternatives to synthetic pesticides (Ansar *et al*., 2011). Bio-pesticides are materials with pesticidal properties that originate from natural living organisms, including microorganisms, plants, and animals (Soil Technologies Corp, 2016). Bio-pesticides can make important contribution to sustainable agriculture and help to reduce over reliance on chemical pesticides that impose environmental pollution and health hazard at the detriment of mankind. To highlight the needs of bio-pesticides for the interest of man and his environment, this paper used analytical approach to review the followings: Bio-pesticide as a concept, potentials of bio-pesticides, categories of bio-pesticides, and agricultural sustainability as regard to bio-pesticides.[30-48]

Bio-pesticides

Different scholars, various national and international organizations defined the term bio-pesticides to fascinate their own point of view, but the most important thing is that all of which embrace reference to the natural or biological origin of the active ingredient. Bio-pesticides are made from naturally occurring substances that controls pests by non-toxic mechanisms as well as eco-friendly manner. They may be derived from animals (e.g., nematodes), plants (*Chrysanthemum, Azadirachta*), and microorganisms (e.g., *Bacillus thuringiensis* [Bt], *Trichoderma*, Nucleopolyhedrosis virus), and include living organisms (natural enemies) and their products (phytochemicals and microbial products) or byproducts (semiochemicals) (Kumar, 2015). Therefore, bio-pesticides pose less threat to the environment and human health. They are generally less toxic than chemical pesticides, often target specific, have little or no residual effects including acceptability for use in organic farming. According to Environment Protection Agency (EPA, 2003), USA "Bio-pesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals." Bio-pesticides are naturally occurring organisms or bio-based formulations that control pests through different mechanisms of action (Tijjani *et al*., 2016). Bio-pesticides are materials with pesticidal characters that extracted from natural living organisms such as microorganisms, plants, and animals. They are the derivatives of plants, microorganisms, and insects. Biopesticides are products and by-products of naturally occurring substances such as insects, nematodes, microorganisms, plants, as well as semi chemicals (Lengai and Muthomi, 2018).

According to CropWatch (2021), bio-pesticides are anything that kills a pest and are biological in origin as opposed to being synthesized in a laboratory. In the potato industry, the best known bio-pesticide is referred to as Bt. This is an example of a microbial bio-pesticide. Bt is a soil bacterium, toxic to many insect larvae. There are several Bt-products registered on potatoes for foliar applications such as DiPel, Du-Ter, and Javelin. Insect-killing genes of Bt have also been introduced into the genome of several crops including potato, for example, the New Leaf clones of several cultivars. As such, Bt has shown to be most effective. In general, bio-pesticides are made of living things found in nature. They tend to pose fewer risks than conventional chemicals. Very small quantities can be effective and they tend to break down more quickly, which implies less pollution. Some bio-pesticides are targeted in their activity to work on a small number of species. Therefore, users need more knowledge to use bio-pesticides effectively; this is because they are often most effectively used as part of an Integrated Pest Management (IPM) approach (National Pesticide Information Center, 2020).

Categories of bio-pesticides and their processes of action

Based on the nature and origin of the active ingredients, bio-pesticides fall into several categories such as botanicals, antagonists, compost teas, growth promoters, predators, and pheromones (Semeniuc *et al*., 2017). Plants and microorganisms are the major sources of bio-pesticides due to the high components of bioactive compounds and antimicrobial agents (Nefz *et al*., 2016). The active compounds in plants are phenols, quinones, alkaloids, steroids, terpenes, alcohols, and saponins. According to European Union, bio-pesticides have been divided into four categories: (a) Products based on pheromone and other semi chemical (for mass trapping or trap cropping), (b) products containing a microorganism, (c) products based on plant extracts, and (d) other novel alternative products. On the other hand, Environment Protection Agency (EPA, 2003) recognizes three categories of bio-pesticides: Microbial pesticides, plant-incorporated protectants (PIP), and Biochemical Pesticides.

