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Abstract

As the awareness about the environment is increasing among the public, the use of chemicals for the food production is scaring them. They are becoming more interested in organic food. Chemical fertilizers and pesticides are in regular use throughout the world, to increase the yield and to keep the plants and their products safe from diseases.

These chemicals have their advantages and disadvantages. However, nowadays, environmentalists, researchers, and the public are looking more critically at disadvantages. Fortunately, now we have options for replacing or at least minimizing the use of these chemicals. These alternatives are the bioformulations containing living microbes such as bacteria and fungi. These are commercially available all over the world as biofertilizers and biopesticides/biofungicides. These can be used alone or in combination of chemical fertilizers. This article is a review of globally available bioformulations which are “in use” in different parts of the world as well as those which are under the process of commercialization.

15.1 Introduction

Since green revolution, the use of chemical fertilizers has increased tremendously. The use of these chemicals is very important to get higher yield from smaller area, but on the other hand, excessive use of these chemicals is contaminating ground water and soil, decreasing soil fertility and ruining the atmosphere as well. It is becoming a major problem for the public, environmentalist, and industry. As these chemicals are becoming a risk to human health, advanced countries are implementing strong rules and regulations for their use. For Third World countries, cost, preparation, and availability of fertilizers are big issues. Biofertilizer is the most feasible solution to these issues as it is an eco-friendly option and maintains the soil and crop health with increased efficiency. The term “biofertilizers” has been used for several kinds of formulations. In general, anything which is not chemically synthesized, biodegradable, and can be used as a fertilizer, is known as biofertilizer, i.e., compost, humus, animal and human waste, organic matter, etc. However, scientifically, biofertilizer means a fertilizer which contains living organisms and can be broadly classified as nitrogen-fixing and phosphate-solubilizing

biofertilizers which contain bacteria or fungi. Recently, zinc and sulfur solubilizers and potash mobilizers have also been identified as biofertilizers.

When hazardous effects of chemical fertilizers are discussed, the contribution of chemical pesticides cannot be ignored as these synthetic formulations are also equally contributing in destroying the soil, water, environment, and human health. When the use of chemical fertilizers increased the vigor and yield of crops, it also increased the diseases and pest attack on the plants. These factors became responsible for losses of billions of dollars, worldwide. As a next step, chemical pesticides, fungicides, herbicides, bacteriocides, etc. were introduced in the market to protect the crop. These chemicals are mostly applied as foliar sprays and as seed treatment and sometimes on fruits as well to protect them against postharvest diseases. Now, biopesticides have been introduced in the market to reduce the use of chemicals. These bioformulations also contain bacteria and fungi, individually or in combination. These can be used in the same way as the chemicals such as foliar spray, as seed dressing, or as soil treatment.

This chapter is focused on all types of bioformulations including biofertilizers and biopesticides, containing bacteria and fungi as main components. Those which do not contain any living organism have not been included. The brief introduction and information about biofertilizers and biopesticides available in different regions of the world, with their mode of action, wherever disclosed, are provided in the following sections.

15.2 Novozymes (www.novozymes.com)

It is a very well-known European company, based in Denmark which sells several bio-products to increase fertility and yield of crops as well as control the diseases. Their products are available with and without lipo-chitooligosaccharide (LCO) Promoter

Technology. LCO Promoter Technology is a unique molecule that, when present “at the time of planting,” enhances growth processes such as root and shoot development, immediately and independently of variety, soil, and environmental conditions. It provides a healthier start for plants, translating into higher yields and better returns at the end of the season.

The products of Novozymes are available in three categories, i.e., biofertilizers, bio-yield enhancers, and biocontrol products. First two products are commercially available and most of the biocontrol products are under registration process. Only those products which contain microbes are listed below, and detailed information is available on the company’s website.

15.2.1 Biofertilizers

JumpStart contains the fungus *Penicillium bilaii* that makes phosphate available to the plant. Fungus colonizes the plant roots, releases organic compounds into the soil that break the bonds between phosphate and other elements. The plant gets access to more phosphate, and the fungus gets its nutrition from plant, forming a symbiotic relationship. It is available for canola, wheat, and legume crops.

JumpStart LCO is a combination of *Penicillium bilaii* and LCO Promoter Technology. *Penicillium bilaii* unlocks bound phosphate, and LCO Promoter Technology increases root and shoot development in the early growth stages.

TagTeam is a multi-action inoculant, specifically for legumes. It makes better use of phosphate and provides more fixed nitrogen. It is a combination of rhizobia strains with *Penicillium bilaii*. This product is available in granular, peat, and liquid formulations for use on pea, lentil, chickpea, soybean, and dry bean.

