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In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils

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ABSTRACT

The sustainability of crop production in Nigeria with much population increase and critical environmental challenges is very problematic. Intense rainfall and high temperature experienced in the area create good condition for various type of pathogens and pest to thrive and cause different kinds of diseases to crop plants. Thus, limiting production period for most crops in the area. Synthetic or chemical pesticides used to confront these disease problems have been found to have pronounced negative effect on human health, natural enemies, environmental and ecosystem balance. Some of the active ingredients of synthetic pesticides have been found to be carcinogenic, thus a threat to human life. While increased use of the synthetic pesticides have been found to cause disappearance of bees and some other useful insects responsible for pollination. Biopesticides offer better alternative to synthetic pesticides due to their low toxicity, biodegradability and very low persistence in the environment. They are readily available and inexpensive, unlike the synthetic that has not been sustainable at the farmer's level. Increased awareness of the public on the dangers pose by synthetic pesticides on the soil, safety and quality of food have hastened the use of biopesticides in agricultural production. This is very important for increased food production to checkmate the population increase as well as income generation and delivery of healthier food to the public.

INTRODUCTION

The sustainability of agricultural activities in Nigeria is herculean task as it faces a lot of challenges; the soils are fragile and prone to erosion and land degradation problems, population explosion that put pressure on available land that today some of the suitable land for crop production now play home to residential building, industries or even roads. Intense rainfall and temperature that have created different scenario or situation in soil such as soil infertility, multiple nutrient deficiency, low soil biodiversity, moisture stress, disease organism, disease and pest

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infestation, toxic substances ecological imbalance etc. While inputs such as improved seeds and cultivars, synthetic pesticides, chemical fertilizer and other synthetic chemicals to confront these challenges are not within the reach of poor resource farmers that form the bulk of crop and food producers in Nigeria. Thus, the inputs whether in form of improved seeds and cultivars or synthetic chemicals has never been sustainable at the farmers level in Nigeria. In the works of Nweke, (2018ab) and Nweke, (2020abc) different ideas and solutions were proffered on how to meet up with most of the above challenges facing crop production in Nigeria using indigenous cultural practices. This particular paper again will try to x-ray the need for the farmers to anchor their knowledge, energy and resources to the use of our indigenous biopesticides for increased healthy growth of crops, yield and healthy food delivery to the populace. This is very important knowing fully well that most of these disease-causing agents and pest inhabit the soil, hence making them more difficult to control. Nematode for example inhabit the soil from where it attacks the underground part of the plant host making nutrient absorption, water uptake and all that dissolve therein impossible leading to the death of the plant. Pests and pathogens are capable of causing monumental damage to a wide range of crops, vegetables, cereals, grains, roots and tubers, flowers etc., making a farmer to be under penury. Sikora and Fernandez (2005) found out that in tropical and sub-tropical agriculture nematode cause great losses in vegetable crops. Maize one of the major crops cultivated across the globe is susceptible to a lot of diseases and pests causing great yield decline and nightmare to the farmers. According to Flet et al. (1996) maize crop is attacked by nematode causing root-knot disease, viral disease such as streak and dwarf mosaic, cob and tassel fungal diseases, bacteria diseases like stalk rot and leaf streak and insect pest species such as aphids, leafhoppers, stalk borers, beetles, boll worms and weevils. Another important crop like cowpea have been noted by Adipola et al. (1999) and Edema (1995) to be attacked by virus disease like anthracnose (rust virus) and scab, bacteria disease like blight and insect pest such as aphids, thrips, pod borers and foliage beetle.

The use of synthetic chemical in the control of plant diseases is still a common practice in Nigeria and other developing countries and even to some extent developed countries. The only different is that in developed countries there is strict compliance to the type of synthetic chemicals that could be used for crop production. And even in sale of the farm produce a tag is placed on the produce to denote chemically produced or organically produced. In this situation the buyer is left with a choice on which product to buy. This is not obtainable in Nigeria and Africa at large. Although with the application of chemicals such as pesticides, fungicides, bactericides, nematicides etc., plant diseases can be controlled but the hazardous impacts of such products in human health and ecosystem are well known. With their excessive applications pest resistance may exist. Chemical control of most pests and plant diseases may be available and could extensively reduce the impact of plant diseases, but field application of synthetic chemicals may not always be desirable. Gill et al. (2012) opined that the mysterious or sudden disappearance of bees and some other insects important in pollination of flowers of agricultural crops was due to increased use of chemical pesticides. While global decline in frog population as noted by Bruhl et al. (2013) may be associated with intensified use of pesticides. Elyous et al (2010) in their studies observed that ground and surface water are contaminated, the ecosystem balance existing between soil-plant-microorganisms are very much disturbed with repeated application of

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various synthetic chemicals under intensive agricultural activities or production. There has been a global awareness that excessive and improper use of chemicals is hazardous to the health of humans, animal,sthe and environment, there an extensive research for environmentally safe and easily biodegradable, biopesticides becthe omes best alternative. According to Gnanamanickam et al. (2002), biopesticides are natural in origin and have minimum adverse effect on the physiological processes of plants and are easily convertible into common eco-friendly organic materials. For the following authors, Radhakrishnan (2010), Akpheokhai et al. (2012) and Faye et al. (2012), are economical, biodegradable and biorenewable resources. Biocontrol is best option for disease and pest control in crop production and to cope with the dangers and losses at chemical control. Biopesticides can be derived or harnessed from microorganisms, plant parts or extracts and animals for pest and disease control. Radhakrishnan (2010) and Pendseet al. (2013) found biopesticides to be environmentally safe and ecologically feasible option for plant protection with great potential for promoting sustainable agriculture. Plant extract, essential oils, gums, resins etc. have been shown to exert biological activity against plant fungal pathogens in vitro and can be used as biofungicidal products (Fawzi et al., 2009; Jalili et al., 2010; Romanazzi et al., 2012). These products according to Chuange et al. (2007) are generally assumed to be more acceptable and less hazardous for the ecosystems and could be used as alternative remedies for treatment of plant diseases. Muthomi et al. (2017) found significant effective reduction against *Alternaria solani*; *Phythium ultinum*, *Rhzoctonia solani* and *Fusarium oxysporum* f. sp. Lycopersici *in vitro* study involving ethanolic plant extract of turmeric (*Curcuma longa*), lemon (*Citrus limon*), garlic (*Allium sativum*), pepper (*Capsicum frutescens*) and ginger (*Zimgibar offcinals*) while turmeric was reported by the authors to be the most effective with a growth inhibition of up to 73% against *Alternaria solani*. In a study conducted at Igabariam southeast, Nigeria Chime et al. (2019ab) observed an increased plant biomass of Indian spinach infected with root knot nematode in soils treated with ginger rhizome extract and pawpaw leaf. Their study showed the potential of ginger extract and pawpaw leaf as biopesticides against root knot nematode that normally attack the Indian spinach at early stage of growth in the study area. Faye et al. (2012) using plant extract and Elyous et al. (2010) using plant extract and *Pseudomonas* spp. found significant reduction in root knot nematode in tomato production. While Pascual et al. (2002) observed suppression of *Pythium ultimum* in crop plant in soils treated with municipal waste compost and its humic fraction. The biopesticides were able to affect these reductions because of their ability to stimulate the defence mechanism of the plant and their physiological processes that make treated crops more resistant to the diseases and pests. Another important aspect of these natural biopesticides especially those applied inform of compost is that they improved the physicochemical and biological properties of the soil as can be found in the works of Randhawa et al. (2001), Pascual et al. (2002), Elyous et al. (2010), and Chime et al. (2019ab).

Biopesticides offer better alternative to synthetic pesticides due to their low toxicity, biodegradability and low persistence in the environment. The base materials for biopesticides are readily available and inexpensive. Data on toxicity levels, chemistry, active compounds and their compatibility with other methods of pests and disease management is needed to aid in formulation and commercialization. Globally, researchers have conducted studies on effectiveness of natural plant protection

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products with significant results. There are also studies on effectiveness of biopesticides under controlled environments and field conditions with varying results. Further research is recommended to close the gaps in formulation of biopesticides. The present study, therefore aims to review and highlight on the following;

i) the various sources of biopesticides.
ii) their various active compounds or ingredients.
iii) their components mode of action on targeted pests.
iv) roles of biopesticides in sustainable agricultural production.

MATERIALS AND METHODS

Materials used for this study were the various work done in the area of synthetic pesticides, biopesticides, bioheat, anaerobic fermentation etc. These are published journal papers, books, seminar papers and student thesis and personal experience gathered. All were reviewed, discussed and conclusion drawn from the results of the various practices.

Synthetic chemicals and biopesticides at a glance

There are harmful effects associated with the use of synthetic pesticides such as toxicity and poisoning (Damalas, et al., 2015). Synthetic pesticides also lead to environmental pollution due to the non-biodegradable nature of their constituent compounds (Kekuda, et al., 2016. According to Parliman, (2001), degradation of metham sodium and other fumigants was reported to last up to over six months after application. In a report by PAN (2011), metham sodium pollutes the air and soil thereby affecting the population of natural enemies in the soil. Methyl bromide has been banned from agricultural use due to its negative impact on the environment. It is associated with depletion of ozone layer which contributes significantly to climate change (Morrissey, 2006). The constituent compounds of chemical pesticides contaminate soils rendering them unsuitable for crop production (Kumari, et al., 2014). They also pollute surface and ground water, killing aqua life after inhalation and consumption (Maksymiv, 2015). Use of dichloro diphenyl trichloroethane (DDT) for instance led to poisoning of birds, marine species and humans. It has been reported to have carcinogenic properties leading to its ban from agricultural use (Harada, et al., 2016). After application, the active compounds of the synthetic pesticides are taken up and retained by crops. Consumption of such crops poses chronic health problems to humans due to the accumulated toxic chemical residues (Jantasorn, et al., 2016). Exposure to pesticides adversely affects the human population, directly or indirectly. For example, pesticides containing Malathion and Trichlorfon have been reported to cause reproductive complications in humans (Ghorab, et al., 2015). Exposure to some pesticides have also been reported to retard growth, induce chemical and structural changes in body organs as well as disturb immune responses. They also reduce resistance of animals to disease-causing pathogen infections (Maksymiv, 2015). Continuous exposure to pesticides such as chloropyrifos cause gene mutations, genetic damages, reproductive health problems and chronic diseases such as asthma, hypertension and cancer (Dey, et al., 2016; Alavanja, et al., 2015). Use of synthetic chemicals has raised numerous concerns due to their negative effects on the environmental, human health, natural enemies and ecosystem balance. Some of the active ingredients of synthetic pesticides have been found to be carcinogenic thus posing a threat to human life.

Biopesticides are products and by-products of naturally occurring substances such as insects, nematodes, microorganisms, plants as well as semiochemicals (Gasic and Tavonic, 2008). Based on the nature and

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origin of the active ingredients, biopesticides 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 biopesticides due to the high components of bioactive compounds and antimicrobial agents (Nefzi, et al., 2016*)*. The active compounds in plants include phenols, quinones, alkaloids, steroids, terpenes, alcohols and saponins (Mizubuti, et al., 2007). Different plant families have varied antimicrobial bioactive compounds which include oil components such as α- and β-phillandrene, limonene, camphor, linalool, and β-caryophyellene and linalyl acetate depending on the plant family (Ali, et al., 2017; Vidyasagar et al., 2013). Microbial biopesticides include bacteria species such as *Pseudomonas, Bacillus*, *Xanthomonas, Rahnella* and *Serratia* or fungi such as *Trichoderma, Verticillium* and *Beauveria* species according to Kachhawa (2017). Biopesticides exhibit different modes of action against pathogens such as hyperparasitism, competition, lysis and predation according to Souza et al. (2007).

