Biocontrol Agents as Strategy of Agro-ecosystem Management to Restitution of Productive Soils for Food Production

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Abstract

This chapter analyzes and describes the importance and application of biocontrol agents as an alternative of managing agroecosystem for restitution of productive soils for food production. Also, the ethics, benchmarks, biosafety rules, and the various approaches and explicit features of controlling the production of food in conventional ways and emerging trends for the conservation of foods are included. Biocontrol has an important impact on the maintenance, safeguarding, and security provision on ecological and environmental aspects toward promoting the biosafety for food production. The term biocontrol incorporates the maintenance, conservation, and care of fauna and flora, as well as the native habitat on this earth. The precautionary courses include all those things where biological security must be guaranteed for all forms of life; consequently, the damages and hazards instigated should be minimalized or diminished. In any course or progression where we are employing physicochemical and biological

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agents, usually there are chances of hidden risk; therefore it becomes very significant for us to understand and look for the preventive measures. Recently, the use of microbial sources as biological agents has become one of the greatest challenges that have captured the attention of everyone globally. This is chiefly owing to the intensified application of biological agents in numerous industries all over the globe, for example, food and feed production, agricultural products, value-added compound production, etc.

10.1 Introduction

Currently, the world population is over 7.5 billion, and according to a United Nations report, it could exceed 10 billion this century. This considerable demographic increase has alarming consequences directly impacting a medium environment by the over production of necessary inputs for daily life, the increase of urbanized zones, the contamination of soil and water air, as well as the exhaustion of natural resources (Al 2017).

This imminent population growth demands a higher production of food, since the rates of soil degradation are higher than the reconstruction of the formation of this. The factors influence the quality and the quantity of raw materials (Wang et al. 2015).

A soil should be considered as productive or fertile implies that can give life to another type of vegetation depending on the characteristics of the region as temperature and humidity, in addition to others such as pH, a balance in the composition of sands, clays and silts among them are soil organisms known as soil-endemic biota (Blaser et al. 2017; Torquebiau 2000). These microbes are particularly an essential part for the reconstruction of the soilfor the reconstruction of the soil and some have the ability to degrade organic matter, such as animal waste and plants being able to use as their food, also helps the plant that excess food such as Nitrogen phosphorus (Santamaría-Romero et al. 2001). The organic matter decomposition is a natural biological progression, and the speed with which it happens is mainly by the nature of organic matter. The quality of organic matter, the physical environment and the composition of soil organisms helps in building up of fertile land (FAO 2006).

The main energy-recycling organisms in the soil are invertebrate grids such as worms and insects and microorganisms; in the part of microorganisms, there is a wide variety such as bacteria, fungi, protozoa, nematodes, viruses, and algae (Sivila de Cary and Angulo 2006). Each microbe fulfill a specific function and complement each other as is the example of the bacteria that help by decomposing simple substrates in contrast the fungi decompose more resistant organic matter like proteins and the protozoans are those that contribute greater nitrogen production releasing it in ammonia to be more digestible for plants, to remark a few (Tokpah et al. 2016).

However, the need to eradicate pathogenic pests affecting crops and products has focused on the use of herbicides, pesticides, and pesticides of synthetic origin of broad-spectrum dating from 1940 in the so-called era of synthetic products which carries consequences (Plenge-Tellechea et al. 2007), as well as environmental damages due to its soil residual capacity and contamination of aquifers, without the damages in natural biota. Pesticides can enter the food chains accumulate successively until they reach a lethal concentration for some organism (Gutiérrez et al. 2013).

For all this, agriculture demands the application of new technologies and strategies to reconstruct the agroecological soil balance where the introduction of alternatives of chemical control is implemented under two approaches: integrated pest management (IPM) consisting in the growth of healthy crops, which disrupts agricultural ecosystems as little as possible and promotes natural pest control mechanisms such as good agricultural practices, biological control, and the rationalization of natural resources, and ecological pest management (MEP), which is the use of biological control agents and organic agriculture (Ripa et al. 2008).

10.2 Damage in Soils

The soil is an invaluable natural resource; it constitutes the support of the plants which provides the necessary conditions that are required to live, and this is where microorganisms that develop some important biochemical cycles live, necessary for the preservation and development of the ecosystems (Lal 2014).

After social human evolution and their transition to sedentary lifestyle humans have developed activities such as agriculture and cattle raising in order to supply themselves with food, and with the passage of time have become a fundamental support for the preservation and development of the societies, starting from the need to supply themselves of resources and turn it later into sources of real economic development (Suding and Hobbs 2009).