TagTeam LCO is a multi-action inoculant that combines the LCO Promoter Technology[®] and

TagTeam, available in liquid and granular formulation, for use on pea, lentil, and soybean.

Cell-Tech (N-Prove) contains “nitrogen-fixing bacteria” (name of organism is not disclosed), making nitrogen available for the plant to use.

Optimize[®] with LCO Promoter Technology[®] combines a nitrogen inoculant with LCO Promoter Technology, available in a liquid formulation for soybean.

Nitragin Gold[®] contains rhizobia strains with patented slow-drying system, assures a high number of bacteria on the seed, and results in high levels of nitrogen fixation for maximum yield, available for alfalfa and sweet clover.

Apron[®] XL/Allegiance[®] FL compatible Nitragin Gold compatibility with Apron XL and Allegiance FL ensures the combined benefits of an inoculant and a fungicide where required. Both products have high bacterial count for excellent longevity (18 months on alfalfa and sweet clover) and treat alfalfa and sweet clovers (white, yellow, hubam, madrid, bitter, and sour clover).

RhizoMyco contains 18 species of endo- and ectomycorrhizae and growth-promoting substances. It is available in a soluble/injectable form to provide broad-spectrum application for increased nutrient uptake and enhances root systems.

RhizoPlex is uniquely formulated with Novozymes proprietary blend of patented bacterial cultures and stress reducing ingredients, plus 18 species of endo- and ectomycorrhiza.

RhizoMyx is an endomycorrhiza inoculant designed to improve the plant performance by increasing root development, making nutrients more available.

Legume inoculants **Glycimax[®]**, **Rhizomax[®]**, and **Legumax[®]** effectively supply nitrogen to a wide range of legume crops.

15.2.2 Bio-yield Enhancers

RhizoBio[®] is composed of 18 species of endo- and ectomycorrhiza and a complex biostimulant for increased nutrient and water uptake and tolerance to stress.

RhizoMyx[®] is uniquely formulated with nine species of endomycorrhiza and a biostimulant to provide broad-spectrum application for increased nutrient and water uptake and tolerance to stress.

15.2.3 Biocontrol Products

Met52 is a bioinsecticide, containing spores of the soil fungus *Metarhizium anisopliae*. Suspended spores of *Metarhizium* attach to the surface of the target insect, germinate, penetrate the exoskeleton, and grow inside the pest, and death of target pest takes place in few days.

Taegro is a bacterial-based biofungicide/bactericide used for suppressing selected soilborne and foliar diseases.

15.2.3.1 Under Registration Process

TrichoderMax[®] contains the fungus *Trichoderma asperellum* for the effective control of a number of significant soilborne crop diseases.

BoveMax[®] is a bioinsecticide containing *Beauveria bassiana* for the control of Broca (*Hedypates betulinus*) infestations in Erva-mate plantations.

MethaMax[®] is a bioinsecticide containing *Metarhizium anisopliae* for the control of Cigarrinha (*Mahanarva fimbriolata*) infestations in sugarcane.

15.3 BioAgri (<http://www.bioagri.se>)

Lantmännen BioAgri AB is established since 1996 in Sweden. The main focus of the company is to control the seed-borne diseases of grains. The company developed and marketed three biopesticides and a biofertilizer. Biopesticides are based on *Pseudomonas chlororaphis* strains. Their products are available all over the Europe for 10 years. Brief information about their products is given below:

15.3.1 Cedomon[®]

Cedomon is a biopesticide that contains *P. chlororaphis* as an active ingredient. However, it also contains other ingredients, such as rapeseed oil, which supports its application. This product is available since 1997, and it is effective against several types of seed-borne diseases on barley and oats except barley loose smut caused by *Ustilago nuda*. In some countries, treated seed has also been approved for use as feed.

Cedomon[®]-treated seed can be stored, transported, and handled in the same manner as normal seed. The product can be used in most treatment equipment. The recommended dosage is 7.5 L/ton of seed. Shelf life of the product at 4–8 °C is up to 8 weeks after delivery and 3 weeks at room temperature. Treated seeds can be stored for up to 1 year. Cedomon[®] is currently approved for use in Sweden, Finland, Norway, Denmark, Poland, Lithuania, and Italy. A large portion of Swedish grain seed is treated with Cedomon[®]. Since its launch, a total of approximately two million hectares (in several countries) have been sown with Cedomon[®]-treated seed.