Plant growth promoting rhizobacteria protect plants from biotic and abiotic stresses and they also enhance plant growth and enhance formation of root hairs (Souza, et al., 2015). The most common species of plant growth promoting rhizobacteria include Agrobacterium, *Ensifer*, Microbacterium, *Bacillus, Rhizobium, Pseudomonas*, Chryseobacteria and Rhodococcus (Abbamondi, et al., 2016). They colonize the environment around the plant roots, fix nitrogen, increase phosphate solubilisation and plant yield (Compant, et al*.,* 2009). Species of Pseudomonas and Bacillus have been used as biofertilizers with reports showing increase in plant growth, yield and phosphorous and zinc content in fruits and soils (Esitken, et al.*,* 2009). Natural enemies including predators, pathogens and some insects are also used as biopesticides in management of insect pests. Parasitoids, wasps, beetles, lace wings, bugs and lady birds are used in management of destructive pests such as boll worms (*Helicoverpa armigera*) in important crops such as cotton (Knutson, et al., 2015; Wu, et al., 2005). Compost teas are filtrates of compost extracts and are similarly used as biopesticides (Ghorbani, et al., 2005).

Limitations and Challenges in the Use of Conventional Pesticides

Continuous use of synthetic pesticides leads to development of resistant plant pathogen strains leading to their resurgence. Farmers apply more chemicals in an effort to eradicate such pests (Birech, et al., 2006) (Halimatunsadiah, et al., 2016). In the process of managing target pests, synthetic pesticides kill non-target beneficial organisms such as pollinators, predators and antagonists thereby disrupting biodiversity (Prasad, et al., 2010; Ndakidemi, et al., 2016). In a study by Xavier, et al., (2016), application of Fenpyroximate on chilli peppers (*Capsicum annum L*) resulted in retention of its residues even after sun drying and processing. Similarly, spinosad (spinosyn A and spinosyn D), Indoxacarb and Deltamethrin containing insecticides used to control *Rhizoctonia dominica, Sitophilus oryzae* and *Trogoderma granarium* were found to be persistent for up to 120 days after application (Pandey, et al., 2016).

The horticulture sector in many developing countries has been particularly adversely affected by the use of synthetic pesticides. The European Union (EU) set out strict regulations regarding levels of pesticide residues and safety of agricultural produce exported to their markets. The use of pesticides containing Dimethoate on vegetables was banned by EU. Failure to comply with this regulation led to rejection and destruction of fresh vegetable consignments containing chemical residues

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above the required limits (Business Daily 2014). Residues of the restricted chemicals should not exceed 0.02 parts per million (ppm) in a sample of vegetables. The percentage of inspection was increased to 10% on fresh produce at ports of entry into the European Union (Business Daily 2013). According to European Commission (2012), Maximum Residue Levels (MRLs) of unknown pesticides should not exceed 0.01 mg/kg and there was imposed a 10% sampling per consignment in fresh beans and pods. Interceptions of fresh produce almost ruined Kenya's export market reputation due to presence of traces of banned pesticides (Business Daily 2014). Following the guidelines made by the EU and the losses incurred due to rejection and destruction of fresh vegetable consignments, there was a reduction in volumes of horticultural exports. This negatively affected the livelihoods of small holder farmers who are the major producers of vegetable crops (Daily Nation 2014). This led to introduction of a cloud-based traceability system which uses a quick reference (QR) code and GPS coordinates to pinpoint the individual farmer whose consignment fails to comply with regulations (Daily Nation, 2016). This has resulted in increase of the cost of production and several farmers opted out of the export business.

Sources of biopesticides and their effect on causative agents

Biopesticides of botanical origin: Based on the method of extraction, botanical pesticides can either be plant extracts or essential oils (Vidyasagar, et al., 2013). They are obtained from plants parts such as leaves, barks, flowers, roots, rhizomes, bulbs, seeds, cloves or fruits which are either fresh or dried. Dried plant parts are preferred as this reduces water concentration resulting in higher yield of active ingredient (Chougule, et al., 2016). A Gas Chromatography-Mass Spectrometry (GC-MS) analysis was carried out on Citrus *sinensis* and d-limonene and myrcene were reported as the major constituents of the oil component. The products were tested against a cereal leaf beetle (*Oulema melanopus*) on wheat and a mortality of up to 85% was reported on larvae observed in 48 hours (Zarubova, et al., 2014). Aqueous fruit extracts of *Withania somnifera* were tested for activity against *Fusarium oxysporum F.SP. radicis-lycopersici*, the causal agent of fusarium crown and root rot disease in tomatoes. According to Nefzi, et al. (2016) at a concentration of 2% the extracts inhibited growth of the fungal pathogen by up to 56%. In vitro experiment involving ethanolic plant extracts, turmeric (*Curcuma longa*), lemon (*Citrus limon*), garlic (*Allium sativum*), pepper (*Capsicum frutescens*) and ginger (*Zingiber officinale*) were reported to be significantly effective against *Alternaria solani, Pythium ultimum, Rhizoctonia solani and Fusarium oxysporum f.sp. lycopersici* (Muthomi et al., 2017). Turmeric (*Curcuma longa*) was reported to be the most effective with a growth inhibition of up to 73% against *Alternaria solani. Pseudomonas syringae p.v*. tomato was effectively managed in vitro by *Rhus coriaria, Eucalyptus globulus* and *Rosmarinus officinalis* (Bastas, 2015). *Eucalyptus globulus* was reported to be efficacious in preventing the bacterial speck of tomato (*Pseudominas syringae p.v.*) by up to 65% under greenhouse conditions. At 5% concentration, a mortality rate of up to 78% was reported on juveniles of root knot nematodes (*Meloidogyne sp*) by extracts of *Nerium oleander*. When the concentration was increased to 10% a mortality of between 65% - 100% was observed on second stage juveniles treated with extracts of *Eucalyptus sp, Cinnamomum verum, Nerium oleander, Azadirachta indica, Zingiber officinale* and *Allium sativum* (Salim, et al., 2016). The most common and already commercialized botanical pesticides are derived from neem (*Azadirachta indica*), pyrethrum (*Chrysanthemum cinerariifolium*), sabadilla

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(*Schoenocaulon officinale*), and tobacco (*Nicotiana tabacum*) (Dar, et al., 2014).

The quality of extracts and oils is highly dependent on the solvent used and method of extraction (Odhiambo, et al., 2011). The solvents should be of low toxicity, able to dissolve as many compounds as possible, evaporate easily at low temperatures should preferably possess preservative properties (Javaid, et al., 2014). The choice of solvent is dictated by the target active compounds. Although water is the universal solvent, it extracts fewer antimicrobial compounds compared to other solvents (Bandor, et al., 2013). Organic solvents such as ethanol and methanol yield better extracts and their results are consistent. Other extraction solvents include dichlomethane, acetone, and hexane (Mahlo, et al., 2013). According to a study by Wetungu et al. (2014), methanol and hexane extracts from *Tarchonanthus camphoratus* gave higher growth inhibition capacity against *Escherichia coli, Salmonella typhi, Staphylocccus aureus, Proteus mirabilis, Candida albicans,* and *Klebsiella pneumoniae*. Methanol was also reported to be efficient in extracting seed components of *Morinda citrofolia* and the extracts showed antibacterial activity of up to 63% against *Escherichia coli* and *Pseudomonas* spp. (Sunder, et al., 2011). The differences among the different solvents are attributed to their polarity (Ahmad, et al*.,* 2009). The plant parts from which the extracts are obtained also influence the quality of the extracts.

Microorganisms as a source of biopesticides:

Microorganism-based biocontrol agents form the bulk of commercialized biopesticides and they include bacteria, viruses, fungi, nematodes, and protozoa **(**Koul, 2011). There are up to 175 reported microbial-based biopesticide active agents and they have been used in the management of pathogens, weeds, insects, and nematodes (Singh, 2014). The majority of the microbial biopesticides are used to manage soil-borne pathogens (Vinale, et al., 2008). Bacterial species that have been utilized as biopesticides include *Bacillus, Pseudomonas, Burkholderia, Xanthomonas, Enterobacter, Streptomyces, Serratia* and these are either obligate facultative or crystalliferous. Fungi used as biopesticides include species of *Trichoderma, Beauveria, Metarhizium, Paecilomyces, Fusarium, Pythium, Penicillim,* and *Verticillium. Steinernama* and *Heterarhabditis* are nematode species used to make biopesticides (Kachhawa, 2017). The mechanisms of action exhibited by microorganisms against plant pathogens include hyperparasitism, competition, and secretion of volatile compounds, antibiosis, and parasitism (Suprapta, 2012). According to Song, et al., (2012), the major source of microorganisms with pesticide activity on agricultural fields is where they co-exist with other microorganisms including pathogens and beneficial species. The rhizosphere is usually concentrated with various classes of important microorganisms. Other rich sources of microorganisms include hay, manure, cowshed, as well as straw (Beric, et al., 2012). Formulation of the microbial pesticides has a great contribution to the effectiveness of the resultant product and it is usually dependent on the substrate used. A study done by Adan et al. (2015) showed that a formulation of *Trichoderma harzianum* prepared in black gram bran, peat soil and water had a high level of activity against damping-off of eggplant seedlings caused by *Sclerotium rolfsii*. The activity was attributed to the high number of spores produced by the fungus.

According to Prasad and Syed (2010), exposure of *Helicoverpa armigera* to conidial suspension of *Beauveria bassiana* resulted in antifeeding habits, blackening of the body, and the larvae becoming sluggish and morbid. The fungus finally consumes the entire larval tissue resulting in its death. Beric

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et al., (2012) reported that isolates of Bacillus showed antagonistic activity against rice pathogen, *Xanthomonas oryzae P.V. oryzae*, and the activity was attributed to the production of a bacteriocin by the bacterium. Treatment of wheat and rice plants with concentrations of *Chaetomium globosum* reduced the severity of wheat rust (*Puccinia recondite*) and rice blast (*Magnaporthe grisea*) by up to 80% (Park, et al., 2005). Late blight (*Phytophthora infestans*) on tomatoes was also controlled by *Chaetomium globosum* by up to 50% while mycelial growth of Pythium ultimum was inhibited in vitro in well diffusion assays. The activity of the fungus was attributed to the production of two types of *chaetoviridins,* A and B (Park, et al., 2005). These studies indicate that microbial biopesticides can be incorporated in integrated pest management for sustainable agriculture.

Predators and parasitoids as biopesticides:

A predator kills and feeds on prey while parasitoids grow on or inside their hosts and eventually kill them (Elzinga, et al*.,* 2002). The predators include beetles (*Carabidae*), ladybirds (*Coccinellidae*), spiders, lacewings (*Chrysopidae*), and true bugs while parasitoids mainly consist of wasps and other hemipterans (Knutson, et al*.,* 2015). These natural enemies are mainly found in the environment and are not evenly distributed. In order to have them in large numbers, they are either reared under controlled conditions and released into the fields or are multiplied in open fields containing the prey (Morales-Ramos, et al*.,* 2014). The most common way of rearing these predators is by growing them on their preferred hosts. This is either done in screen houses or growth chambers where the host plants are first grown and then exposed to pest infestation (Silva, et al., 2010). The predators are then introduced and they are maintained by growing on the prey (Lee, et al*.,* 1990). Alternatively, the predators can be grown in cylinders where they are supplied with the prey and all other necessary conditions for growth are provided. An example is the mass rearing of *Phytoseiulus persililis* on *Tetranychus urticae Koch* (Morales-Ramos, et al*.,* 2014). The optimum growth of predator mite, *Neoseiulus californicus*, was observed when grown on an artificial diet supplemented with eggs of *Ephestia kuehniella, Artemia franciscana* cysts, and maize bran (Khanamani, et al*.,* 2017). Such artificial diets are important in the reproduction, development, and survival of the predators during rearing as well as reduction of production costs.