However, as it is well known, the misuse of resources most of the time ends by deteriorate or exhausting them in the worst case and this is not the exception, bad practices and lack of planning and setting long-term and medium-term developed over the years have made the soil affected in a way that it is damaging its quality to the degree to leave it in some cases eroded and infertile (Dubovyk 2017). In this way they are incapacitated to continue the agricultural production as well as livestock because they lose the properties that allow to develop the agriculture and the characteristics necessary to keep livestock animals, representing on this way, a real impact not only ecological but also economic (López Reyes 2001).

The wear of the soil is made present indiscriminately in all parts of the world; the poor state of the land is derived from pollution, physical and biological degradation (Suding and Hobbs 2009). Activities such as cattle raising produce considerable damage to this resource due to their inadequate and careless implementation, leading to a deterioration of soil, derived from an animal overpopulation, which by pasturage and compacting the land generated by the passage of livestock, ends with great percentage of natural vegetation of the lands (Pietola et al. 2005). Such is the case of

Sonora, Mexico, where wear is such that practically all the state suffers this condition, despite the restoration activities implemented (López Reyes 2001).

On the other hand, the role of agriculture is not left behind. In the province of Cienfuegos, Cuba, studies have been carried out to determinate through the use of a technique based on the analysis of the tracer radius "cesio 137" areas with the highest erosion rate obtaining as a result that there were those destined to agriculture. Similarly, other regions of the country have been assessed by the same technique as the Pinar del Rio obtaining similar results, indicating a larger cup of erosion in agricultural production lands than those with topographical characteristics who naturally favor it (Gil et al. 2009).

Another example we have is southern Uruguay, a country with significant 30.1% erosion derived from activities such as pasturage, burning that causes soil infertility by volatilizing essential nutrients and root damage, and deforestation, among others (Ananda and Herath 2003). Horticultural production is a common activity that is unfortunately carried out without a well-defined planning, causing soil wear and thus almost 87% of the erosion, affecting not only the land but also the economy of the producers because with nutrient losses, they have to invest even larger amounts in the introduction of inputs and irrigations in their systems, to maintain the conditions to continue with the required production, while the cost of the products, on the other hand, remain without rising in the market, representing in this way a huge problem, when it means getting lower income for their families. Fortunately the research carried out this role, proving that it was possible to decrease erosion by up to 60% by adding pastures to crops incorporating also green manures, what represents a palpable hope (Ananda and Herath 2003).

On the other hand, urbanization is also a factor of environmental deterioration derived of the topographical modification involving the growth of a city, as the construction of works such as roads and bridges that make it difficult to recharge the mantle underground aquifers and complicates soil regeneration (Lal 2014). It is also worth mentioning the participation of forest fires that can easily change ecosystems eliminating the protection provided by vegetation as well as the nutrients and organic matter that are the source of enrichment of the soil, and that together with other factors are able to generate different levels of runoff and erosion (Zemke 2016).

Erosion constitutes only one of the types of damage that the soil can suffer. Water is a process that is characterized by the loss of layers of soil committing its productivity; it is considered with the major importance because of its irreversible nature, and it is generated by the impact of rain on the earth with a posterior runoff of water; it causes the drag of organic matter and minerals being intensified by the presence of slopes (Honorato et al. 2001). In the same way, the climatic conditions like the strong currents of wind favor to a great extent its development. The absence of plant protection activities, carrying out agricultural activities or stemming from problems such as wildfires are also considered predisposing factors (Zemke 2016).

It is very important to evaluate soil erosion, to have an idea of the pace of wear, identifying the factors that produce it and thus the magnitude of the problem, as well as to find a concrete way to fight it, using techniques such as analysis of radio tracers or by using oxides of rare terrestrial elements that can determine the level of erosion of an area (Gil et al. 2009). Through analysis, it has been possible to develop software such as “la Ecuación Universal de Pérdida de Suelo” (Universal Soil Loss Equation) USLE (Honorato et al. 2001). This allows to identify and analyze the factors that produce erosion under a wide range of series conditions. From this have been developed reviews to be able to work on efficient way according to the conditions where is wanted to implement it, as the case with its revised version “RUSLE” has also served as the basis for the generation of new programs that constantly seek to overcome their limitations.

It is clear that there is a need to find effective ways to combat the deterioration of soils, whether for ecological or productive purposes; fortunately the efforts aimed at research and development of new technologies for their control and treatment in addition to the implementation of new methodologies that seek to avoid this condition are promising panorama for the conservation and restoration of this precious resource (Aziz et al. 2013; Langdale et al. 1992).