Bio-pesticides can be either microbial, biochemical or PIP bio-pesticides. Their modes of action come under five groups: Neuromuscular toxins, metabolic poisons, gut disruptors, growth regulators, and nonspecific multi-site inhibitors based on the physiological processes they affect (Spark and Nauen, 2015). Microbial bio-pesticides exert their control through antagonism, predation, parasitism, and antibiosis for a natural substance to be considered as a biochemical bio-pesticide, its mechanism of action must be nontoxic (Ivase *et al.*, 2017; Mishra *et al*., 2018; Inam-ul-Haq *et al*., 2019). PIP are dependent on the incorporated molecule which may be derived from microorganisms or plants.

Microbial bio-pesticides

Microbial bio-pesticides can be bacteria, fungi, viruses, protozoa and nematodes, or compounds derived from these organisms that influence pest activities, through competition, pathogenicity, or inhibitory toxins. These agents are broadly divided into multifactorial microbial generalists and hyper parasitic microbial specialists. The generalists control a wider range of pests whereas the specialists act against a particular pest. More than 3000 microbes have been recognized to cause diseases in insects implicating two major groups of nematodes (Steinernema; 55 species and Heterorhabditis; 12 species), more than 100 bacteria, 800 fungi, 1000 protozoa, and 1000 viruses (Nawaz *et al*., 2016; Marche *et al*., 2018; Ruiu, 2018). Specific examples are Bt, *Paenibacillus* (bacteria), HearNPV (*Baculovirus*), *Metarhizium anisopliae, Verticillium* (fungi), *Heterorhabditis, Steinernema* (nematodes), *Nosema, Vairimorpha* (protozoa), and *Chlorella, Anabaena* (microalgae; Costa *et al*., 2019).

This category of bio-pesticides has the advantages of specificity (non-pathogenic to non-target), synergisms (can be used alongside synthetic pesticides), eco-friendliness (their residue has no negative impact on the ecosystem or ecoreceptors), permanent effects (the microorganism becomes an integral component of the insect population or its habitat exhibiting the inhibitory effects), and growth improvement to plants (Nawaz *et al.,* 2016). However, understanding of microbial pesticides could be hampered by challenges such as detailed scientific research, ecological study, and mass production technologies. These challenges may differ from the known and common entomopathogenic microorganisms.[49-58]

The bacteria Bt is entomopathogenic, and produces Bt toxins. When insects ingest Bt toxins, the following sequence of events occurs: Binding of the toxins to the midgut receptors, a pore-forming process is triggered, disruption of the intestinal barrier functions and finally infestation leading to the death of insects. A similar mechanism is confirmed in mosquito and blackfly control with *Lysinibacillus sphaericus* (formally *Bacillus sphaericus*) active agent. In this example, the complementary biosynthesis of crystal proteins (BinA and B) and Mtx (mosquitocidal toxin) act as the insecticidal toxins (Ruiu, 2018). In the instances of fungal infection, the host cuticle serves as a point of contact to fungi, and when the environmental conditions are favorable, fungal spores, and conidia germinate. The enzymatic and mechanical actions enhance the penetration of the fungi into the host body. As a result these, the mycelia develop internally giving rise to different types of spores, conidia, metabolites, toxins, and virulence factors (Ruiu, 2018). Baculoviruses exert their effects via the production of crystalline occlusion bodies, possessing infectious particles, in the host cell. Once contaminated food is ingested, the occlusion bodies within the midgut release virions (occlusion derived viruses) affecting the membranes of microvillar epithelial cells through the action of their envelope proteins (Townsend *et al*., 2010). The cadaver of the affected insects liquefies thereby dispersing the virus particle in the environment.