Predators can also be grown on egg masses of their prey or other suitable hosts which gives them a longer storage capacity. This has been employed in the management of mealy bugs using parasitoids (Steinberg, 2013). The predators can also be grown on other feeds such as rice bran as long as it provides the necessary nutrients to the insects (Fernando, et al*.,* 2006). Due to economic concerns, these organisms are reared on artificial media with carefully evaluated nutritional needs and requirements. Their growth media ranges from beef and liver to crushed *lepidopteran pupae*. This provides a combination of hormones and nutrients needed by the predators for growth (Grenier, 2012). Artificial media provides as good nutrients as the host plants and reduces the cost of growing the plants. The artificial media is mostly used in laboratories and has been used for rearing *Trichogramma* and *Anastatus spp* (Grenier, 2009). An in vitro study by Xu and Enkegaard (2010) showed that *Amblyseius swirskii* predated on *Frankliniella occidentalis* and *Tetranychus urticae* nymphs with preference to their first instars. The predation rate on *T. urticae* was 4 - 6 nymphs in 12 hours. The authors reasoned that the outcome of the predation is highly dependent on several factors among them being the host plant traits. A synergistic effect on predation between *Amblyseius swirskii* and *Phytoseiulus persimilis* against

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two-spotted spider mite (*Tetranychus urticae*) with a mortality rate of up to 86% was reported by Fiedler (2012). He further said that introduction of *Amblyseius californicus* and *Amblyseius degenerans* into a population of *Tetranychus urticae* under laboratory conditions recorded mortality of up to 72% within 15 days.

Formulation, production, and commercialization of biopesticides

Botanical pesticides are prepared from plants and plant parts obtained from the environment, natural or man-made (Dubey, et al., 2016). The materials are cleaned of dirt or foreign materials and then extracted either using solvents or distillation to obtain extracts or essential oils, respectively (Goufo, et al., 2008). The resultant extracts are then subjected to screening for activity in vitro against different pests using different methods such as disc diffusion, agar well diffusion, agar dilution, and poisoned food technique (Ademe, et al., 2013; Jahangiriana, et al., 2013). The most active botanicals are then evaluated for efficacy in managing pests and diseases under field conditions. The active constituents of the selected extracts are then identified for optimum formulation (Nashwa, et al., 2012). Intensive laboratory and field trials conditions are carried out to ensure that the most efficacious combination of the active compounds, carrier materials, emulsifiers, surfactants and other components used in pesticide development are optimized. The efficacy report from the laboratory and field trials is used to request for registration of the product from the pest control products body.

Production of microbial pesticides follows the same procedure as botanicals, except that the antagonistic microorganisms are collected from sources like the cowshed, hayfields, rhizosphere, compost, and manure (Hassanein, et al., 2010). They are isolated into pure cultures in the laboratory and maintained in agar slants (Sahu, et al., 2014). In vitro efficacy trials are carried out following methods such as dual culture, agar discs diffusion and agar well diffusion (Karimi, et al., 2012). The active microorganisms are multiplied on a suitable substrate in the laboratory and mixed with carrier materials, enhancers and stabilizers for field application (Naing, et al., 2013). Repeated laboratory and field efficacy trials are conducted until the registration process begins).

Before the natural products are commercialized, they are usually tested in the laboratory and under field conditions for efficacy against the target pests. The active compounds are also identified using techniques such as thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), and gas chromatography-mass spectrometry (GC-MS) (Hossain, et al., 2013; Araújo, et al., 2014). Stabilizers and carrier materials are always added to the active compounds to enhance their applicability and longevity. Formulation of the active compounds should improve the stability of the compound as well as increase its efficiency and applicability. It should also reduce its degradability due to climatic factors such as heat, water and acids. Carrier materials majorly used include petroleum distillates, corn starch, talc, clays, and water. Emulsifiers such as soap are also added to the compounds during formulation and they are optimized to ensure effectiveness is not lost. Biopesticides of plant origin that have been formulated and commercialized for agricultural use include neem and pyrethrum (Khater, 2012) while microorganisms include species of *Bacillus* and *Trichoderma* (Cawoy, et al., 2011).

Modes of action of biopesticides

Each type of biopesticide exhibits varied modes of action. Microbial pesticides act on pathogens by antagonism, hyperparasitism, antibiosis, and predation. Botanical pesticides inhibit the growth of pathogens,

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modify their cellular structures and morphology, and exhibit neurotoxicity on insects. Botanicals also repel insects, suppress oviposition and feeding. Predators mainly kill the prey through parasitization or injection of toxic substances which eventually kill the prey. Semiochemicals are used to lure the target pests and they can then be managed through other means such as sterilization or death.

Extracts from plants belonging to the *Asteraceae* family have been reported to inhibit hyphal growth and induce structural modifications on the mycelia of plant pathogenic fungi (Vidyasagar, et al*.,* 2013). *Asteraceae* plants contain compounds such as flavonoids, coumarins alkaloids, and terpenoids which could lead to absolute fungal toxicity. Some compounds lead to changes in the cell wall as well as the morphology of cellular organelles (Iberê, et al*.,* 2014). In some instances, the bioactive compounds cause partitioning of fungal cell membranes making them permeable leading to leakage of cell contents. Plant bioactive compounds also lead to separation of the cytoplasmic membrane which leads to damage of the intracellular components and swelling of cells leading to eventual death (El-Wakeil, 2013). Compounds such as allicin found in garlic (*Allium sativum*) bulbs lead to suffocation of the pest due to effects on receptors of neurotransmitters (Baidoo, et al*.,* 2016). Phenolics and terpenoids build hydrophobic and ionic bonds which attack multiple of proteins in the insects leading to physiological malfunction (Rodino, et al*.,* 2012). Compounds in plant extracts and essential oils also interfere with receptor cells leading to malfunctioning of the nervous system and failure of coordination leading to the death of the insect (Moreira et al*.,*2007).

Different classes of microorganisms have different modes of action. Hyperparasitism is one of the most reported modes of action on many biocontrol agents (Akrami et al*.,* 2011). The antagonist kills the pathogen or its propagules while some attack the sclerotia or the hypha of the fungal pathogen. A single pathogen could be attacked by a number of biocontrol agents (Blaszczyk et al*.,* 2014). *Pasteuria penetrans* is an example of a biocontrol agent that parasitizes on root-knot nematodes of *Meloidogyne spp.* (Kokalis-Burelle, 2015). Species of genus *Trichoderma* exhibit a predation mode of action by producing enzymes that directly kill cell walls of the pathogens and colonize the environment therein.

Some microorganisms produce compounds that kill other microorganisms, a mechanism called antibiosis. This is most common with bacteria belonging to species of Pseudomonas, Agrobacterium, Bacillus, *Burkholderia, Pantoea* and it has also been reported in the fungus *Trichoderma spp*. (Mendoza, et al*.,* 2015). Sufficient quantities of antibiotics need to be produced for enhanced biocontrol. Some microbial species such as Bacillus cereus produce multiple compounds that could suppress more than two pathogens and this is effective in crop disease management (Pal, et al*.,* 2004). Other classes of microorganisms such as *Lysobacter* and *Myxobacteria* produce lytic enzymes which hydrolyze compounds leading to the suppression of pathogens (Xiao, et al*.,* 2011). *Beauveria bassiana* inhibits chitin development in insects by conidia attaching to the body of insects. After germination, the hypha penetrates through the cuticle and grows throughout the insect body eventually killing it (Prasad, et al*.,* 2010).

Semi chemicals such as female sex pheromones are used to lure the male insect pests which are then sterilized thereby decreasing their effectiveness. Upon mating with the sterile male insects, the females lay unfertilized eggs thereby reducing harmful insect populations (Refki et al*.,* 2016). Host location pheromones lure insects into sites with mass traps from where they may be sterilized or starved to death (Chermiti et al*.,*

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2012). Predators may feed on the prey or a particular life stage of the prey such as nymphs or larvae (Xu, et al*.,* 2010). The predator-prey ratio is of importance in balancing the populations of the pests as well as biodiversity (Rao et al*.,* 2017).

Efficacy of different types of biopesticides

Synthetic pesticides are considered more effective than biopesticides in managing crop pests (Khan, et al*.,* 2015). Their effectiveness sometimes has nonetheless not much significance in managing a particular population of pests as would the biopesticides (Ahmad, et al*.,* 2007). Biopesticides in other instances perform better than synthetic pesticides when applied in the right regimes, concentrations, and appropriate frequencies (Shah, et al*.,* 2013). Research reports across the world have presented different plants, microorganisms, and predators with potential as biopesticides. Natural enemies predate on insect pests which balance their population in the ecosystem. Such predators are important in agricultural systems (Rao et al*.,* 2017; Kenis et al*.,* 2017). The mechanisms used by predators to lure insects include scents and other attractants. Some of these scents, called pheromones, have been commercialized and are being used in the management of important crop pests such as *Tuta absoluta* (Refki et al*.,* 2016). The commercial pheromones are baited to aid in luring the adult insects and then deactivating them by sterilization or starvation to death (Galko et al*.,* 2016). Certain plants contain compounds which they use to protect themselves against pests and this ability has been explored by researchers in an effort to manage different crop pests (Rizvi et al*.,* 2016). Some plants have been found to contain compounds that are effective against several pests including fungi and nematodes (Hussain et al*.,* 2015; Sidhu et al*.,* 2017). Some species of microorganisms have antagonistic properties towards other species and are therefore effective as biopesticides (Aw et al*.,* 2017).

Ngegba, et al*.,* (2018) reported that extracts of neem (Azadirachta indica) and Mexican sunflower (*Tithonia diversifolia*) inhibited growth of rotting disease pathogens of tomato, *Aspergillus niger*, *Fusarium oxysporum,* and *Geotrichum candidium* by up to 100%. Extracts of castor seeds (*Ricinus communis*) effectively inhibited the growth of post-harvest pathogens *Penicillium oxalicum* and *Aspergillus niger* of yams *(Dioscorea alata*) in a dose-dependent poisoned food technique experiment (Patrice et al*.,* 2017). Similar effects were reported by Devi et al. (2017) on post-harvest fungi including *Fusarium solani, Rhizopus arrhizus,* and *Sclerotium rolfsii* after using extracts from *Duranta erecta and Lasonia ineruis*. Methanolic extracts of *Chenopodium ambrosioides* exhibited antifungal activity against *Fusarium oxysporum f.sp. ciceris* a pathogen that causes wilt of chickpea (*Cicer arietinum*) by up to 50% (Minz et al*.,* 2012).