10.3 Pesticides and Synthetic Fertilizers

The pesticides are organic chemicals which are man-made and are being employed in the agricultural sector to control different types of pests (Valavanidis and Vlachogianni 2010) and promote crop yields (Ren et al. 2013). Pesticide use has experienced a dramatic increase worldwide (Zhang et al. 2015). To feed the growing world population, countries have made irresponsible use of pesticides. For example, the use of pesticides in China has increased sharply, from 0.76 million tons in 1991 to 1.8 million tons in 2011, amounting to an average annual growth rate of 4.9% (Li et al. 2017). This has caused China to apply 1.5 and 4 times more pesticides than the world average (Zhang et al. 2015).

The extensive use of synthetic chemicals for pest control is recognized as a major threat to ecosystem integrity, besides produced about 14% of the world’s total greenhouse gas emissions (Oertel et al. 2016). Pesticides also have adverse health effects. Farmers who spray more pesticides are more likely to have headache, nausea, and skin problems; pesticides have significant invisible impact on farmers’ liver and neurological and kidney systems Nicolopoulou-Stamati et al. 2016).

Pesticides include different organic-based chemicals, which are used to inhibit the growth of weeds, insects, fungi, nematodes, and rodents. Commonly used pesticides are customarily herbicides (to kill unwanted herbs), amounting to 44 % around the globe, insecticides (to kill unwanted insects) around 28%, and fungicides around 26 % (to kill pathogenic fungi) (Valavanidis and Vlachogianni 2010). DDT was an organochlorine-based pesticide, widely employed for agricultural and household pest control between the 1950s and 1980s (Zhang et al. 2015). Subsequently, pesticides having pyrethroid (PYR) and organophosphate (OP) bases have become appealing replacements owing to their comparatively less persistence and environmental toxicity (Li et al. 2017). Though, recently, scientific research has reported that still chemical insecticides classified as lesser lethal may also lead to chronic

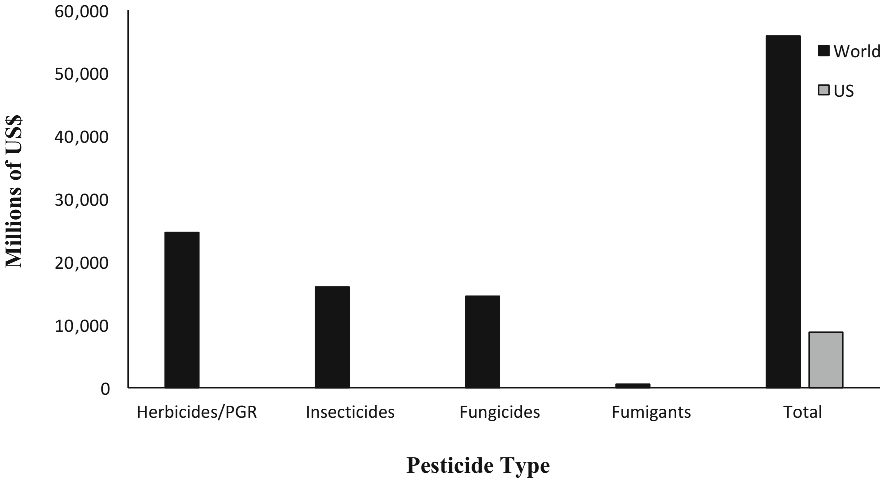

Fig. 10.1 The world market for pesticides in 2012. (Source: Phillips McDougall, AgriService (2008–2012). (http://phillipsmcdougall.co.uk/agriservice/). Modified from: EPA (2017))

diseases and that few of these chemicals are even fatal for human beings having continual disclosure (Wang et al. 2012).

According to the US Environmental Protection Agency (EPA), the global market for chemical pesticides has increased considerably from 2.7 billion $ in 1970s, 18.5 billion $ in 1990s, $ 32.7 billion in 2001 to $56 billion in 2012 (see Fig. 10.1).

Table 10.1 shows the expenditure on different pesticides during 2008–2012

10.3.1 Synthetic Pesticides: Human Health Risks

Pesticides refer to any substance addressed to stopping, averting, abolishing, repelling, attracting, or controlling any type of pest, during production process, storing, transporting, distributing, and processing of food or animal feeds or any agricultural commodity (FAO WHO 2001); pesticides can be divided according to their chemical composition, and the most widely used are the synthetic or organic pesticides, synthetized by combination from elements like carbon, hydrogen, and oxygen which can be enumerated and subdivided into organochlorines, organophosphates, peroxyacetic acids, carbamates, and synthetic pyrethroids (Hough 2014).

Developing countries need to enhance agriculture production, and therefore, the use of agrochemicals allows higher crop yields, being synthetic pesticides the first option due to their low costs; however the indiscriminate use of this kind of substances results in environmental damage and high health risks (Peshin 2014).