15.3.2 Cerall[®]

Cerall[®] is also a biopesticide with *P. chlororaphis* and water. It has been developed

so as to be specially adapted to bare seeds such as wheat. It is effective against the seed-borne diseases of wheat such as common wheat bunt (*Tilletia caries*), wheat leaf spot (*Septoria nodorum*), and *Fusarium* (*Fusarium* spp.) in wheat. It is also effective against the seed-borne diseases caused by *Ascochyta* spp. The recommended dosage is 10 L/ton of seed. Its shelf life is same as for Cedomon. Cerall[®] is currently approved for use in Sweden, Finland, Switzerland, Lithuania, and Austria.

15.3.3 Cedress[®]

This product also contains the same ingredient as Cerall (*P. chlororaphis* and water), but it has been developed specially for the treatment of pea seeds. Recommended dosage and shelf life are same as for Cerall. Cedress[®] is currently approved for use in Sweden.

15.3.4 Amase[®]

It is a biofertilizer, based on *Pseudomonas azotoformans* and organic and inorganic nutrients. It is a dry product for growth stimulation of plants and can be mixed in peat-based substrates or in irrigation water. It is easily absorbed by the roots to provide long-term growth-promoting effects. It helps plants to quickly produce a large and strong root system, more resistant to stress and grow faster. It is recommended to be used for potted plants and nursery plants. Pine, spruce seedlings, cucumber, lettuce, tomato, peppers, eggplant, cabbage, and broccoli have shown good results with this product.

15.4 Fertibio (www.fertibio.com)

Fertibio is a Spanish company which makes biofertilizers and biopesticides as well as organic fertilizers and pesticides which are biodegradable. Their bio-products are described below.



Fig. 15.1 Bioformulations of Fertibio, Spain; biopesticide Bioscrop BT16 and biofertilizer Rhizosum N

15.4.1 Bioscrop BT16

It is a biopesticide based on *Bacillus thuringiensis* var. *kurstaki* (16 million IU/g) (Fig. 15.1). It is active against lepidopteran larvae and beetles. δ -Endotoxin synthesized by this bacterium is ingested by insect and causes injuries and paralysis of the digestive tract. Insect dies within 24–48 h. It is applicable to cotton, citrus, cauliflower, deciduous fruit trees, horticultural brassicas, olives, pepper, banana, and tomato. It is dissolved in water and applied as foliar spray (0.5–1.5 kg dissolved in 800–1,000 L and applied on 1 ha).

15.4.2 Rhizosum[®] N

The biofertilizer product is named as Rhizosum N (Fig. 15.1). It contains nitrogen-fixing bacteria but genera are not disclosed. The advancement of technology allows the crops to get nitrogen from the atmosphere. Recommended doze supplies 30–50 units of nitrogen per hectare, depending on soil moisture and season.

15.5 Symborg (www.symborg.com)

Symborg SL is a Spanish company which sells its product all over Europe and USA. The company has launched three products (Fig. 15.2) described below.



Fig. 15.2 Bioformulations of Symborg, Spain

15.5.1 MycoUp

It is a biological inoculant based on *Glomus iranicum* var. *tenuihypharum*, a mycorrhizal fungus (1.2×10^4 propagules/100 ml substrate). It is a root colonizer that boosts plant growth by more efficient water and nutrient absorption, improving plant vigor. It is recommended for vegetables, fruits, and woody crops at the rate of 2 kg/ha.

15.5.2 MycoUp Attack

This biological inoculant is a combination of MycoUp (1.2×10^4 propagules/100 ml substrate) and “Attack.” Attack is an organic complex, with MycoUp; it promotes the microbiotic activity of the soil, stimulates mycorrhizal growth, and activates the plant’s defense system against nematodes and other phytopathogens. It is recommended for vegetables and woody crops at the rate of 2–3 kg/ha. Diluted solution of the product should be applied close to root system by injection or drip irrigation.

15.5.3 Resid

It is a biological product which contains *G. iranicum* var. *tenuihypharum* as its active ingredient with two mineral clay substrates, bentonite

and smectite with a concentration of 0.5×10^3 propagules in 100 ml substrate. It is recommended for grains as seed coatings at the rate of 5 kg/100 kg seeds. Resid increases agricultural yields by optimizing fertilizer, water and soil inputs, tolerance to drought and salinity, and protection against fungal root diseases; contributes to soil regeneration through mycelium network; restricts the loss of CO₂ by recapturing it and converting it into fungal biomass; and produces no harmful residues.

15.6 Biagro (<http://www.biagrosa.com.ar>)

Biagro S.A. was established in 1984 in Argentina. Legume inoculants are their main products.