Biochemical bio-pesticide

Biochemical bio-pesticides are substances of natural origin with active agents to control pests by mechanisms that are not toxic to the host, the environment and humans (Kumar, 2012; Leahy *et al*., 2014). Based on this, a natural chemical can be considered a biopesticide if it acts as an attractant, deterrents repellant, antifeedant, suffocant, confusants, arrestants, and desiccant as well (Stankovic *et al*., 2020). Being natural implies that such chemicals would be discrete or mixed bioactive substances from nature. However, a synthetic analogue that is identical to a natural compound, both structurally and functionally exhibits the same mode of action (MOA). Certain factors have made some synthetic analogues of naturally occurring substances to dominate the commercial market (Dang *et al*., 2016). Although toxicity is a subjective term, a substance could be said to be nontoxic if direct lethality of the target host does not arise as a result of the chemical or biological interference of the substance active ingredients with the physiology of the target pest. This definition does not guarantee the absence of ill-fated biochemical and metabolic reactions in the target pest organism by the presumed nontoxic substance. Instead, the initiation of such ill-fated reactions is linked to one or more physical processes attributable to the substance. For instance, essential oil causes asphyxia (a physical process) which obstructs pest respiration leading to death. A substance still merits the nontoxic status if its active ingredients invoke biochemical reactions that interfere with the behavior or reproductive system of the target pests without resulting in death. A substance is environmentally safe if it is exogenous to that environment and has no impact on the physicochemical signature of the environment or affects the ecological services provided by that environment causes no distortion or harm to ecological receptors including wildlife and humans. Chemicals that pass these criteria of naturalness, nontoxicity and eco-friendliness are semiochemicals (pheromones and allelochemicals), essential oil (from neem and sour orange), insect growth regulators (juvenile hormones and chitin synthesis inhibitors), plant growth-promoting regulators (Rhizobacteria), and natural minerals (diatomaceous earth and kaoline). The semiochemical MoA is concerned with the disruption of hormones and neuropeptides associated with metamorphosis and insects' growth. The MoA of mineral-based insecticides (kaoline, insecticide soaps, and diatomaceous earth) is mostly physical. The abrasive nature and sorption properties of diatomaceous earth and the waxy layer of insects are damaged giving way for desiccation and eventual death (Nukenine *et al*., 2010; Sousa *et al*., 2013). Similarly, kaoline exerts its insecticidal effect through its sorption property, which causes desiccation in insects. Besides, surface activity, the coating property of kaoline can cause reduced sublethal effects, repellence, and oviposition deterrence. The MOA of insecticidal soap is expressed through cuticle dissolution leading to suffocation and desiccation. Bioactive compounds in botanical extracts can cause inhibition of hyphal growth, structural modifications of mycelia, changes in the cell wall, partitioning of cell membranes, and separation of the cytoplasmic membrane in entomopathogenic fungi (Lengai and Muthomi, 2018). Plant extracts apart from inducing behavioral changes (as it concerns feeding habit, oviposition, and mating behavior) in insect pests also inhibit insect reproduction, growth and development. Essential oils act as antifeedants, repellants, and oviposition deterrents. Besides, they possess active ingredients that make them larvicidal, ovicidal, and insecticidal thereby displaying properties that interfere in all stages of insect metamorphosis (Sarma *et al*., 2019). The MoA of semiochemicals acts by inhibiting lipid biosynthesis resulting in a significant decrease in total lipids in immature insects (Linda *et al*., 2010), disruption and prevention of metamorphosis caused by the binding of juvenile hormone analogues to the receptor of juvenile hormone in insects (Jindra and Bittova, 2020), and inhibition of molting and chitin synthesis which determines growth and development of insects (Ullah *et al*., 2019).[59-64]

PIP

A PIP is a biopesticide generated by a gene inserted into a plant through transgenesis (Ibrahim and Shawer, 2014). It does not require killing the pest but keeps the plant unsuitable for an attack. In some cases, the protected plant may act as a repellant or disrupt the normal physiology of the insect pests when insects ingest PIPs. Once it is ingested it overcomes the digestive and physical barriers and then gets to the target site where it acts. The digestive system has been confirmed as a strong determinant of insect vulnerability and susceptibility therefore, gut function disruption has been a common theme in the development and discovery of PIPs (Nelson and Alves, 2014).

Insecticidal proteins, especially Bt, are suitable for application in PIPs and are thus being explored in pest control (Koch *et al.*, 2015). The insecticidal property of Bt was first discovered in 1902 against silkworm (*Bombyx mori*) and from then the search for Bt strains as an insect control agent has continued (Jisha *et al.*, 2013). The insecticidal proteins from *Bt* are effective, diverse, and specific thus they are widely used as a model in PIP biotechnology. According to the findings of Schwnek *et al*., (2020) *Bt* has demonstrated non-negligible pathogenic potentials. The insecticidal crystal protein produced by *Bt* is known as Cry proteins, they are diverse and therefore exhibit insect selectivity. For example, there are those that are selective for *Lepidoptera*, *Coleoptera,* and those for *Diptera* (Maciel *et al*., 2014). At present, not <70 classes (based on sequence homologies and target selectivity) of Cry proteins have been used to protect corn, cotton, potato, soybean, and other crops (Pardo-Lopez *et al*., 2013). Cry proteins are toxins produced during the sporulation period but toxins produced during the vegetative phase are called vegetative insecticidal proteins (Vips) and are commonly used in PIPs.