Pesticides comprise a group of toxic and bioactive substances that can interact not only with their target and can disturb soil productivity and ecosystem quality; they tend to persist much longer and affect soil microflora and soil health, specifically

Table 10.1 The world and US pesticide expenditures at the producer level by pesticide type, 2008–2012 estimates

Year and type of pesticide	Global market Million $	%	USA market Millions of $	%	US percentage of global market
2012					
Herbicide/PGR	24,727	44	5,115	58	21
Insecticides	16,023	29	2,184	25	14
Fungicides	14,565	26	1,430	16	10
Fumigants	606	1	137	2	23
Total	55,921		8,866		16
2011					
Herbicides/PGR	23,322	44	4,904	58	21
Insecticides	15,055	28	2,125	25	14
Fungicides	13,898	26	1,348	16	10
Fumigants	554	1	145	2	26
Total	52,829		8,522		16
2010					
Herbicides/PGR	21,131	45	4,755	58	23
Insecticides	13,356	28	2,038	25	15
Fungicides	12,106	26	1,232	15	10
Fumigants	578	1	138	2	24
Total	47,171		8,163		17
2009					
Herbicides/PGR	21,376	46	5,058	59	24
Insecticides	12,382	27	2,009	23	16
Fungicides	11,692	25	1,166	14	10
Fumigants	557	1	122	1	22
Total	46,007		8,355		18
2008					
Herbicides/PGR	23,516	48	5,364	63	23
Insecticides	12,486	26	1,882	22	15
Fungicides	12,249	25	1,186	14	10
Fumigants	591	1	123	1	21
Total	48,842		8,555		18

Source: Phillips McDougall, AgriService (2008–2012) (http://phillipsmcdougall.co.uk/agriservice/)
Taken from: EPA (2017)

nutrient contents, soil organic carbon, pH, moisture, soil enzymes, and others (Prashar and Shah 2013).

In terms of environmental damage, these molecules may enter groundwaters, provoking lethal effects in aquatic organisms and increasing water temperature due to these chemicals' presence, and the fact that the molecules are most easily concentrated in aquatic organism is concerning (Hough 2014). Pesticides as water contaminants can promote a set of side effects in water living organisms, like cancer or tumors, reproductive failure, immune suppression, disruption of endocrine system, cellular and DNA damage, and teratogenic effects; thus ecological effects can be considered as a primary warning indicator for potential human health impact (Ongley 1996), and the most concerning preoccupation is the damage that this chemical molecules can exhibit in human health through contaminated water, air, occupational exposure, or traces in food.

There exists a high prevalence of pesticides found in food purchased in markets, where approximately from 8 fruits to 12 vegetables, 73% contain pesticide residues (Baker et al. 2002), and wide evidence has presented that most common issues in health effects linked to pesticides include endocrine disruption (Song et al. 2017), cancer, diabetes, asthma, cognitive effects, or sperm damage (Kim et al. 2017).

10.4 Biological Control Agents as an Alternative for Soil Restoration

10.4.1 Definition and Generalities

All over the globe, people are using several definitions of the term biopesticide; however, the EPA has the most managed definition in the field of agricultural science that includes particular types of pesticides obtained from such natural substances as plant, animal, plants, fungal and bacterial species, and some minerals (EPA 2017). Biopesticides are also called as biological pesticides; these are a specific group which considers three main classes: (1) biochemical pesticides, (2) plant-incorporated protectants (PIPs), and (3) microbial pesticides (Moshi and Matoju 2017). *Biochemical pesticides* are innately occurring chemical substances or unnaturally derived counterparts to a naturally happening chemical substance that controls pests by action of nontoxic means. Biochemical pesticides use enzymatic or protein mediation or natural antimicrobial substances which inhibit or kill the desired organism and also have a plus point in that they are degraded in short times and are not persistent in the environment (Leahy et al. 2014; Matthews 2014). *Plant-incorporated protectants (PIPs)* are defined as a substance that is incorporated through genetic engineering to the plants in order to induce the expression of genes encoding insecticidal toxins. That way, plants can produce their own pesticide providing itself the protectant effect. The active ingredient could be inert substances or genetic substance which is required for specific protectant substance, produced by a plant (Matthews 2014; Sarwar 2015). *Microbial pesticides* (MPs) consist of a naturally occurring or genetically altered microorganism (e.g., a bacterium, fungus, virus, or protozoan) as the active ingredient. MPs are intended to prevent, repel, mitigate, or destroy many different kinds of pests (Matthews 2014). MPs can be either naturally occurring or genetically engineered. Modes of action of microbial pesticides include ecological competition, growth inhibition, direct toxicity, and parasitism using the pest biomass as a substrate (Gasic and Tanovic 2013). MPs are the largest section of the biopesticide group, including 53 registered products in the USA, 22 in Canada, and 21 in the European Union (Koul 2011). That is because of the advantages shown by most MPs such as safety (wildlife, humans, and other organisms), specific toxic action (beneficial insect is not affected), and compatibility with synthetic chemical pesticides. In some cases, the pest control is subsequent for generations and seasons, and most of the microorganisms used as MP are an enhancer of roots and plant growth as well as benefiting the microflora of the soil (Usta 2013). However, due to the biological origin of MPs, they also have limits, such as specificity and selectivity because most of the products might handle only a fraction of different pests existing in that area. Other important issues include the high sensitivity to heat, desiccation, and ultraviolet exposure that reduces the viability and effectiveness of the microbial products. Also, it is necessary to consider the specific proceedings for application, formulation, and storage (Usta 2013).