15.6.1 Nodulest 10

The soybean inoculant “Nodulest 10” is prepared by mixing a pure culture with sterilized *Sphagnum* peat moss. The product contains two different strains of *Bradyrhizobium japonicum* (USDA 138 for USA, 532C for Canada) depending on the country where it is used. The product has very high concentration of *B. japonicum* ($>2 \times 10^{10}$ /ml). Therefore, a small quantity of carrier (peat moss) is used per bushel (60 lbs) of soybean seed. This characteristic allows the inoculant with

lesser risk of blockage of seeders. Biagro S.A. is actively engaged in the search and selection of more efficient rhizobial genotypes to be used under suboptimal soil and climatic conditions.

15.6.2 Liquid PSA

It is a commercial formulation that contains *Pseudomonas aurantiaca* strain SR1. It is registered with Argentina's National Service for Agricultural Health (SENASA) for wheat growth promotion.

15.7 Labiofam (www.labiofam.cu)

It is a scientific institution of Cuba producing pharmaceutical products, biopesticides, and biofertilizers as well. Biopesticides are for killing mosquito larvae and rats. Biofertilizers under the name of Nitrofix and Bioenraiz are available. Nitrofix contains *Azospirillum brasilense*, and Bioenraiz contains phytohormones extracted from *Rhizobium*. Information about application of these biofertilizers or any detail about these products is not shared on the website.

15.8 Flozyme (<http://www.flozyme.com/agriculture>)

Flozyme Inc. was founded in 2012 in Atlanta, USA, and offers the solution for cleaning wastewater and agriculture. One of their biofertilizer products is described below.

15.8.1 Inogro

It is a cocktail of more than 30 microbes, selected for their abilities to rehabilitate soil and make it more productive. The product is organic, sustainable, environment friendly, and highly compatible with organic farming practices. It is suspended in 12 % humic acid carrier and stabilized at pH 7, due to which it effectively works in varied climates and soil conditions. These humates are high in organic matter and micronutrients, including Ca, Mg, Zn,

Mn, etc. and also act as carbon sources for the microbes. This microbial formulation unlocks bound nitrogen in the soil and absorbs nitrogen from the air, solubilizes bound phosphate, and makes it available to plants for optimal growth and development. It is highly competent in soil and also promotes a healthy soil pH. It captures additional water and available nutrients from naturally occurring organic matter in the soil that enables plants to better sustain adverse environmental conditions. This product is claimed to inhibit plant pathogens, enhance the plant's natural defense mechanisms by *Trichoderma* strains (present in product), and increase the plant's resistance to pests.

Inogro is shown to increase crop yields by 20–400 % and decrease the use of chemical fertilizer from 50 % to 100 %. The product also reduces water requirements (~20 %) and pesticide usage. Crops have shown higher nutrient content, faster and earlier germination, earlier maturation, and ability to withstand stresses. During greenhouse trials, increased yields of 301 % for rice, 400 % for tomatoes, 127 % for soybeans, 86 % for peas, 258 % for okra, 234 % for peanuts, and over 100 % for garden beans and wonder bush beans have been shown.

15.9 AgriBiotics Product, Inc. (www.agribioticproducts.com)

The product is developed by Michigan State University (MSU) and manufactured by BioSoil Enhancers, Inc. Mississippi. Product brand is described below.

15.9.1 AgriBiotic Microbics with SumaGrow

SumaGrow is a combination of several microbes including bacteria and fungi (Fig. 15.3). It is a polymicrobial inoculant, a cocktail of more than 30 microbes with multiple functions. These microbes include nitrogen-fixing microbes isolated from leguminous and nonleguminous crops. Liquid humate is used as a carrier for the microbes. These microbes work under aerobic,



Fig. 15.3 A bioformulation developed by Michigan State University, USA

non-aerobic, acidic, and alkaline conditions, therefore useful for multiple crops under multiple conditions. The SumaGrow microbial formulations improve nutrient and water uptake, enhance root and plant growth and crop yield, improve plant efficiency to use solar energy, reduce stresses of transplanting and drought, increase cation exchange capacity, improve soil health and water retention, help release micronutrients and trace elements, stimulate germination, increase healthy decomposition of organic matter, and reduce putrefaction.