Acoording to Shingote *et al*. (2013), Chakroun *et al*., (2016) and Sopko, Narvaand Bowling. (2019), more than 50 Vips proteins, including Vips 1, Vips 2, and Vips 3, have been reported to be effective in plant protection. Other insecticidal proteins from other bacteria proved to be effective in transgenic control are toxic complex (Tc) proteins expressed by Photprhabdus and Xenorhabdus. Furthermore, plants possess transgenic enzyme inhibitors that have been explored in PIP technology, such as αamylase inhibitors (Franco *et al*., 2002). Mir1-CP protease from maize, enhancing protease from *Baculovirus* and also indicated potency in protecting plants through the PIP technology (Mohan *et al*., 2006; Wei *et al*., 2018). Besides, double stranded ribonucleic acids (dsRNAs) are commonly used as approved PIPs due to the rapid progress in ascertaining RNAi biological processes (Liu *et al*., 2020). The dsRNA triggers host-induced gene silencing and protein synthesis inhibition which improves endogenous gene expression in plants while bringing about pest mortality within the plants (Parker and Sander, 2017; Raruang *et al*., 2020).

The *Bt* MOA could be interpreted as the correlation of the Cry protein ingestion and insect susceptibility. Immediately the Cry protein reaches the mid gut after ingestion, it attacks the "brush border" epithelium with the attendant manifestation of feeding cessation with the right concentration of the toxin. At this point, ATPases that concerned with active transport, become inhibited, followed by modulation of endogenous potassium channels and pore formation that occasionally leads to uncontrolled ionic flux, the collapse of normal cellular function and death (Lee, Walters and Hart 2003; Knaak *et al.*, 2010). However, the Cry proteins exist in different classes and structures with structure-dependent toxicities specific to particular insect orders. For example, Cry 3 and Cry 1 proteins are toxic to *Coleoptera* and *Lepidoptera* respectively (Chakroun *et al*., 2016).

POTENTIALS OF BIO-PESTICIDES AND ECONOMIC IMPORTANCE OF INSECT-PESTS

Bio-pesticides can make important contribution to sustainable agriculture and help reduce reliance on chemical pesticides. Microbial insecticide such as Bt produces a proteinic toxin which induces paralysis of the midgut and brings about cessation in feeding after being ingested by insect pests. Other promising candidates are *Beauveria bassiana* and *M. anisopliae*. The spores penetrate the host cuticle, once inside the body, producing toxic metabolites called beauvericin (*B. bassiana*) and destruxins (*M. anisopliae*) responsible for death of the insects. Baculoviruses (Nuclear Polyhedrosis Virus and Granulosis Virus) are safe to human beings and wildlife, their specificity is very narrow. They do not infect beneficial insects and have capacity to persist in the environment, making them very suitable for use in sustainable agriculture. Semiochemicals such as attractants and pheromones, and botanicals are important sources of agrochemicals used for the management of insect pests. They degrade rapidly and therefore, are considered safer than chemical pesticides to the environment (Ansar *et al*., 2011).

At present, great emphasis is given on organically produced food, conservation of biodiversity, environment protection, and sustainable agriculture. Bio-pesticides and bio-control agents are the tools to meet to these challenges. These are the renewable alternative to conventional pesticides. Bio-pesticides are beneficial in view of their less toxicity, ecosafety, specificity, reduced number of application, no resistance in pests, increased yields and quality and higher value of produce for exports and suitability for rural masses. It takes care of losses of crops, losses of exports, losses of man hours and lives and losses of beneficial, natural parasites and predators. When used as a component of IPM, efficacy of bio-pesticides can be equal to the conventional pesticides, especially for crops such as fruits, vegetables, nuts, and flowers. By combining performance and environmental safety, bio-pesticides perform effectively with the flexibility of minimum application restrictions, and superior resistance management potential (Dhakal and Singh, 2019).