10.4.2 Bacteria-Based Biopesticides (BBBs)

This category is the most common and inexpensive form of MPs, because of the facilities and high-scale production. BBBs are mainly focused on the control and elimination of insect pests such as moths, butterflies, beetles, flies, and mosquitoes (Mnif and Ghribi 2015). In this particular case, BBBs need to be ingested by the insect to be effective and cause death. These products are subclassified into four sections: (1) crystalliferous spore formers, (2) obligate pathogens, (3) potential pathogens, and (4) facultative pathogens (Koul 2011). The spore formers are the most studied, produced, and commercialized due to their high effectiveness and safety. The species of *Bacillus* can be found everywhere around the world in seawater, soil, etc. *Bacillus* appears as the main bacterial strain used as biopesticide (Melo et al. 2016). The high biocontrol potential is because of the production of a crystalline protein highly toxic and responsible for the gut cells lysis after consuming by insects, which ultimately leads to its death (Hung et al. 2016). Besides *Bacillus*, other important bacterial genera such as *Clostridium*, *Saccharopolyspora*, *Streptomyces*, *Pseudomonas*, *Agrobacterium*, *Xanthomonas*, *Ralstonia*, and *Serratia* are also popular as biopesticides (Chattopadhyay et al. 2017; Montesinos 2003).

10.4.3 Fungal-Based Biopesticides (FBBs)

This section also is composed of four kinds of products including herbicides (*Chondrostereum purpureum*), fungicides (*Trichoderma harzianum*, *Coniothyrium minitans*), nematicides (*Paecilomyces lilacinus*), and insecticides (Balasubramanian and Tyagi 2016; Gupta and Dikshit 2010). This last subsection of FBBs is the most commercialized product around the world integrating important fungal genera such as *Beauveria* and *Metarhizium* as insecticides (Mohammadbeigi and Port 2013). These entomopathogenic fungi are mainly focused on the control of insects such as spittlebugs, locust, and grasshopper (Chandler et al. 2011). The adhesion and germination of the spores from entomopathogenic fungi are very crucial steps in order to kill insect pests. After that, a combination of a physical and enzyme activities allows fungi to penetrate the insect and proliferate inside of it (Fernandes et al. 2012). The last step is the production of toxic metabolites, mainly destruxins (Muñiz-Paredes et al. 2017). However, the activity of the fungal entomopathogenic continues until it develops propagules (spores) over the dead body for a posterior dispersion (Beris et al. 2013) (Table 10.2).

10.4.4 Yeast-Based Biopesticides (YBBs)

There are a few commercialized bioproducts containing yeasts as a biopesticide. However, several investigations have been carried out in order to select effective yeast strains against important pests. Among the most studied yeast, it is possible to find species such as *R. mucilaginosa*, *R. glutinis*, *Trichosporon pullulans*, *Metschnikowia pulcherrima*, *Cryptococcus flavescens*, and *Cryptococcus laurentii* as biopesticides against phytopathogenic fungus like *Botrytis cinerea*, *Fusarium graminearum*, and *Penicillium expansum* (Qin et al. 2003; Rong et al. 2016; Spadaro et al. 2010; Zapata et al. 2016). Insecticidal yeast is also reported including strains of *Pichia onychis*, *Pichia pastoris*, and *Debaryomyces hansenii* with high activity against *Drosophila suzukii*, *Mamestra brassicae*, and *Acyrthosiphon pisum* (Hinchliffe et al. 2010; Murphy et al. 2016). The mechanisms of action reported for yeasts are similar to those reported for bacterial biopesticides such as production of antibiotic substances and severe competition for space and nutrients, as well as host resistance induction, biofilm formation, quorum sensing, and competition for iron (Droby et al. 2016).