A biopesticide formulation containing onion (*Allium cepa*) and ginger (*Zingiber officinale*) was evaluated for efficacy against tomato fruit worm (*Helicoverpa armigera*) and registered a 70% - 80% control (Sumitra, et al*.,* 2014). During the study, yield increment was also observed on plants treated with the formulation compared to the untreated controls. Muzemu et al. (2011) reported over 50% reduction of rape aphids (*Brevicoryne brassicae*) and tomato red spider mites (*Tetranychus evansi*) by powder extracts of *Lippia javanica* and *Solanum delaguense.* Populations of *Megalurothrips sjostedti* were reduced by extracts of *Piper nigrum, Cinnamomum zeylanium,* and *Cinnamomum cassia* and were reported to be strong repellents (Abtew, et al*.,* 2015). The number of larvae and pupa of *Helicoverpa armigera* were effectively reduced by extracts of Curcuma longa, *Allium sativum,* and *henge* (Ferula assa-foetida) in a study by Shah et al. (2013). Extracts of *Artemisia herbaalba,* *Eucalyptus camaldulensis* and *Rosmarinus officinalis* soaked on leaves of broad bean (*Vicia faba*) caused a mortality of 60% - 100% of green peach aphid (*Myzus persicae*) after 24 hours of exposure in dose-dependent in vitro experiments (Nia et al*.,* 2015). In another study, topical application of *Azadirachta indica, Mangifera indica, Polyalthia longifolia, Annona squamosa,* and *Ficus benghalensis* caused a 100% mortality of bed bugs (*Cimex lectularius*) after 19 seconds of contact (Parte et al*.,* 2015). The effectiveness of plant extracts on insects is credited to the solvents used and their ability to extract major compounds with insecticidal properties (Oyedokun et al., 2011; Barbosa et al., 2013). *Bacillus subtilis, Pseudomonas putida,* and *Pseudomonas aeruginosa* were evaluated against *Fusarium oxysporum f. sp. ciceris* and reported to have better control in seed treatment and resulted in an increment in growth parameters (Karimi, et al*.,* 2012). Species of Bacillus have been reported to produce compounds effective against important fungal pathogens including *Rhizoctonia solani* and *Xanthomonas oryzae pv. oryzae* (Beric et al*.,* 2012; Islam et al*.,* 2012). Compounds from *Chaetomium globosum* have also been reported effective against important fungal pathogens of rice such as *Magnaporthe grisea* and *Puccinia recondita* (Park et al*.*, 2005). Anitha and Rabeethet al. (2009), reported reduced severity of *fusarium* wilt of tomato after using *Streptomycesgriseus*. In a seeded media experiment, *Stenotrophomnas maltophilia*, *Bacillus subtilis* and *Pseudomonas aeruginosa* exhibited antagonism against *Erwinina carotovora* (Selim et al., 2016). A formulation consisting of compost tea extracts and poultry litter reduced the severity of bacterial wilt (*Ralstonia solanacearum)* of *brinjals (Solanum melongena*) (Islam et al., 2010). Higher efficacy was observed when the compost tea extract was applied as a soil drench and the poultry litter applied on the soil which resulted in healthy plants and improved yield. A similar formulation reduced the incidence and severity of late blight (*Phytophtora infestans*) of potato *(Solanum tuberosum*) when the compost tea was applied as a foliar spray (Islam, et al*.,* 2013). Research by Pane et al. (2014) showed that a compost tea formulation containing wood chips improved the yield of lettuce (*Lactuca sativa var. gentilina*) and Kohlrabi or German turnip (*Brassica oleracea var. gongylodes*) when applied as a foliar spray. Semi chemicals have been employed in the management of insect pests. As reported by Chermiti and Abbes (2012), mass trapping by use of sex pheromones with water traps has been used in the management of *Tuta absoluta* by delaying initial attacks on tomato plants. Similarly, fruit flies (*Rhagoletis cingulata*) have been managed through semi chemicals such as sex pheromones, oviposition, host location, and mating pheromones (Sarles et al., 2015). According to Powell and Pickett (2003), these semi chemicals could be insect-plant induced or insect induced and the end result is enhanced parasitizing of the insect populations.

Predators of insect and microbial nature have been effectively used in management of insect pests. Species of *Amblyseius swirskii* have been used in the management of thrips, *Frankliniella occidentalis* and *Scirtothrips dorsalis* and spider mites (*Tetranychus urticae*) (Xu et al*.,* 2010; Arthurs et al., 2009). *Phytoseiulus persimilis* is an effective predator mite against spider mites (*Tetranyshus* spp.) (Rizvi et al., 2016). According to a study by Vá Squez et al. (2006), aphid predators (*Aphidius colemani*) were reported to be effective on *Aphis gossypii* on *crysanthemums* (*Dendranthema grandiflora*).

The role of biopesticides in sustainable agricultural production

Biopesticides are as effective as synthetic pesticides in the management of crop pests

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(Birech, et al., 2006). Natural products are also eco-friendly since they are easily biodegradable and therefore do not pollute the environment according to Leng, et al. (2011). Okunlola, et al. (2014) stated that Consumer tastes and preferences fluctuate over time, and following the demand for organically produced food, this makes biopesticides suitable alternatives to synthetic pesticides. Biopesticides have very short pre-harvest intervals and are therefore safe to use on fresh fruits and vegetables (Khater, 2012). They are also target-specific and hence do not affect the beneficial organisms such as the natural enemies (Shiberu et al., 2016). They are effective in small quantities and their use promotes sustainable pest management and hence contributes towards sustainable agriculture, according to Nawaz et al. (2016).

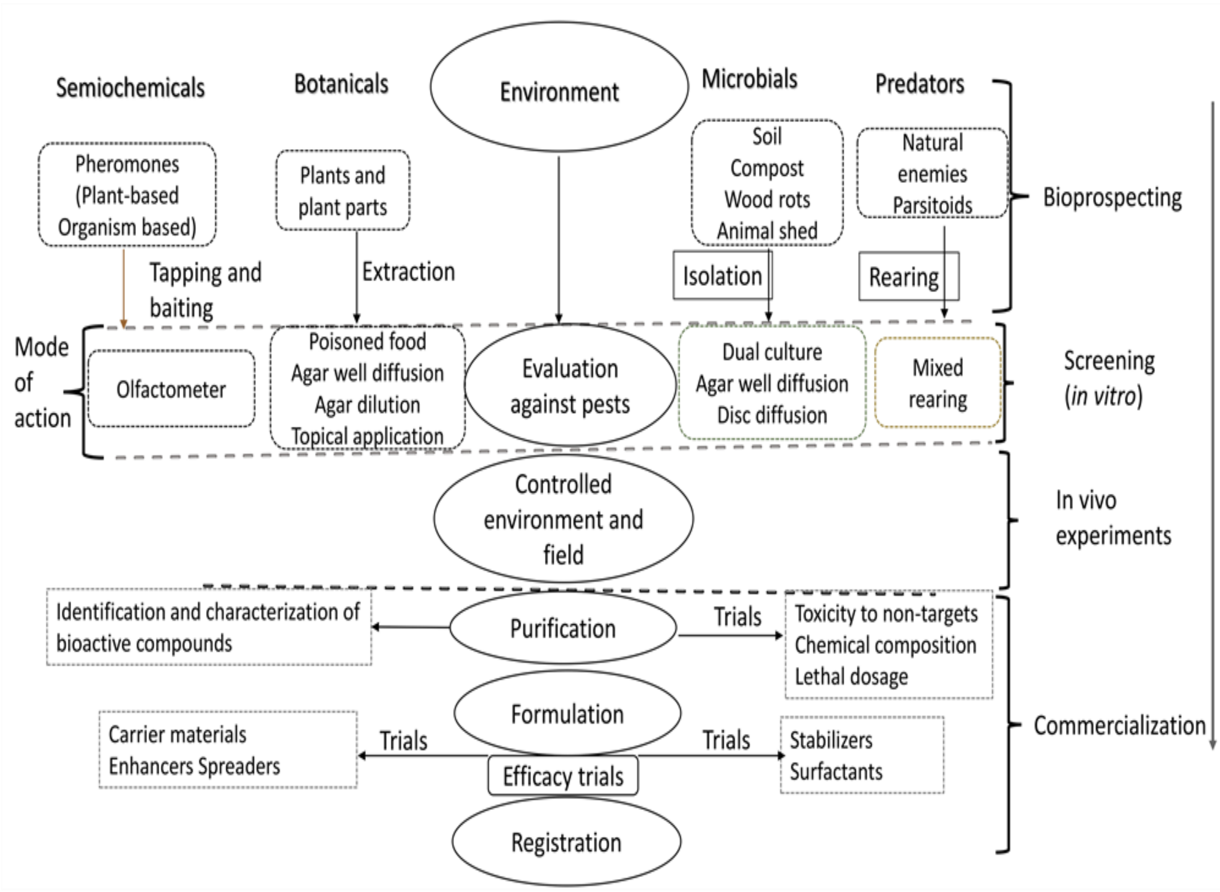
Natural pesticides do not cause resistance build up among pests (Tadele et al., 2017). Availability of their source materials makes them inexpensive to attain since they are found within the natural environment and some of them are used for other purposes like food and feed (Srijita, 2015). Biopesticides are safe products both for the applicant and the consumer since they have no toxicity (Damalas et al., 2015). Therefore, biopesticides can suitably be incorporated in integrated pest management (IPM) which helps reduce the amounts of chemical pesticides used in the management of crop pests (Sesan et al., 2015). Natural products decompose quickly which makes them safer for use in the environment (Kawalekar, 2013). Pesticides from natural sources have very short re-entry intervals which guarantee safety for the applicant (Stoneman, 2010). Biopesticides are also used in the decontamination of agricultural soils through the introduction of important microbial species (Javaid, et al., 2016)

Limitations facing the use of biopesticides

While biopesticides provide such advantages as a safe environment and healthy food for human consumption, there are factors that limit their full adoption as pest and disease management options. High doses of the constituent compounds are needed for efficacy under field conditions (Shiberu et al., 2016). The concentration of the bioactive compounds in plants is dictated by the environment under which they grow (Ghorbani et al., 2005). The constituent active compounds are also dictated by the diversity of plants and their varieties resulting in differences in the responses to pathogens (Sales et al., 2016). The quality of botanical extracts is also dependent on the method of extraction used (Sesan et al., 2015). During formulation, it is sometimes challenging to get the right proportions of the active and inert ingredients needed. There are also no standard preparation methods and guidelines for efficacy testing especially under field conditions (Okunlola et al., 2014). While the in vitro tests produce excellent results, there are always inconsistencies in the field due to low shelf life and sometimes poor quality of source materials or preparation methods.

Adoption of biopesticides of predatory nature needs a lot of consideration such as host crops and dispersal capability according to Gerson, (2014). Crop coverage and exposure time are essential and for small acreage, this could prove expensive since the application may be manual (Lanzoni et al., 2017). Registration of the products requires data on chemistry, toxicity, packaging, and formulation which is not always readily available (Gupta et al., 2010). The cost of producing a new pesticide product is usually high and has a lot of resource limitations (Stoneman, 2010). The lack of a readily available market makes it hard to invest in biopesticides (Stoneman, 2010). There are insufficient facilities and capital for the production of biopesticides, especially in slowly developing countries. The shelf life of natural products is dependent on many factors such as temperatures and moisture which are sometimes difficult to control (Koul, 2011). Biopesticides also face high competition from synthetic pesticides and if the former were produced for a small agricultural activity, the costs may be relatively high and therefore not feasible. There is insufficient awareness about biopesticides especially among the small-scale growers, stake holders and policy makers. In the case of microbial pesticides, there is usually no trust in the value and use chain between producers, buyers and users and considering the risk of importation, synthetic pesticides appear reliable (Kumar et al., 2015).