Insect-pests cause huge global losses to crops. However, more than 180 host plants including cotton and chickpea are attacked by cotton bollworm (*Helicoverpa armigera*) with an economic loss of \$2 billion on an annual basis (Tay *et al*., 2013) while onion thrips (*Trips tabaci*) ranked top as the most important pest of onion (Negash *et al*., 2020) and other plant hosts. Research has showed that more than 500 host plants belonging to 60 plant families suffer pestilent attack from tobacco whitefly (*Bemisia tabaci*) along with the potential of reducing crop yield up to 50% (Gangwar and Gangwar, 2018). Above 200 plants, including tomato and common bean are destroyed by *Tetranychus urticae* commonly known as the two-spotted spider mite which has resulted in a control cost of \$400 million/year (Litskas *et al*., 2019). An annual budget of between \$4 and \$5 billion has been estimated to cover weekly insecticide application and yield lost to the insecticide-resistant diamondback moth (Zalucki *et al.*, 2012) which destroys more than 15 genera of plants (Willis, 2017), including Brassica (cabbage).

More so, *Spodoptera litura*, commonly known as taro caterpillar, has been reported to cause 0.85 million tonnes of loss per year in an arable field of 1.46 million hectares planted with soybean and cotton (Sharma *et al.*, 2019). The polyphagous *S. litura* covers more than 120 species of plants as a pest (Bragard *et al*., 2019). The red flour beetle, a well-known secondary pest, feeds on stored food products such as dry fruits, cereals and cocoa beans. *Myzus persicae*, the green peach aphid, is a resistant global pest and virus vector that feeds on more than 400 plant species and their hosts are mostly essential crops such as oilseed rape, potato and tomato. They have the potential to reduce yield up to 30% in unprotected farmland (Silva *et al.*, 2019; Alyokhin *et al*., 2020).

A research carried out in 12 African countries indicated that in a year, losses incurred from maize cultivation and harvesting reach up to 4.1 to 17.7 million tons following an infestation of the fall armyworm *Spdoptera frugiperda* (Kassie *et al*., 2020). *S. frugiperda* is an invasive pest and can affect many crop types, especially maize and cotton (De Groote *et al.*, 2020; Willis, 2017). Thrips (*Frankliniella occidentalis*), Mediterranean fruit fly (*Ceratitis capitate*), and codling moth (*Cydia pomonell*) attack pepper, citrus, and apple, respectively, with substantial damage done to more than 177 plant genera (Abdullah *et al*., 2015; Willis, 2017). The cowpea weevil is a pest that feeds on stored cowpea and legumes in the tropics with 10–50% storage loss (Tiroesele *et al.*, 2015; Sanon *et al.*, 2018). The infestation of cotton, maize, and other plant species by the noctuid moth of the cotton leafworm (*Spodotera littoralis*) wildly occurs in Africa and Europe, thereby posing a threat to food security. Alfalfa and pea have been extensively attacked by *Acyrthosiphon pisum* (pea aphid). Citrus are attacked by the Asian citrus psyllid (*Dtaphorina citri*) and tomato leafminer (*Tuta absoluta*). Apart from the preference for the specific plants previously stated, these last three pestilent species have also affected more than 46 plant genera (Willis, 2017; Calevro *et al.*, 2019; Biondi and Desneux, 2019).