10.4.5 Nematodes as Biopesticides (NBs)

The use of nematodes as biopesticides is a section integrated mainly by two genera, *Steinernema* and *Heterorhabditis* (Chavarría-Hernández et al. 2014). Both nematodes infect only insects living as endoparasite inside of them until the insect dies, including butterflies, moths, beetles, flies, crickets, and grasshoppers (Atwa 2014; Shields 2015). There are 61 species of *Steinernema* and 14 species of *Heterorhabditis* proved as bioinsecticides; however *S. glaseri*, *S. carpocapsae*, *S. rarum*, *S. feltiae*, *S. kraussei*, *H. bacteriophora*, *H. indica*, *H. megidis*, and *H. amazoenzis* were found as the most efficient species (De Brida et al. 2017; Del Valle et al. 2017; Guy et al. 2017; Heve et al. 2017; Matadamas-Ortiz et al. 2014; McGraw and Schlossberg 2017). Among the insect with more sensitivity against these nematodes, it is possible to find *Dacus ciliatus*, *Spodoptera cilium*, *Thaumatotibia leucotreta*, *Diloboderus abderus*, *Anasthrepa suspensa*, *Gromphadorhina portentosa*, *Nauphoeta cinerea*, and *Blaptica dubia*, among others (Cutler et al. 2017; Gulcu et al. 2014; Kamali et al. 2013; Manrakhan et al. 2014). Several nematodes showed synergistic activities as symbiote with bacteria like *Xenorhabdus* or *Photorhabdus* killing insects in 24–48 h; in addition, NBs are safe for animals, plants, and nontarget organisms (Shields 2015).

Table 10.2 Bacterial- and fungal-based biopesticides registered by EPA (2017)

Microbial agent	Target pest
Trichoderma harzianum T-39	*Botrytis cinerea*
T. asperellum ICC 012	Soil-borne plant pathogens on various plants including different vegetables, fruits, turfs, orchards, aromatic plants, and legumes
T. gamsii ICC 080	
T. hamatum 382	
Bacillus firmus	Plant-parasitic nematodes
B. thuringiensis var. *aizawai*	
PS811	Larvae of lepidopteran (moth)
NB200	
B. pumilus	
QST2808	*Rhizoctonia* and *Fusarium*, as well as molds, mildews, blights, and rusts
GB34	
B. licheniformis SB3086	Fungal species, especially those causing leaf spot and blight diseases
B. subtilis	
Amyloliquefaciens FZB24	*Rhizoctonia* and *Fusarium*
Israelensis EG2215	Mosquito larvae
Kurstaki M-200	Lepidopterous pests of tree fruits and vegetables
QST713	Sour rot disease, powdery mildew, early leaf spot, scab, bacterial spot, downy mildew, walnut blight diseases, early blight and late blight diseases
Pasteuria usgae	*Belonolaimus longicaudatus*
Candida oleophila O	*B. cinerea* and *P. expansum*
Beauveria bassiana	
HF23 (70787-1)	House flies in chicken manure
447	Fire ants and other ants found indoors
Pythium oligandrum DV 74	20 soil-borne pathogenic fungi
Colletotrichum gloeosporioides f.sp. *aeschynomene* (82681-1)	*Aeschynomene virginica*
Pantoea agglomerans	
C9-1 (71368-45)	*Erwinia amylovora*
E325 (71975-1)	
Chondrostereum purpureum	
HQ1	Hardwood trees such as red alder, Sitka alder, speckled alder, and trembling aspen
PFC 2139	
Paecilomyces lilacinus 251	Plant-parasitic nematodes in soil
P. fumosoroseus Apopka 97	Whiteflies, thrips, aphids, and spider mites
Alternaria destruens 059	*Cuscuta* spp., known as dodder, swamp dodder, large seed dodder, small seed dodder, and field dodder
Muscodor albus QST 20799	Root rot, damping off, and wilt disease-producing fungi and bacteria
Aspergillus flavus	
NRRL 21882	*A. flavus* that produce aflatoxin
AF36	
Metarhizium anisopliae F52	Various ticks and beetles; root weevils, flies, gnats, thrips

(continued)

Table 10.2 (continued)

Microbial agent	Target pest
Puccinia thlaspeos	*Isatis tinctoria*
Pseudozyma flocculosa PF-A22 UL	Powdery mildew on roses and cucumbers
C. minitans CON/M/91-08	*Sclerotinia sclerotiorum* and *S. minor*
Pseudomonas chlororaphis 63-28	Certain fungal species which infect plant roots and induce wilt diseases also cause root and stem rots
P. aureofaciens Tx-1	*Sclerotinia homoeocarpa*, *Colletotrichum graminicola*, *Pythium aphanidermatum*, *Microdochium nivale*
Reynoutria sachalinensis	Powdery mildew and gray mold
Agrobacterium radiobacter K1026	*Agrobacterium tumefaciens* and *A. rhizogenes*
Gliocladium catenulatum J1446	Fungi that cause damping off disease, seed, stem and root rot, and also wilt disease
Burkholderia cepacia J82	Certain diseases of seedlings and for controlling nematodes that attack the roots of crops