The company claims innovation as compared to competitors due to four reasons, First, it contains multiple groups of organisms (up to eight), second, the product has six functions vs. two functions, third, it retains viability over a long period of time at ambient temperature, and fourth, it is concentrated at 10^{17} vs. 10^8 – 10^{10} CFU/ml. The product has demonstrated the ability to increase crop yields by 20–200 plus % while decreasing fertilizer usage from 50 to 100 % and reduces water (estimated 20 plus %) and pesticide usage. Experiments performed by MSU showed a 301 % increase in rice yield, 400 % increase in tomato yield, 127 % in soybeans, 86 % in peas, 258 % in okra, 234 % in peanuts, and over 100 % in garden beans and wonder bush beans in greenhouse.

Recommended application dose is one gallon per acre, diluted in the desired amount of water. For second application, foliar spray is recommended. It can be applied with irrigation water and with liquid nitrogen and herbicides but not with fungicides. Product should be applied

without any fertilizer or with half dose of fertilizer.

15.10 Mapleton Agri Biotec Pty Limited (mabiotec.com)

It is an Australian company with three major products. This company is distributing its products in Australia, USA, UK, Europe, North and South Africa, Turkey, South America, and several other countries.

15.10.1 TwinN

It is a freeze-dried microbial inoculum packed under vacuum which provides it a longer shelf life. For application, initially, it is dissolved in small amount of water and later in large amount. It contains a consortium of microbes which includes nitrogen fixers, phosphate solubilizers, and growth hormone producers. These microbes can live in rhizosphere, root, shoot, and leaves as endophytes. It is an inoculant for crops, pastures, and trees. This product can be applied through irrigation system, sprinkler, spray, etc., depending on the crops.

15.10.2 CataPult

It contains the vesicular-arbuscular mycorrhizal (VAM) fungus *Glomus intraradices* and two species of *Bacillus* with its unique release and catch technology. It is available in granular form. It is easily applied at planting stage at the rate of 1.75 kg/ha. The P-solubilizing *Bacillus* species in CataPult colonize the roots and rhizosphere and solubilize P that is unavailable to the plant. In many soils, large amount of applied P ends up in bound form that can be accessed by CataPult “release and catch” technology. The *Bacillus* species stimulate a more vigorous root system and root hairs and suppress a number of root pathogens. VAM colonizes the roots and a network of hyphae extend beyond the root hair zone.

These hyphae collect P, N, Ca, Mg, and micronutrients and deliver them to the plant.

15.10.3 Nitroguard

Information about this product is not released.

15.11 EM Pro-agriculture

During 1980, EM technology was developed in Japan. EM is a naturally fermented liquid probiotic solution which contains “effective microorganisms” including lactic acid bacteria, yeast, and phototrophic bacteria. These are non-pathogenic and not genetically modified organisms (non-GMO). It is a cost-effective technology and beneficial for agriculture. EM works by improving the soil ecology to assist in plant growth and health.

EM microbes secrete vitamins, organic acids, minerals, and antioxidants, increase humus content of the soil, and provide better environment for other microorganisms and plants for better growth. Photosynthetic microbes, another constituent of EM, have powerful detoxifying, antioxidative, and antientropic properties which improve the poor soil. Plants inoculated with EM had shown higher yields. It improves soil structure and nutrient availability, lowers disease

pressure, and improves the quality of produce and storage life. EM can be applied on seeds, at the time of transplantation, as foliar spray and for soil treatment.

15.12 Bio Power Lanka (www.biopowerlanka.com)

It is a company based in Sri Lanka. Among their agri-related bio-products, three of them contain microbes.

15.12.1 Bio Vaccine

It is a biofungicide that contains *Trichoderma viride* (Fig. 15.4). It protects the plant from rot and wilt diseases. It destroys the pathogenic fungi including *Pythium*, *Rhizoctonia*, and *Fusarium* spp. that cause root rot, stem rot, seed rot, fruit rot, and wilt diseases. *T. viride* grows like coils around the pathogen and degrades the cell wall of the pathogenic fungi by secreting a wide variety of enzymes including celluloses and chitinases. This process is known as mycoparasitism – one fungus killing the other fungus by limiting its growth and metabolic activity. *T. viride* also induces systemic resistance and prepares the plants to destroy the pathogens. The product helps the root system to

Fig. 15.4 A biofungicide and a liquid biofertilizer launched by BioPower, Sri Lanka



increase uptake level of nutrients and moisture which will improve the tolerance to stressful growth conditions. The product contains 2×10^8 spores/ml. It is recommended to dilute and apply at nursery and transplantation stage to control soilborne diseases.