BIO-PESTICIDES AS AN INNOVATION FOR AGRICULTURAL SUSTAINABILITY IN THE DEVELOPING COUNTRIES

Starting from the middle of 19th century to the present time, synthetic pesticides have been an agent for controlling the pests. There is no doubt that they have been promising agent for pest control but within more than seven decades of their use, the synthetic pesticides have so thoroughly been distributed throughout the world, in fact they occur virtually everywhere. The land which used to be productive 50 years back is now showing declining yield. According to latest revision of the UN population prospects, the world population is projected to grow by 34 percent from 6.8 billion today to 9.1 billion in 2050. To feed this increasing population is a great challenge, especially when the productivity of land is declining day-by-day. Environmental pollution by agrochemical residues is increasing and eroding the natural resource base. Sustainability must be maintained in production system to feed the burgeoning population of the word. Sustainable agriculture systems are those which are economically viable and meet society's need for safe and nutritious food while maintaining or enhancing natural resources and the quality of the environment for future generation. It aims at producing food that is both nutritious and safe to human health. Since, all of the materials are of natural or biological origin, it is very safe to use bio-pesticides as potential source of pest control in sustainable agriculture (Dhakal and Singh, 2019). Therefore, agriculture that is directed to achieve economic viability, environmental objectives and social acceptability can be regarded as sustainable agriculture.

Sustainable agriculture is directly or indirectly connected to all the various variants of sustainable development, including the 17 SDGs and Green Chemistry (Perlatti *et al*., 2014; Ganasen and Velaichamy, 2016; Saleh and Koller, 2018). Green Chemistry (processing, synthesis and use of innocuous chemicals) directly connects sustainable agriculture and the SDGs in eight areas based on the consumption of possible renewable chemicals and the associated green technologies. These eight goals are SDG15, SDG14, SDG12, and SDG6 (concerned with the environmental conservation and restoration which mostly require organic materials), SDG7 and SDG9 (concerned with green energy and technology, respectively), and SDG1 and SDG2 (concerned with improving agro outputs, which thus require bio-fertilizers and bio-pesticides). Bio-pesticides are naturally occurring organisms and substances derived from plants and natural inorganic compounds that can control pests' populations by different mechanisms of action (Tijjani *et al.*, 2016), excluding those that interfere with the nervous system of pests (Marrone, 2019). Bio-pesticides are of three categories: microbial bio-pesticides (microorganisms and their products that have pest controlling influences or compounds), biochemical bio-pesticides (natural substances with an active agent that control pests by non-toxic mechanisms) and plant incorporated protectants (transgenic plants) (Kumar, 2012; Ibrahim and Shawer, 2014; Leahy *et al*., 2014). These bio-based pesticides exert their effects through different modes of action and they are classified into five groups: Metabolic poison, growth regulators, gut disruptors, neuromuscular toxins, and non-specific multi-site inhibitors (Spark and Nauen, 2015). Moreover, in most cases, bio-pesticides have multiple modes of action against targeted pests making it difficult for the pest to develop resistance as is common with synthetic pesticides (Hassan and Gokce, 2014). Due to their eco-friendliness and low toxicity properties, they do not harm not-targeted organisms including humans and the environment. They are also specific, easily biodegradable, pose no post-harvest contamination problem, as well as suitable in an IPM system. The effectiveness of bio-pesticides is made pronounced in IPM. IPM is a multifaceted approach that combines all suitable control methods, including cultural practices into one management portfolio (James *et al*., 2010; Barzman *et al*., 2015). IPM implementation aims to obtain the best result at the lowest cost while maintaining environmental safety. Many authors and mechanized farmers have indicated that bio-pesticide-driven IPM is a prerequisite for sustainable agriculture provided that awareness and skills associated with the IPM are given at the right of place and time. (Emmanuel *et al.*, 2020)

CONCLUSION

At present, great emphasis is given on organically produced food, conservation of biodiversity, environment protection, and sustainable agriculture. Bio-pesticides and bio-control agents are the tools to meet these challenges. Because, these are the renewable alternative to conventional pesticides. Bio-pesticides are beneficial in view of their less toxicity, ecosafety, no resistance in pests, increased yields, and quality as well as higher value of produce for exports and suitability for rural masses. It takes care of losses of crops, losses of exports, losses of man hours and lives and losses of beneficial, natural parasites and predators. When used as a component of IPM, efficacy of bio-pesticides can be equal to the conventional pesticides, especially for crops such as fruits, vegetables, nuts, and flowers. By combining performance and environmental safety, bio-pesticides perform effectively with the flexibility of minimum application restrictions, and superior resistance management potential. In view of these, this paper used analytical approach to review the followings: Bio-pesticide as a concept, potentials of bio-pesticides, categories of bio-pesticides, and agricultural sustainability as regard to bio-pesticides.

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