10.4.6 Insects as Biopesticides (IB)

Several insects are a concern worldwide because of the damage they cause in a huge number of plants and fruits. The phytopathogenic insects can cause damage to the plant in three ways such as mainly (1) direct affection on the plant surface, (2) transmission of different viral diseases, and (3) contamination of leaves and fruits through the secretion of some kind of gum called honeydew (Peng et al. 2017; Wang et al. 2016). The most dangerous insect pests are shown in Table 10.3. Insects have an incredible capacity to generate resistance against the chemical pesticides; therefore in many cases, the application of chemical pesticides is done in an excessive way (Rodríguez-Álvarez et al. 2017). One of the principal management strategy to control the population of insect pests is the increase of the population of their natural insect enemies including the genera of *Neoseiulus*, *Amblyseius*, *Stratiolaelaps*, *Hypoaspis*, *Encarsia*, and *Eretmocerus*, among other important ones (Fernández et al. 2017; Seiedy et al. 2017; Wu et al. 2017). It is relevant to mention that the use of this kind of treatment is more effective when is applied in greenhouse conditions, helping to keep the biopesticides in contact with the pest (Rakha et al. 2017). Also, warm regions are more feasible in order to accelerate the biopesticide multiplication and development, increasing the effectively (Fernández et al. 2017). The group of insects used as biopesticides is more commonly named as parasitoids because its larval stage feeds on the host until to death and taking advantage to oviposit on the body to generate more individuals. In some cases of compatibility, it is possible to apply in a synergistic way with some fungal entomopathogens, such as *Beauveria bassiana* or *Metarhizium anisopliae*, generating a better impact in the control of pests (Wu et al. 2017).

Table 10.3 Most dangerous insect pests and their natural enemies used as biopesticides

Pest insect	Entomopathogenic insect	Reference
Bemisia tabaci (whitefly)	*Encarsia formosa*	Bonato et al. (2011), Hanafi et al. (2007), and He et al. (2017)
	Eretmocerus californicus	
	Macrolophus caliginosus	
Thysanoptera spp. (thrips)	*Neoseiulus barkeri*	Kakkar et al. (2016), Wu et al. (2017), and Otieno et al. (2017)
	Amblyseius cucumeris	
Tetranychus cinnabarinus (carmine spider mite)	*Phytoseiulus persimilis*	Moghadasi et al. (2016)
Aphidoidea (plant lice)	*Aphidoletes aphidimyza*	Barbosa et al. (2017) and de Azevedo et al. (2017)
	Chrysoperla carnea	
	Aphidius colemani	
Spodoptera spp. (armyworms)	*Trichogramma* spp.	Leite et al. (2017) and Takada et al. (2000)
Phyllocnistis citrella (citrus leaf miner)	*Ageniaspis citricola*	de Morais et al. (2016) and Goane et al. (2015)

10.5 Traditional Strategies for Food Control and Security

Food security is a term that sometimes may be indistinctly used with food safety; however, the best known and widely used term was that coined by FAO et al. (2015), which states that food security is “a situation that exist when each person, in all time, have social, physical and economically approach to enough, nutritious and safe food to meet its daily need and preference to live a healthy and an active life.” Defra (2009) used a similar definition for food safety: “ensuring access to, availability of, inexpensive or affordable, nutritious and safe food sufficient for and active life-style, for each, at all times.” While food safety is related with problems in raw materials, food processing, and pathogens and cross contamination, food security deals more with food utilization, access, and availability. Food utilization deals with good health indicators, clean water, food quality and safety, sanitation, and nutritious food, whereas food access refers more to equitable distribution, affordability, transport, purchasing power, and marketing; finally, food availability is related to processing, water and soil management, production, and trade and stockpiling. Although, there is a relation between both terms, food safety and security; external conditions such as poverty and climate change may affect both food safety and food security. Another term is *biosecurity*, which is defined as “the protection of the environment, economy and health of living beings from various diseases, bioterrorism and pests.”

Table 10.4 Food security risk of different countries according to the food security index 2013

Low	Middle	High	Extreme
USA, Canada, Chile	Latin America	India	Somalia, Congo
Europe	South of Africa	Most African countries	Haiti, Chad, Ethiopia
Australia, Japan	North Asia	Pakistan	Afghanistan
	Oceania (except Australia)	Guatemala	Sudan, Burundi, Eritrea

According to FAO, food safety management systems should also be based on risk analysis approach and also endorse the use of Codex Alimentarius Commission (CAC) which is comprised of three components which are interlinked: (1) risk assessment, (2) risk management, and (3) risk communication (FAO/WHO 2004, 2010).