15.12.2 Bio Gold

Bio Gold is a liquid formulation that contains native isolates of compatible microorganisms such as *Azotobacter chroococcum* and *Pseudomonas fluorescens* (Fig. 15.4). *A. chroococcum* is a nitrogen-fixing soil bacterium which improves the soil properties by secreting polysaccharides and provides nitrogen to the crop in a balanced way. This bacterium also contributes to drought and disease resistance by improving soil's physical properties and secreting various growth-promoting substances. *P. fluorescens* is a potential bionematicide and used for cardamom, potato, and other vegetable crops, fruits, and cereal crops. Secondary metabolites produced by this bacterium are highly effective to control rot and wilt diseases of plants and nurseries. This bacterium also secretes various organic acids that help in the solubilization of insoluble phosphorus, and hence, the phosphorus availability to crops is increased. The product can be applied to all agricultural and horticultural crops by spraying around the root zone, as a foliar spray, by drip irrigation, and as a seed inoculant.

15.12.3 Bio Phos[®]

It is a liquid formulation which contains *Bacillus megaterium* – a phosphate-solubilizing bacterium. The use of Bio Phos[®] and Eppawala rock phosphate (ERP) mixture for plantation crops can reduce the recommended ERP doze by 50–75 % to the fact that available phosphorus content is increased. ERP+ Bio Phos[®] mixture could be used for annual crops to supply the recommended phosphorus requirement, as a substitute of Triple Super Phosphate (TSP).

15.13 AgriLife (www.agrilife.in)

The company is based in Hyderabad, India, and their products include biofertilizers, biopesticides, biostimulants, and other agri-related products. Among biopesticides, three types of products are available based on botanicals, microbes, and nanoparticles. Those which contain microbes have been discussed in this chapter.

15.13.1 Biofertilizers

AgriLife has launched 15 biofertilizers (Fig. 15.5), based on nitrogen fixing, phosphate solubilizing, potassium, ferrous, sulfur, silica and zinc mobilizing bacteria, manganese-solubilizing fungus, and vesicular arbuscular mycorrhizae (VAM). Each biofertilizer has a



Fig. 15.5 Biofertilizer formulations of AgriLife, India

single bacterial strain; consortium is not used in any biofertilizer. For each nutrient, a specific biofertilizer is available.

15.13.1.1 Agrilife Nitrofix

These are nitrogen-fixing biofertilizers that contain *A. chroococcum* (MTCC 3853), *A. vinelandii* (NCIM 2821), *Acetobacter diazotrophicus* (MTCC 1226), *Azospirillum lipoferum* (NCIM 2908), and *Rhizobium japonicum* (NCIM 2743). Each biofertilizer is recommended for a different crop and with a different mode of application depending on crop. However, all of these are available as carrier-based powders containing 5×10^7 CFU/g or in liquid form 1×10^8 CFU/ml.

15.13.1.2 P Sol B

These are phosphate-solubilizing biofertilizers and contain *Pseudomonas striata* (NCIM 2847), *Bacillus polymyxa* (NCIM 2188), and *Bacillus megaterium* (NCIM 2087). All of these are available as carrier-based powder containing 5×10^7 CFU/g or in liquid form 1×10^8 CFU/ml. These biofertilizers can be applied on seed, seedling, and soil or through drip irrigation.

15.13.1.3 Agri Life AgriVAM

It is based on spores and fragments of VAM (*Glomus* species) with vermiculite as carrier. It has 100 infective propagules/g. It helps in water absorption, phosphorus solubilization, and macro- and micronutrient availability and improves drought tolerance and resistance to soilborne fungal pathogen. It can be applied to soil, seed, and nursery bed and at planting stage.

15.13.1.4 Fe Sol B

It contains an autotrophic, acidophilic *Acidithiobacillus ferrooxidans* that releases iron oxidase which metabolizes ferrous. It is available as carrier-based powder or in liquid form. It can be applied to seedlings and soil or by drip irrigation.

15.13.1.5 K Sol B

It contains *Frateria aurantia* which produces organic acids and enzymes which mobilize potassium ions. It is available as carrier-based

powder containing 5×10^7 CFU/g or in liquid form 1×10^8 CFU/ml and can be applied to seedlings and soil or through drip irrigation.

15.13.1.6 Mn Sol B

It contains an aerobic fungus *Penicillium citrinum* which produces citric acid and oxalic acid and solubilizes manganese. It is available as wettable powder and contains 5×10^7 CFU/g, applicable to seedlings and soil and through drip irrigation as well.

15.13.1.7 Si Sol B

It contains spores of *Bacillus* species releasing organic acids which play role in silicate weathering. Silica helps the plant to tolerate biotic and abiotic stresses and pest and disease attack. This product is available as wettable powder containing 1×10^8 CFU/g, applicable to seed, seedling, and soil and by drip irrigation.