Biopesticides cycle of forms, sources, formulations and mode of action on targeted pest



CONCLUSION

Despite the many challenges facing the adoption of biopesticides, they remain suitable alternatives to conventional pesticides. Stable products under field conditions will guarantee the utter effectiveness of biopesticides in crop pest management. Researchers should therefore work together with experts in the government and industry as well as farmers to provide stable, durable, and endurable formulations of biopesticides.

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with regard to the use of biopesticides in crop production.

REFERENCE

Abbamondi, G. R.; Giuseppina, T.; Nele, W.; Sofie, T.; Wouter, S.; Panagiotis, G.; Carmine, I.; Wesley, M. R.; Barbara, N.; Jaco, V. Plant Growth-Promoting Effects of Rhizospheric and Endophytic Bacteria Associated with Different Tomato Cultivars and New Tomato Hybrids. *Chem. Biol. Tech. Agric*. 2016, 1, 1-10.

Adan, M. J.; Baque, M. A.; Rahman, M. M.; Islam, M.; Jahan, A. Formulation of *Trichoderma* Based Biopesticide for Controlling Damping off Pathogen of Eggplant Seedling. Universal *J. Agric. Res*. 2015, 3, 106-113.

Adipala, E.; Omongo, C. A.; Sabiti, A.; Obou, J. E.; Edema, R.; Bua, B.; Atanya, A.; Nusbuga, E. N.; Oganga-Latigo, M. W. Pests and diseases on cowpea in Uganda experience from diagnostic survey, *African Crop Sci. J.* 1999, 4, 465-478.

Ademe, A.; Ayalew, A.; Woldetsadik, K. Evaluation of Antifungal Activity of Plant Extracts against Papaya Anthracnose (*Colletotrichum gloeosporioides*). *Pl. Path. Microbiol*. 2013, 10, 1-4. https://doi.org/10.4172/2157-7471.1000207.

Ahmad, A.; Alkarkhi, A. F. M.; Hena, S.; Lim, H. K. Extraction, Separation and Identification of Chemical Ingredients of *Elephantopus scaber L*. Using Factorial Design of Experiment. *Inter. J. Chem*. 2009, 1, 36-49. https://doi.org/10.5539/ijc.v1n1p36.

Ahmad, S.; Khan, I. A.; Hussain, Z.; Shah, S. I. A.; Ahmad, M. Comparison of a Biopesticide with Some Synthetic Pesticides against Aphids in Rapeseed Crop. Sahrad *J. Agric*. 2007, 4, 1117-1120.

Akpheokhai, I. L.; Cole, A. C.; Fawole, B. Evaluation of some plant extracts for the management of *Meloidogyne incognita* on soybean (*Glycine max*). *World J. Agric. Sci.* 2012, 8(4), 429-435.

Akrami, M.; Golzary, H.; Ahmadzadeh, M. Evaluation of Different Combinations of *Trichoderma* Species for Controlling Fusarium Rot of Lentil. *Afr. J. Biotech*. 2011, 14, 2653-2658.

Alavanja, M. C. R.; Ross, M. K.; Bonner, M. R. Increased Cancer Burden among Pesticide Applicators and others Due to Pesticide Exposure. *A Cancer J. Clinic*. 2013, 63, 120-142. https://doi.org/10.3322/caac.21170.

Ali, A. M.; Mohamed, D. S.; Shaurub, E. H.; Elsayed, A. M. Antifeedant Activity and Some Biochemical Effects of Garlic and Lemon Essential Oils on *Spodoptera littoralis* (*Boisduval*) (*Lepidoptera: Noctuidae*). *J. Entom. Zool. Stud*. 2017, 3, 1476-1482.

Anitha, A.; Rabeeth, M. Control of Fusarium Wilt by Bioformulation of *Streptomyces griseus* in the Green House Condition. *Afr. J. Basic Appl. Sci*. 2009, 1-2, 9-14.

Araújo, K. M.; Lima, A.; Silva, J. N.; Rodrigues, L. L.; Amorim, A. G. N.; Quelemes, P. V.; Santos, R. C.; Rocha, J. C.; Andrades, E. O.; Leite, J. R. S. A.; Mancini-Filho, J.; Trindade, R. A. Identification of Phenolic Compounds and Evaluation of Antioxidant and Antimicrobial Properties of *Euphorbia tirucalli L. Antiox id*. 2014, 3,159-175. https://doi.org/10.3390/antiox3010159.

Aw, K. M. S.; Hue, S. M. Mode of Infection of *Metarhizium* spp. Fungus and Their Potential as Biological Control Agents. *J. Fungi*. 2017, 30, 120, https://doi.org/10.3390/jof3020030.

Bandor, H.; Hijazi, A.; Rammal, H.; Hachem, A.; Saad, Z.; Badran, B. Techniques for the Extraction of Bioactive Compounds from *Labanese Urtica diotica*. *Amer. J. Phytomed. Clinic. Therapeut*. 2013, 6, 507-513.

Barbosa, F. S.; Leite, G. L. D.; Martins, E. R.; D'avila, V. A.; Cerqueira, V. M. Medicinal

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Plant extracts on the Control of *Diabrotica speciosa* (Coleoptera: Chrysomelidae). *Brazil. J. Med. Pl.* 2013, 1, 142-149.

Bastas, K. K. Determination of Antibacterial Efficacies of Plant Extracts on Tomato Bacterial Speck Disease. *J. Turk. Phytopath*. 2015, 1-3, 1-10.

Beric, T.; Koji, M.; Stankovi, S.; Topisirovi, L.; Degrassi, G.; Myers, M.; Venturi, V.; Fira, D. Antimicrobial Activity of Bacillus sp. Natural Isolates and their Potential use in the Biocontrol of Phytopathogenic Bacteria. *Food Techn. Biotech*. 2012, 1, 25-31.

Birech, R.; Bernhard, F.; Joseph, M. Towards Reducing Synthetic Pesticides Imports in Favour of Locally Available Botanicals in Kenya. Proceedings International Agricultural Research for Development, Bonn, 2006, 8-12.

Blaszczyk, L.; Siwulski, M.; Sobieralski, K.; Lisiecka, J.; Jedryczka, M. *Trichoderma* spp.—Application and Prospects for Use in Organic Farming and Industry. *J. Pl. Protect. Res*. 2014, 4, 309-317.

Brühl, C. A.; Schmidt, T.; Pieper, S.; Alscher, A. Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline. *Sci Rep.* 2013, 3, 1135.

Business Daily. Chemical Ban Hits Vegetable Exports to the EU Market. Business Daily, 14 February 2013.

Business Daily. Illegal Horticulture Exports Risk Kenya's EU Market. Business Daily, 26 May 2014.

Business Daily. Regulator Suspends Use of Pesticides on Vegetables. Business Daily, 13 October 2014.

Cawoy, H.; Wagner, B.; Fickers, P.; Ongena, M. Bacillus-Based Biological Control of Plant Diseases, Pesticides in the Modern World, Pesticides Use and Management 2011, Margarita Stoytcheva (Ed.), ISBN: 978-953-307-459-7, In Tech, Available: http://www.intechopen.com/books/pesticides-in-themodern-world-pesticides-use-and-management/bacillus-based-biological-control-of-plant-diseases.

Chermiti, B.; Abbes, K. Comparison of Pheromone Lures Used in Mass Trapping to Control the Tomato *Leafminer Tuta absoluta* in Industrial Tomato Crops in Kairouan (Tunisia). *EPPO Bulletin*, 2012, 241-248. https://doi.org/10.1111/epp.2561.

Chime E. U.; Nweke I. A.; Ibeh C.U.; Nsoanya L.N. Biopesticide and biofertilizer effect on some growth parameter of indian spinach and soil physical properties *Inter. J. Inform. Res. Rev.* (2019, 10(1), 6051-6054.

Chime E. U; Ibeh C.U; Nweke I. A.; Nsoanya L. N. Bioefficacy of some biopesticide agents and treated *pennisetum* biofertilizer against root- knot nematode (*meloidogyne incognita*) on Indian spinach (*basellaalba*) and soil chemical properties *Inter. J. Inform. Res. Rev.* 2019, 10(1), 6047-6050.

Chougule, P. M.; Andoji, Y. S. Antifungal Activity of Some Common Medicinal Plant Extracts against Soil Borne Phytopathogenic Fungi Fusarium oxysporum Causing Wilt of Tomato. *Inter. J. Dev. Res*. 2016, 3, 7030-7033.

Chuang, P. H.; Lee, C. W.; Chou, J. Y.; Murugan, M.; Shieh, B. J.; Chen, H. M. Antifungal activity of crude extracts and essential oil of *Moringa oleifera* Lam. *Biores. Techn.* 2007, 98, 232-236.

Compant, S.; Clément, C.; Sessitsch, A. Plant Growth-Promoting Bacteria in the Rhizo- and Endosphere of Plants: Their Role, Colonization, Mechanisms involved and Prospects for Utilization. *Soil Biol. Biochem*. 2009, 42, 669-678. https://doi.org/10.1016/j.soilbio.2009.11.024

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Bio-Pesticides in Focus as Safety Concerns Reshape Export Trade. Daily Nation, 7 June 2014.

Boost for Horticulture as New System Set to Improve Quality. Daily Nation, 9 September 2016.

Damalas, C. A.; Koutroubas, S. D. Farmers' Exposure to Pesticides: Toxicity Types and Ways of Prevention. *Toxics*, 2015, 1, 1-10.

Dar, A.S.; Nisar, A. D.; Mudasir, A. B.; Mudasir, H. B. Prospects, Utilization and Challenges of Botanical Pesticides in Sustainable Agriculture. *Inter*. *J*. *Mole*. *Biol*. *Biochem*. 2014, 1, 1-14.

Devi, K. B.; Pavankumar, P.; Bhadraiah, B. Antifungal Activity of Plant Extracts against Post-Harvest Fungal Pathogens. *Inter*. *J*. *Cur*. *Microbiol*. *Appl*. *Sci*. 2017, 6, 669-679. https://doi.org/10.20546/ijcmas.2017.601.081.

Dey, K. R.; Choudhury, P.; Dutta, B. K. Impact of Pesticide Use on the Health of Farmers: A study in Barak Valley, Assam (India). *J*. *Environ*. *Chem*. *Ecotoxic*. 2015, 10, 269-277.

Dubey, M.; Thind, T. S.; Dubey, R. K.; Jindal, S. K. Efficacy of Plant Extracts against Tomato Late Blight under Net House Conditions. *Ind*. *J*. *Ecol*. 2016, 1, 375-377.

Edema, R. Investigation into factors affecting diseases occurrence and farmer control strategies on cowpea in Uganda M.Sc Thesis Mackerel University Kampala, 1995, pp100.

El-Wakeil, N. E. Botanical Pesticides and their Mode of Action. *Gesunde Pflanzen*, 2013, 65, 125-149. https://doi.org/10.1007/s10343-013-0308-3.

Elyousr, K. A. A.; Khan, Z.; Award, E. M. M.; Moneim, M. F. A. Evaluation of plant extracts and *Pseudomonas spp* for control of root-knot nematode, *Meloidogyne incognita* on tomato. *Nematropica.* 2010, 40, 289-299.

Elzinga, J. A.; Biere, A.; Harvey, J. A. The Rearing of the Gregarious Koinobiont Endoparasitoid Microplitis tristis (Hymenoptera: Braconidae) on Its Natural Host Hadena bicruris (Lepidoptera: Noctuidae). Proceedings Section Experimental and Applied Entomology of the Netherlands Entomological Society, 2002, 13, 109-115.