15.13.1.8 S Sol B

This product contains autotrophic, acidophilic bacterium, *Thiobacillus thiooxidans*, that oxidizes sulfur and secretes organic acids, bringing down the pH of soil and helpful in reclaiming alkaline soil. It is applicable to seedling and soil and by irrigation.

15.13.1.9 Zn Sol B

This biofertilizer contains another strain of *T. thiooxidans* that oxidizes zinc and makes it available to the plant. This product can be applied in the same way as S Sol B.

15.13.2 Biopesticides

Twenty-two biopesticides have been launched by the company (Fig. 15.6). One of them is for mosquitoes; however, the rest of them are to treat agriculture-related problems. Few of them are consortium based and their active ingredient and/or details of microbes are not shared. Some of them are based on individual bacterial or fungal strains to kill nematodes and insects or treat fungal diseases. A brief introduction is given below.



Fig. 15.6 Biofungicides formulated and marketed by AgriLife, India

15.13.2.1 BioKuprum

This product contains the fungus *Chaetomium cupreum* and protects the plants from diseases like rusts, blights, rots, and leaf spots. It is formulated as wettable powder with 2×10^6 CFU/g. It can be applied on seeds and tubers or as a foliar spray.

15.13.2.2 Biotilis

This biofungicide also works as biofertilizer as it contains *Bacillus subtilis*, plant growth-promoting rhizobacteria (PGPR). As a fungicide, it targets rots, blights, wilt, leaf spot, and mildews. This product is available in powder form containing 1×10^8 CFU/g or 1×10^9 CFU/g.

15.13.2.3 Downycare

This product is specifically formulated to treat downy mildew disease of plants caused by different fungal pathogens. It contains spores and mycelium fragments of fungus *Fusarium proliferatum*. Powder formulation containing 1×10^8 CFU/g is recommended to be used as foliar spray.

15.13.2.4 Ecosom TV

Trichoderma viride containing bioformulation protects the plants from soilborne and seed-borne fungal pathogens. With 2×10^6 CFU/g, it can be applied as seed dressing, in the soil, or by drip irrigation.

15.13.2.5 Ecosom TH

Trichoderma harzianum containing formulation is a biofungicide and a bionematicide. It protects the plants from fruit rot and pathogenic nematodes. Formulation is available in powder form containing 2×10^6 CFU/g. It can be applied as foliar spray, by drip irrigation, by soil drenching, by root dipping, and at nursery stage.

15.13.2.6 Powderycare

Ampelomyces quisqualis is a fungus that protects plants from powdery mildew causing plant pathogens. Powdery formulation contains 2×10^6 CFU/g and it is applied as foliar spray.

15.13.2.7 Sheathguard

This product is a biofungicide, a bionematicide, and a biofertilizer as it contains the PGPR *P. fluorescens*. It kills pathogenic nematodes and protects plants from sheath blights and other fungal diseases. Formulation is used as a seed dressing or applied on nursery beds before transplanting the crops.

15.13.2.8 Biofit

It is a microbial consortium with an antifungal and PGP activity. It targets the fungi which cause rots, blights, and mildews.

15.13.2.9 Biorub

This product is specific for pink disease of rubber plant caused by a fungus. Formulation contains

consortium of antagonistic microbes with 1×10^8 CFU/g. It can be applied as foliar spray, by soil application, and by stem swabbing.

15.13.2.10 Diebackcare

It is a consortium-based biofungicide for dieback disease of orchards and should be applied on soil.

15.13.2.11 Seedguard

It comprises PGPR and microbial cultures with antifungal properties which encourage seed germination and control seed-borne fungal diseases. It is a microbial concentrate developed for seed coating.

15.13.2.12 Insecticides and Nematocides

Other than biofungicides, several nematocides and insecticides have also been launched (Fig. 15.7). They include: Bionemagon (nematocide) which contains *Bacillus firmus*; Paecilo (nematocide) which contains *Paecilomyces lilacinus*; BorerGuard (insecticide) which contains microbial consortium and protects plants from borer attacks; Lipel which contains *B. thuringiensis* var. *kurstaki* and protects crops from flying insect pests; Mealikil plus (insecticide) which contains *Verticillium lecanii* that kills mealybugs and sucking insects; Pacer (insecticide) which contains *Metarhizium anisopliae* and kills soil insects; Paecilomite (insecticide) which contains *Paecilomyces fumosoroseus* and kills many types of insects

and mites; and Racer (insecticide) which contains *B. bassiana* and kills insects pests.

15.14 Commercially Available Biofertilizers in Pakistan

15.14.1 Fertibio

It is a biofertilizer launched by a private company “Microbial Biotechnologies.” It contains a mixture of nitrogen-fixing, phosphate-solubilizing, and growth hormone-producing bacteria. Formulation is available in powder form, and it can be applied as a seed dressing and through irrigation as well as by sprinkling. It is recommended for rice, wheat, corn, cotton, sugarcane, and vegetables.

15.14.2 BioPower

A government research institute has launched a biofertilizer with the commercial name of “BioPower” in 1996. It is being produced and marketed for various leguminous and nonleguminous crops, like cotton, maize, rice, sugarcane, and wheat (Fig. 15.8). For every crop, a different consortium of PGPR has been used. It can be applied in powder form as well as in solution form, at the time of transplantation and after transplantation depending on the type and requirement of crops.

15.14.3 Auriga Group (www.aurigagroup.com)

Biofertilizer is one of the products manufactured by Auriga Group of industries. This product contains gram-positive phosphate-solubilizing bacteria which increase fertilizer use efficiency of added phosphate fertilizer and ensures phosphorus availability till crop matures. Plant growth hormone-producing bacteria are also included in this product that enhance the plant growth and enable the high yield. This company



Fig. 15.7 Bioinsecticide and bionematicides products by AgriLife, India



Fig. 15.8 A biofertilizer produced by a research institute of Pakistan

is currently working on formulation of biopesticides.

15.15 Future of Bioformulations

Among bioformulations, biofertilizers can be divided into two major categories: nitrogen fixers and nutrient solubilizers/mobilizers. Most of the nitrogen-fixing biofertilizers contain *Azospirillum*, *Azotobacter*, and *Rhizobium*, and phosphate solubilizing have *Bacillus* and VAM. Recently, zinc, sulfur, and potash mobilizers/solubilizers have also been launched in the form of biofertilizers. Biofungicides are based on *Trichoderma*, *Bacillus*, and *Pseudomonas* strains of different species. These bacterial and fungal strains are common residents of plants rhizosphere.

For more than 100 years, biofertilizers are in use, in developed part of the world. However, it could not get the same level of popularity and usage as the chemical fertilizers still do. Among advanced countries, the major reason is inconsistency in the results of field application of biofertilizers. In the developing world, lack of awareness among

farmers is the major hurdle in the growth of biofertilizer market. Looking at the current situation of fossil fuels, other alternative energy resources, high prices of chemical fertilizers, pesticides, herbicides, fungicides, and insecticides, on-time availability of these chemicals; bioformulations seem the only answer and the most effective solutions of these problems.

North America is promoting the use of bioformulations over chemical ones, due to their concern about human health- and environment-related issues. European union is promoting not only the use of bioformulations but organic farming as well through “common agriculture policy” by providing up to 30 % of payment as direct green payment. Among Asian countries, the government of China is promoting the production of bioformulations indirectly by tax holidays, exemption of VAT, and excise and agriculture tax to manufacturing industries of these products. Promoting the use of biofertilizers is part of the 5-year plan of the Indian government. The first biofertilizer, “BioPower,” in Pakistan was launched by a government organization in 1996, and since then, they are selling it. Later on, several private companies started its manufacturing. Currently, at private level, Auriga is the biggest group of companies manufacturing as well as promoting the awareness and use of bioformulations among farmers.

A statistical review on the global scale of biofertilizers was published in January 2014. (<http://www.grandviewresearch.com/industry-analysis/biofertilizers-industry>). According to this, North America is the most dominant market of biofertilizers as it is valued at USD 420 million in 2012, followed by Europe. It reflects the fact that biofertilizers were first commercialized in North America and Europe; however, now, demand is increasing in South America and Asia Pacific as well, making it third in the row, in the biofertilizers market. Among the global revenues from biofertilizers, nitrogen fixers make the major contribution of 77 %, phosphate solubilizers are at 15 %, and the rest of the biofertilizers are responsible for 8 %. The global biofertilizers market is projected to generate USD 1650 million by 2019.

Looking at the current scenario, the future of bioformulations seems very bright. Due to awareness about hazardous effects of chemical formulations on human health and environment, acceptance of these formulations by general public has been increased. Now, it is time that governments should interfere, and with the help of regulatory authorities, the use of these formulations should be enforced in countries where farmers are not using them at large scale. Researchers should also play their role by searching for more diverse bacterial and fungal organisms rather than sticking to only two to three traditional genera.

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