Esitken, A.; Yildiz, H. E.; Ercisli, S.; Donmez, M. F.; Turan, M.; Gunes, A. Effects of Plant Growth Promoting Bacteria (PGPB) on Yield, Growth and Nutrient Contents of Organically Grown Strawberry. *Scientia Horticulturae*, 2009,124, 62-66. https://doi.org/10.1016/j.scienta.2009.12.012

European Commission. Amending Annex I to Regulation (EC) No 669/2009 Implementing Regulation (EC) No 882/2004 of the European Parliament and of the Council as Regards the Increased Level of Official Controls on Imports of Certain Feed and Food of Non-animal Origin. *Official J*. *Eur*. *Uni*. 2012, L. 350/44. 20/12/2012.

Fawzi, E. M.; Khalil, A. A.; Afifi, A. F. Antifungal effect of some plant extracts on *Alternaria alternata* and *Fusarium oxysporum*. *Afr. J. Biotech.* 2009. 8(11), 2590–2597.

Fernando, L.C.P.; Aratchige, N. S.; Kumari, S. L. M. L.; Appuhamy, P. A. L. D.; Hapuarachchi, D. C. L. Developmet of a Method for Mass Rearing of Neoseiulus baraka, a Mite Predatory on the Coconut Mite, Aceria guerreronis. *J. Coconut Res*. *Inst*. *Sri Lanka*, 2006, 16, 22-36.

To cite this article: Aloysius, N. L.; Tochukwu, C. R.; Chukwuma Roseline Tochukwu. In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils. *J. Agric. For. Res.* 2021, 1 (2), 136-160.

Fiedler, Z. Interaction between Beneficial Organisms in Control of Spider Mite Tetranychus urticae (Koch.) J. Pl. Protect. Res., 2012, 2, 226-229. https://doi.org/10.2478/v10045-0.12-0035-2.

Flett, B. C.; Bensch, M. J.; Smit, E.; Fourier, H. A field guide for identification of maize diseases in South African Agricultural Research Council potchefstoom 1996.

Galko, J.; Nikolov, C.; Kunca, A.; Vakula, J.; Gubka, A.; Zúbrik, M.; Rell, S.; Konopka, B. Effectiveness of Pheromone Traps for the European Spruce Bark Beetle: A Comparative Study of Four Commercial Products and Two New Models. *Lesnícky Casopis-Forestry J.*, 2016, 62, 207-215. https://doi.org/10.1515/forj-2016-0027.

Gasic, S.; Tanovic, B. Biopesticide Formulations, Possibility of Application and Future Trends. *J. Pest. Phytome*d. (*Belgrade*), 2013, 2, 97-102.

Gerson, U. Pest Control by Mites (acari): Present and Future. *Acarologia,* 2014, 4, 371-394. https://doi.org/10.1051/acarologia/20142144.

Ghorab, M. A.; Khalil, M. S. Toxicological Effects of Organophosphates Pesticides. *Inter. J. Environ. Monito. Anal.* 2015, 4, 218-220. https://doi.org/10.11648/j.ijema.20150304.13

Ghorbani, R.; Wilcockson, S.; Leifert, C. Alternative Treatments for Late Blight Control in Organic Potato: Antagonistic Micro-Organisms and Compost Extracts for Activity against Phytophthora infestans. *Potato R es*. 2005, 48, 181-189. https://doi.org/10.1007/BF02742375

Gill, R. J.; Rodriguez, O. R.; Raine, N. E. Combined pesticide exposure severely affects individual and colony level traits in bees. *Nat*. 2012, 491:105–108

Gnanamanickam, S. S. Biological control of crop diseases. Marcel Dekker Inc., New York, USA, 2002, 468 p.

Goufo, P.; Mofor, T. C.; Fontem, D. A.; Ngnokam, D. High Efficacy of Extracts of Cameroon Plants against Tomato Late Blight Disease. *Agron. Sust. Dev.* 2008, 4, 567-573. https://doi.org/10.1051/agro:2008036.

Grenier, S. In Vitro Rearing of Entomophagous Insects - Past and Future Trends: A Mini review. *Bulletin Insectology*, 2009, 1, 1-6.

Grenier, S. Artificial Rearing of Entomophagous Insects, with Emphasis on Nutrition and Parasitoids-General Outlines from Personal Experience. *Karaelmas Sci. Eng. J.* 2012, 2, 1-12. https://doi.org/10.7212/zkufbd.v2i2.97.

Gupta, S.; Dikshit, A. K. Biopesticides: An Ecofriendly Approach for Pest Control. *J. Biopesticides*, 2010, 1, 186-188.

Halimatunsadiah, A. B.; Norida, M.; Omar, D.; Kamarulzaman, N.H. Application of Pesticide in Pest Management: The Case of Lowland Vegetable Growers. *Inter. Food Res. J.* 2016, 1, 85-94.

Harada, T.; Takeda, M.; Kojima, S.; Tomiyama, N. Toxicity and Carcinogenicity of Dichlorodiphenyltrichloroethane (DDT). *Toxicol. Res*. 2016, 32, 21.

Hassanein, M. N.; Abou, Z. M. A.; Youssef, A. K.; Mahmoud, A. D. Control of Tomato Early Blight and Wilt using Aqueous Extract of Neem Leaves. *Phytopathologia Mediterranea*, 2010, 49, 143-151.

Hossain, M. A.; ALsabari, K. M.; Weli, A.M.; Al-Riyami, Q. Gas Chromatography-Mass Spectrometry Analysis and Total Phenolic

To cite this article: Aloysius, N. L.; Tochukwu, C. R.; Chukwuma Roseline Tochukwu. In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils. *J. Agric. For. Res.* 2021, 1 (2), 136-160.

Contents of Various Crude Extracts from the Fruits of Datura metel L. *J. Taibah Uni. Sci*. 2013, 7, 209-215. https://doi.org/10.1016/j.jtusci.2013.06.004.

Hussain, F.; Abid, M.; Shaukat, S.; Farzana, S.; Akbar, M. Anti-Fungal Activity of Some Medicinal Plants on Different Pathogenic Fungi. *Pakis*. *J. Bot*. 2015, 5, 2009-2013.

Iberê, F.S.; Oliveira, R. G.; Soares, I. M.; Alvim, T. C.; Ascêncio, S. D.; Martins, D. T .O.; Evaluation of Acute Toxicity, Antibacterial Activity and Mode of Action of the Hydro Ethanolic Extract of Piper umbellatum L. *J. Ethnopharma*. 2014, 151, 137-143. https:// doi.org/10.1016/j.jep.2013.10.011.

Islam, M. R.; Jeong, Y. T.; Lee, Y. S.; Song, C. H. Isolation and Identification of Antifungal Compounds from Bacillus subtilis C9 Inhibiting the Growth of Plant Pathogenic Fungi. *Mycobiology,* 2012, 1, 59-66. https://doi.org/10.5941/MYCO.2012.40.1.059.

Islam, M. R.; Mondal, C.; Hossain, I.; Meah, B. M. Organic Management: An Alternative to Control Late Blight of Potato and Tomato Caused by Phytophthora infestans. *Inter*. *J*. *Theor*. *Appl*. *Sci*. 2013, 2, 32-42.

Islam, M. R.; Mondal, C.; Hossain, I.; Meah, B.M. Compost Tea as Soil Drench: An Alternative Approach to Control Bacterial Wilt in Brinjal. *Archiv*. *Phytopath*. *Pl*. *Protect*. 2014, 12: 1475-1488. https://doi.org/10.1080/03235408.2013.847654.

Jahangiriana, H.; Haron, M. D. J.; Mohd, H. S. I. A.; Roshanak, R.; Leili, A. D. Y. A. E.; Majid, R. C.; Nazanin, V. Well Diffusion Method for Valuation of Antibacterial Activity of Copper Phenyl Fatty Hydroxamate Synthesized from Canola and Palm Kernel Oils. *Digest J. Nanomater*. *Biostruct*. 2013, 3, 1263-1270.

Jalili-Marandi, R.; Hassani, A.; Ghosta, Y.; Abdollahi, A.; Pirzad, A.; Sefidkon, F. *Thymus kotschyanus* and *Carumcopticum* essential oils as botanical preservatives for table grape. *J. Med. Pl. Res.* 2010. 4(22), 2424- 2430.

Jantasorn, A.; Moungsrimuangdee, B.; Dethoup, T. In Vitro Antifungal Activity Evaluation of Five Plant Extracts against Five Plant Pathogenic Fungi Causing Rice and Economic Crop Diseases. *J. Biopest*. 2016, 1, 1-7.

Javaid, A.; Rehman, A. H. Antifungal Activity of Leaf Extracts of Some Medicinal Trees against *Macrophomina phaseolina*. *J. Med*. *Pl*. *Res*. 2011, 13, 2858-2872.

Javaid, M. K.; Ashiq, M.; Tahir, M. Potential of Biological Agents in Decontamination of Agricultural Soil, 2016, https://doi.org/10.1155/2016/1598325.

Kachhawa, D. Microorganisms as a Biopesticides. *J. Entom*. *Zoo*. *Stud*. 2017, 3, 468-473.

Karimi, K.; Amini, J.; Harighi, B.; Bahramnejad, B. Evaluation of Biocontrol Potential of Pseudomonas and Bacillus spp against Fusarium Wilt of Chickpea. *Aust*. *J. Crop Sci*. 2012, 6, 695-703.

Kawalekar, J. S. Role of Biofertilizers and Biopesticides for Sustainable Agriculture. *J. Bio Innov*. 2013, 2, 73-78.

Kekuda, P.T. R.; Akarsh, S.; Nawaz, S. A. N.; Ranjitha, M. C.; Darshini, S. M.; Vidya, P. In Vitro Antifungal Activity of Some Plants against Bipolaris sarokiniana (Sacc.) Shoem. *Inter*. *J*. *Cur*. *Microbiol*. *Appl*. *Sci*. 2016, 6, 331-337. https://doi.org/10.20546/ijcmas.2016.506.037.

Kenis, M.; Hurley, B. P.; Hajek, A. E.; Cock, M. J. W. Classical Biological Control of Insect Pests of Trees: Facts and Figures. *Biological Invasions*, 2017, 19, 3401-3417. https://doi.org/10.1007/s10530-017-1414-4.

Khan, A. I.; Hussain, S.; Akbar, R.; Saeed, M.; Farid, A.; Ali, I.; Alam, M.; Shah, B. Efficacy of a Biopesticide and Synthetic Pesticides against Tobacco Aphid, Myzus persicae Sulz. (Homoptera, Aphididae), on Tobacco in Peshawar. *J. Entomol. Zoo. Stud*. 2015, 4, 371-373.

Khanamani, M.; Fathipour, B.Y.; Talebi, A. A.; Mehrabadi, M. Evaluation of Different Artificial Diets for Rearing the Predatory Mite Neoseiulus californicus (Acari: Phytoseiidae): Diet Dependent Life Table Studies. *Acarologia* , 2017, 2, 407-419. https://doi.org/10.1051/acarologia/20174165.

Khater, H. F. Prospects of Botanical Biopesticides in Insect Pest Management. *Pharmacologia*, 2012, 12, 641-656.

Knutson, A. and Ruberson, J. Field Guide to Predators, Parasites and Pathogens Attacking Insect and Mite Pests of Cotton. In: Smith, E.M., Ed., Texas Cooperative Extension, TX Publication, 2015, Pp136.

Kokalis-Burelle, N. Pasteuria penetrans for Control of Meloidogyne incognita on Tomato and Cucumber, and M. arenaria on Snap Dragon. *J. Nematol*. 2015, 3, 207-213.

Koul, O. Microbial Biopesticides: Opportunities and Challenges. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2011, 6, 056. http://www.cabi.org/cabreviews.

Kumar, S. Singh, A. Biopesticides: Present Status and the Future Prospects. *J. Fert. Pest*. 2015, 2, 1-2. https://doi.org/10.4172/2471-2728.1000e129

Kumari, A.; Kumar, K. N. R.; Rao, C. H. N. Adverse Effects of Chemical Fertilizers and Pesticides on Human Health and Environment. Proceedings National Seminar on Impact of Toxic Metals, Minerals and Solvents leading to Environmental Pollution. *J. Chem. Pharma. Sci*. 2014, 3, 150-151.

Lanzoni, A.; Martelli, R.; Pezzi, F. Mechanical Release of *Phytoseiulus persimilis* and *Amblyseius swirskii* on Protected Crops. *Bull. Insectol.* 2017, 2, 245-250.

Lee, W.; Ho, C.; Lo, K. Mass Production of Phytoseiids: Evaluation of Eight Host Plants for the Mass-Rearing of *Tetranychus urticae* and *T. kanzawai Kishda* (*Acarina: Tetranychidae*). *Agric. Sci. China*, 1990, 2, 121-132.

Leng, P.; Zhang, Z.; Pan, G.; Zhao, M. Applications and Development Trends in Biopesticides. *Afr. J. Biotech*. 2011, 86, 19864-19873.

Mahlo, S. M.; Chauk, H. R.; McGaw, L. J.; Eloff, J. N. Antioxidant and Antifungal Activity of Selected Plant Species Used in Traditional Medicine. *J. Med. Pl. Res*. 2013, 33, 2444-2450.

Maksymiv, I. Pesticides: Benefits and Hazards. *J. Vasyl Stefanyk Precarpathian Nat. Uni*. 2015, 1, 70-76. https://doi.org/10.15330/jpnu.2.1.70-76.

Mendoza, J. L. H.; Pérez, M. I. S.; Prieto, J. M. G.; Velásquez, J. D. Q.; Olivares, J. G. G.; Langarica, H. R. G. Antibiosis of Trichoderma spp Strains Native to Northeastern Mexico against the Pathogenic Fungus *Macrophomina*

To cite this article: Aloysius, N. L.; Tochukwu, C. R.; Chukwuma Roseline Tochukwu. In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils. *J. Agric. For. Res.* 2021, 1 (2), 136-160.

phaseolina. *Brazil*. *J*. *Microbiol*. 2015, 4, 1093-1101. https://doi.org/10.1590/S1517-838246420120177

Minz, S.; Samuel, C. O.; Tripathi, C. S.; The Effect of Plant Extracts on the Growth of Wilt Causing Fungi Fusarium oxysporum. *J*. *Pharm*. *Biol*. *Sci*. 2012, 1, 13-16. https://doi.org/10.9790/3008-0411316.

Mizubuti, G. S. E.; Junior, V. L.; Forbes, G. A. Management of Late Blight with Alternative Products. *Pest Tech*. 2007, 2, 106-116.

Morales-Ramos, J. A.; Rojas, M. G. A Modular Cage System Design for Continuous Medium to Large Scale in Vivo Rearing of Predatory Mites (*Acari: Phytoseiidae*) 2014, https://doi.org/10.1155/2014/596768.

Moreira, M. D.; Picanco, M. C.; Barbosa, L. C. A.; Guedes, R. N. C.; Campos, M. R.; Silva, G. A.; Martins, J. C. Plant Compounds Insecticide Activity against Coleoptera Pests of Stored Products. *Pesquisa Agropecuária Brasileira*, 2007, 7, 909-915. https://doi.org/10.1590/S0100-204X2007000700001.

Morrissey, W. A. Methyl Bromide and Stratospheric Ozone Depletion. CRS Report for Congress, 2006, 1-6.

Muthomi, J. W.; Lengai, G. M. W.; Wagacha, J. M. Narla, R. D. In Vitro Activity of Plant Extracts against Some Important Plant Pathogenic Fungi of Tomato. *Aust*. *J*. *Crop Sci*. 2017, 6, 683-689. https://doi.org/10.21475/ajcs.17.11.06.p399.

Muzemu, S.; Mvumi, B. M.; Nyirenda, S. P. M.; Sileshi, G. W.; Sola, P.; Chikukura, L.; Kamanula, J. F.; Belmain, S. R.; Stevenson, P. C. Pesticidal Effects of Indigenous Plant Extracts against Rape Aphids and Tomato Red Spider Mites. African Crop Science Conference Proceedings, 2011, 10, 171-173.

Naing, W. K.; Anees, M.; Nyugen, H. X.; Lee, S. Y.; Jeon, W. S.; Kim, Y. S.; Kim, H. M.; Kim, Y. K. Biocontrol of Late Blight Diseases (*Phytophthora Capsici*) of Pepper and the Plant Growth Promotion by *Paenibacillus chimensis* KWNJ8. *J*. *Phytopath*. 2013, 2, 164-165.

Nashwa, S. M. A., Abo-Elyousr, A. M. K. Evaluation of Various Plant Extracts against the Early Blight Disease of Tomato Plants under Green House and Field Conditions. *Pl*. *Prot*. *Sci*. 2012, 2, 74-79. https://doi.org/10.17221/14/2011-PPS.

Nawaz, M.; Mabubu, J. I.; Hua, H. Current Status and Advancement of Biopesticides: Microbial and Botanical Pesticides. *J. Entomol. Zoo. Stud*. 2016, 2, 241-246.

Ndakidemi, B.; Mtei, K.; Ndakidemi, P.A. Impacts of Synthetic and Botanical Pesticides on Beneficial Insects. Agric. Sci. 2016, 7, 364-372. https://doi.org/10.4236/as.2016.76038.

Nefzi, A.; Abdallah, B. A. R.; Jabnoun-Khiareddine, H.; Saidiana-Medimagh, S.; Haouala, R.; Danmi-Remadi, M. Antifungal Activity of Aqueous and Organic Extracts from *Withania somnifera L.* against *Fusarium oxysporum f.sp. radicislycopersici*. *J*. *Microbial Biochem*. *Techn*. 2016 8, 144-150. https://doi.org/10.4172/1948-5948.1000277

Ngegba, P.M.; Kanneh, S. M.; Bayon, M. S.; Ndoko, E. J.; Musa, P. D. Fungicidal Effect of Three Plants Extracts in Control of Four Phytopathogenic Fungi of Tomato (Lycopersicum esculentum L.) Fruit Rot.

Inter. *J*. *Environ*. *Agric*. *Biotechn*. 2018, 1, 112-117. https://doi.org/10.22161/ijeab/3.1.14.

Nia, B.; Frah, N.; Azoui, I. Insecticidal Activity of Three Plants Extracts against Myzuspersicae (Sulzer, 1776) and Their Phytochemical Screening. *Acta Agric*. *Slovenica*, 2015, 2, 261-267. https://doi.org/10.14720/aas.2015.105.2.09.

Nweke I. A. In support of a well-planned intercropping systems in south eastern soils of Nigeria: A review. *Afr*. *J*. *Agric*. *Res*. 2018, 13(26), 1320-1330 DOI:10.5897/AJAR2017.12743

Nweke I. A. Residual effect of organic waste amendment on soil productivity and crop yield-A review. *Greener J*. *Agric*. *Sci*. 2018, 8(9), 209-218. DOI: 10.15580/GJAS.2018.9.090618129

Nweke, I. A. Soil testing a panacea to crop yield and agricultural sustainability – a case for farmers of south eastern, Nigeria. *J. Agric*. *Sci*. 2020), 2(2), 7-14. https://doi.org/10.30560/as.v2n2p7

Nweke, I. A. Potentials of intercropping systems to soil - water - plant-atmosphere. *J. Agric*. *Sci*. 2020, 2(1), 31-38. https://doi.org/10.30560/as.v2n1p31

Nweke I. A. Alley cropping for soil and agricultural sustainability in south eastern soils of Nigeria. *Sumerianz J*. *Agric*. *Veter*. 2020, 3(1): 1-6.

Odhiambo, A. J.; Siboe, G. M.; Lukhoba, C. W. Dossaji, F. S. Antifungal Activity of Crude Extracts of Selected Medicinal Plants Used in Combination in Lake Victoria Basin, Kenya. *Pl*. *Prod*. *Res*. *J*. 2009, 13, 35-43.

Okunlola, A. I.; Akinrinnola, O. Effectiveness of Botanical Formulations in Vegetable Production and Bio-Diversity Preservation in Ondo State, Nigeria. *J*. *Hortic*. *For*. 2014, 1, 6-13.

Oyedokun, A.V.; Anikwe, J. C.; Okelana, F. A.; Mokwunye, I. U.; Azeez, O. M. Pesticidal Efficacy of Three Tropical Herbal Plants' Leaf Extracts against *Macrotermes bellicosus*, an Emerging Pest of Cocoa, *Theobroma cacao L*. *J*. *Biopest*. 2011, 2, 131-137.

Pal, K. K.; McSpadder, G. B. Biological Control of Plant Pathogens. *The Pl*. *Health Instr*. 2006, 10, 1-25. https://doi.org/10.1094/PHI-A-2006-1117-02.

Pandey, S.; Gill, R. S.; Mandal, K. Persistence and Efficacy of Spinosad, Indoxacarb and Deltamethrin against Major Insect Pests of Stored Wheat. *Pest*. *Res*. *J*. 2016, 28, 178-184.

Pane, C.; Palese, A. M.; Celano, G.; Zaccardelli, M. Effects of Compost Tea Treatments on Productivity of Lettuce and Kohlrabi Systems under Organic Cropping Management. *Italian J*. *Agron*. 2014, 3,1-4. https://doi.org/10.4081/ija.2014.596.

PAN https://www.pan-europe info/old Resources/Reports/PAN 2011, report%20on/%20essential%20use%20 of%20Metam.pdf

Park, J. P.; Gyung, J. C.; Kyoung, S. J.; He, K. L.; Heung, T. K.; Kwang, Y. C.; Kim, J. C. Antifungal Activity against Plant Pathogenic Fungi of Chaetoviridins Isolated from Chaetomium globosum. *FEMS Microbiol*. *Letters*, 2005,252, 309-313. https://doi.org/10.1016/j.femsle.2005.09.013.

Parliman, D. J. Soil Analyses for 1,3-Dichloropropene (1,3-DCP), Sodium N-Methyldithiocarbamate (Metam-Sodium), and Their Degradation

To cite this article: Aloysius, N. L.; Tochukwu, C. R.; Chukwuma Roseline Tochukwu. In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils. *J. Agric. For. Res.* 2021, 1 (2), 136-160.

Products near Fort Hall, Idaho, September 1999 through March 2000. Water-Resources Investigations Report 01-4052, 2001 https://pubs.usgs.gov/wri/2001/4052/report.pdf.

Parte, S. G.; Kharat, A. S.; Mohekar, A. D.; Chavan, J. A.; Jagtap, A. A.; Mohite, A. K.; Patil, R. N. Efficacy of Plant Extracts for Management of Cimex lectularius (Bed Bug). *Inter*. *J. Pure App*l. *Biosci*. 2015, 3, 506-508.

Pascual, J. A.; Hernandez, T.; Garcia,C.; Lerma, S.; Lynch, J. M. Effectiveness of municipal waste compost and its humic fraction in suppressing *pythiumultimum*. *Microbial Ecol.* 2002, 44, 59-68.

Patrice, A. K.; Séka, K.; Francis, Y. K.; Théophile, A. S.; Fatoumata, F.; Diallo, H. A. Effects of Three Aqueous Plant Extracts in the Control of Fungi Associated with Post-harvest of Yam (*Dioscorea alata*). *Inter*. *J. Agro*n. *Agri*c. *Res*. 2017, 3, 77-87.

Pendse, M. A.; Karwander, P. P.; Limaye, M. N. Past, present and future of neuropathogenic fungi as bioagent to control plant-parasitic nematodes. *J. Pl. Protect. Sci.* 2013, 5(1), 1-9.

Powell, W.; Pickett, J. A. Manipulation of Parasitoids for Aphid Pest Management: Progress and Prospects. *Pest Manag*. *Sc i*. 2003, 59,149-155. https://doi.org/10.1002/ps.550.

Prasad, A.; Syed, N. Evaluating Prospects of Fungal Biopesticide Beauveria bassiana (Balsamo) against Helicoverpa armigera (Hubner): An Eco-Safe Strategy for Pesticidal Pollution. *Asian J*. *Experi*. *Biol*. *Sci*. 2010, 3, 596-601.

Radhakrishnan, B. Indigenous botanicals preparations for pest and disease control in tea. *Bul. UPASI Tea Res. Found.* 2010, 55: 31-39.

Randhawa N.; Sakhuja P. K.; Singh I. Management of root- knot nematode Meloidogyne incognita in tomato with organic amendments. *Pl. Dis. Res.* 2001, 16: 274–276.

Rao, K.S.; Vishnupriya, R.; Ramaraju, K. Efficacy and Safety Studies on Predatory Mite, Neoseiulus longispinosus (Evans) against Two-Spotted Spider Mite, Tetranychusurticae Koch under Laboratory and Greenhouse Conditions. *J. Entom*. *Zoo*. *Stud*. 2017, 4, 835-839.

Refki, E.; Sadok, B. M.; Ali, B. B.; Faouzi, A.; Jean, V. F.; Rudy, C. M. Effectiveness of Pheromone Traps against *Tuta absoluta*. *J. Entom*. *Zoo*. *Stud*. 2016, 6, 841-844.

Rodino, S.; Butu, A.; Butu, M.; Cornea, C.P. In Vitro Efficacy of some Plant Extracts against Damping off Disease of Tomatoes. Journal of International Scientific Publications: *Agric*. *Food*, 2012, 2, 240-244.

Romanazzi, G.; Lichter, A.; Gabler, F. M.; Smilanick, J. L. Recent advances on the use of natural and safe alternatives to conventional methods to control postharvest grey mold of table grapes. *Postharvest Bio. Techn.* 2012, 63:141–147.

Sahu, D. K.; Khare, C. P.; Patel, R. Eco-Friendly Management of Early Blight of Tomato Using Botanical Plant Extracts. *J. Ind*. *Poll*. *Cont*. 2014, 2, 215-218.

Sales, M. D. C.; Costa, H. B.; Fernandes, P. M. B.; Ventura, J. A.; Meira, D. D. Antifungal Activity of Plant Extracts with Potential to Control Plant Pathogens in Pineapple. *Asian Pacific J. Trop*. *Biomed*. 2016, 1, 26-31. https://doi.org/10.1016/j.apjtb.2015.09.026.

Salim, H. A.; Salman, I. S.; Ishtar, I. M.; Hatam, H. H.; Evaluation of Some Plant Extracts for their Nematicidal Properties against

To cite this article: Aloysius, N. L.; Tochukwu, C. R.; Chukwuma Roseline Tochukwu. In Support of Biopesticides, Bioheat And Anaerobic Fermentation in Sustainable Agricultural Production in Nigerian Soils. *J. Agric. For. Res.* 2021, 1 (2), 136-160.

Root-Knot Nematode (*Meloidogyne sp*). *J. Gen. Environ. Res. Conserv*. 2016, 3, 241-244.

Sarles, L.; Verhaeghe, A.; Francis, F.; Verheggen, F. J. Semiochemicals of Rhagoletis Fruit Flies: Potential for Integrated Pest Management. *Crop Protect*. 2015, 78, 114-118. https://doi.org/10.1016/j.cropro.2015.09.001.

Selim, H. M. M.; Gomaa, N. M.; Essa, A. M. M. Antagonistic Effect of Endophytic Bacteria against Some Phytopathogens. *Egyptian J. Bot*. 2016, 1, 74-81.

Semeniuc, C. A.; Pop, C. R.; Rotar, A. M. Antibacterial Activity and Interactions of Plant Essential Oil Combinations against Gram-Positive and Gram-Negative Bacteria. *J. Food Anal*. 2017, 25: 403-408. https://doi.org/10.1016/j.jfda.2016.06.002

Sesan, T. E.; Enache, E.; Iacomi, M.; Oprea, M.; Oancea, F.; IacoPenicilliummi, C. Antifungal Activity of some Plant Extract against Botrytis cinerea Pers. in the Blackcurrant Crop (Ribes nigrum L). *Acta Scientiarum Polonorum Technologia Alimentaria,* 2015, 1, 29-43.

Shah, J. A.; Inayatullah, M.; Sohail, K.; Shah, S. F.; Shah, S.; Iqbal, T.; Usman, M. Efficacy of Botanical Extracts and a Chemical Pesticide against Tomato Fruit Worm (*Helicoverpa armigera*). *Sarhad J. Agric*. 2013, 1, 93-96.

Shiberu, T.; Getu, E. Assessment of Selected Botanical Extracts against *Liriomyza* Species (*Diptera: Agromyzidae*) on Tomato under Glasshouse Condition. *Inter. J. Fauna Bio. Stud*. 2016, 1, 87-90.

Sidhu, S. H.; Kumar, V.; Madhu, M. R. Eco-Friendly Management of Root-Knot Nematode, *Meloidogyne javanica* in Okra (*Abelmoschus esculentus*) Crop. *Inter. J. Pure Appl. Biosci*. 2017, 1, 569-574. https://doi.org/10.18782/2320-7051.2507.

Sikora R. A.; Fernandez E. Nematode parasites of vegetables, 2005, p. 319–392. In: "Plant- Parasitic Nematodes in Sub- tropical and Tropical Agriculture" (M. Luck, R.A. Sikora, J. eds)

Silva, F. R.; Moraes, G. J.; Gondim, M. G. C.; Knapp, M.; Rouam, S. L.; Paes, J. L. A.; Oliveira, G. M. Efficiency of *Phytoseiulus longipes* Evans as a Control Agent of *Tetranychus evansi* Baker & Pritchard (*Acari: Phytoseiidae: Tetranychidae*) on Screen house Tomatoes. *Neotropical Entomology*, 2010, 6, 991-995. https://doi.org/10.1590/S1519-566X2010000600022.

Singh, H. B. Management of Plant Pathogens with Microorganisms. Proceedings of the Indian National Science Academy, 2014, 2, 443-454. https://doi.org/10.16943/ptinsa/2014/v80i2/55120.

Song, C. H.; Islam, R. M. D.; Jeong, Y. T.; Lee, Y. S. Isolation and Identification of Antifungal Compounds from Bacillus subtilis C9 Inhibiting the Growth of Plant Pathogenic Fungi. *Mycobiology,* 2012, 1, 59-66.

Souza, R.; Ambrosini, A.; Passaglia, L. M. P. Plant Growth-Promoting Bacteria as Inoculants in Agricultural Soils. *Gen. Mol. Bio*. 2015, 4, 401-419. https://doi.org/10.1590/S1415-475738420150053.

Srijita, D. Biopesticides: An Eco-friendly Approach for Pest Control. *World J. Phar. Pharmaceut. Sci*. 2015, 6, 250-265.

Steinberg, S. (2013) Novel Technologies in Mass Rearing of Beneficial Arthropods. Proceedings of the Annual Biocontrol Industry Meeting, Bael, 1-28.

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Stoneman, B. Challenges to Commercialization of Biopesticides. Proceedings Microbial Biocontrol of Arthropods, Weeds and Plant Pathogens: Risks, Benefits and Challenges. National Conservation Training Center, Shepherdstown, WV, 2010

Sumitra, A.; Kanojia, A. K.; Kumar, A.; Mogha, N.; Sahu, V. Biopesticide Formulation to Control Tomato *Lepidopteran* Pest Menace. *Cur. Sci*. 2014 7, 1051-1057.

Sunder, J.; Singh, D. R.; Jeyakumar, S.; Kundu, A.; Kumar, A. Antibacterial Activity in Solvent Extract of Different Parts of *Morinda citrifolia* plant. *J. Pharmaceut. Sci. Res.* 2011, 8, 1404-1407.

Suprapta, D. N. Potential of Microbial Antagonists as Biocontrol Agents against Plant Fungal Pathogens. *Inter. Soc. Southeast Asian Agric. Sci. J.* 2012, 2, 1-8.

Taye, W.; Sakhuja, P. K.; Tefera, T. Evaluation of plant extracts on infestation of root-knot nematodes on tomato (*Lycopersicon esculemtum* Mill). *J. Agric. Res. Develop.* 2012, 2(3): 86-91.

Vidyasagar, G. M.; Tabassum, N. Antifungal Investigations on Plant Essential Oils: A Review. *Inter. J. Phar. Pharmaceut.* Sci. 2013 2, 19-28.

Vinale, F.; Krishnapillai, S.; Ghisalbertic, L. E.; Marraa, R.; Wooa, L. S.; Loritoa, M. *Trichoderma*-Plant-Pathogen Interactions. *Soil Bio. Biochem*. 2008, 40, 1-10. https://doi.org/10.1016/j.soilbio.2007.07.002.

Wetungu, M. W.; Matasyoh, J. C.; Kinyanjui, T. Antimicrobial Activity of Solvent Extracts from the Leaves of *Tarchonanthus camphoratus* (Asteraceae). *J. Pharmacog. Phytochem.* 2014, 1, 123-127.

Wu, K.; Lin, K.; Miao, J.; Zhang, Y. Field Abundances of Insect Predators and Insect Pests on δ-Endotoxin-Producing Transgenic Cotton in Northern China. Second International Symposium on Biological Control of Arthropods, Davos, 2005, 362-368

Xavier, G.; Chandran, M.; Naseema, B. S.; Mathew, T. B.; George, T.; Vijayasree, V.; Pratheeshkumar, N.; Kumar, S. V. Persistence of Fenpyroximate in Chilli Pepper (*Capsicum annum* L.) and Soil and Effect of Processing on Reduction of Residues. *Pest. Res. J*. 2016, 2, 145-151.

Xiao, Y.; Wei, X.; Ebright, R.; Wall, D. Antibiotic Production by Myxobacteria Plays a Role in Predation. *Journal of Ba cteriology*, 2011, 18, 4626-4633.https://doi.org/10.1128/JB.05052-11.

Xu, X.; Enkegaard, A. Prey Preference of the Predatory Mite, *Amblyseius swirskii* between First Instar Western Flower Thrips *Frankliniella occidentalis* and Nymphs of the Two-Spotted Spider Mite *Tetranychus urticae*. *J. Insect Sci*. 2010, 149, 1-11. https://doi.org/10.1673/031.010.14109.

Zarubova, L.; Lenka, K.; Pavel, N.; Miloslav, Z.; Ondrej, D.; Skuhrovec, J. Botanical Pesticides and Their Human Health Safety on the Example of Citrus sinensis Essential Oil and *Oulema melanopus* under Laboratory Conditions. *Mendel Net*, 2014, 330-336.

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