Although the impressive improvements have been seen in agriculture, agrochemicals, food technology, soils, fertilizers, irrigation, food processing and storing techniques in recent years, but inspite of this development, everybody do not have guarantee of the safe and healthy food for today and tomorrow. Food security risk of different countries is measured taking into account different parameters such as food production, accessibility, transportation, etc. In Table 10.4 are shown different countries according the food security risk (Global Food Security Index 2013).

Currently, hunger in the world is a big problem, and it is estimated that 795 million people are malnourished (FAO et al. 2015) and 9 out of 10 live in developing countries. Causes of this hunger are poverty (896 million of impoverished people live with less than 2 US dollars per day), adverse economic systems, political conflicts, population growth, wrong food and agricultural policies, and climate change. In addition, there are some threats to food security such as evolution of pest and pathogens, genetic contamination of landrace plant cultivars by transgenic crops, high production costs, and less nutritious food. In addition to hunger, there are mineral deficiencies prevalent in the human diet, especially in countries with low income, which currently affect about 3000 million of persons (Peleg et al. 2008), referred to as hidden hunger (Bohra et al. 2015). Some causes of mineral deficiencies are diet based on cereals and no diversified diet which is poor in nutrients (Mulualem 2015).

If food supply is compromised, there would be economic, physical, political, and psychologic consequences. But also, if eatable food is conceded with harmful chemicals or pathogenic bioagents, it may lead to indirect result of hunger, morbidity, and mortality. For this reason, providing safe food is the responsibility of the central government, many federal organizations as well as the local and state counterparts, professional agencies, and food processing units (Bruemmer 2003).

The preventive policies are the first line of defense against potential hazards; however, controlling chemical and biological agents and rapid detection of pollutants is vital as well as essential to food safety. In this sense, there is a scheme or method which assures safety of foods at producer's level. The technique "Hazard

Analysis Critical Control Points" (HACCP) identifies technical means and approaches in process of food production which is able to eradicate chemical, physical, and biological hazards. In this technique the food producer has to ascertain or determine limits or ranges of certain critical control points (CCPs), their monitoring methods, and steps for correction. Another system that sets processing rules and eliminates the risk of occurrence of a harmful food is "Good Manufacturing Practice" (GMP). These two systems, HACCP and GMP, follow up and are complementary to each other (Steinhauserova and Borilova 2015).

In 2015, the WHO assessed that around 2 million people die annually, owing to unsafe food consumption all over the world. One major risk for food security is evolution of plant pest and pathogens which day by day is more difficult to control and have improved genes for pathogenicity. It has been reported that around 200 diseases may be spread by consuming contaminated or polluted water or food stuff. On the other hand, the foodborne infections or disorders may also be augmented by enhanced international food transportation and people's movement. Waterborne and foodborne diseases are mainly caused by pathogenic microbes (bacteria, fungi, viruses, and potential parasites) and harmful chemicals (heavy metals, pesticides, allergen, toxins, mycotoxins), and the severity of disease ranges from mild gastroenteritis to life-frightening (Fusco et al. 2015). In case of plant pathogens, one of the more difficult to control is *Rhizoctonia solani* Kühn teleomorph fungus [*Thanatephorus cucumeris* (Frank) Donk] which damages different potato parts: root, shoots, stems, stolons, and tubers (*Solanum tuberosum* L.) (Carling et al. 2002). Its incidence during potato cultivation causes losses in production that vary between 7% and 64% and up to 100% in quality aspects (Hernández et al. 2001).

Management of this kind of pathogens depends mainly on application of synthetic fungicides through all crop season. In some regions, there are more than ten synthetic fungicide applications through the whole crop season in order to manage of regulate plant pest and pathogens. However, the indiscriminate use of these synthetic fungicides has consequences since some fungal isolates have showed resistance to the active ingredients of synthetic fungicides (Hernández et al. 2005). In addition, there is also important evidence of serious environmental contamination derived from application of synthetic fungicides, which not only affects flora and fauna but also contributes to quality deterioration of air, water, soil, and food, in addition to health of humans (Albert 2004). With the intention to maximize the efficiency of plant pests and disease control at field level, studies on the monitoring of pest and pathogen populations to sensitivity of the main fungicides used in crop commercial production are necessary. These studies are a determinant of the behavior and the degree of sensitivity of these pest and pathogen populations in the field. The necessity to find mechanisms that increase crop productivity has promoted development of new strategies for pest and pathogen control which should be efficient alternatives to chemical control and also reduce environmental and health risk without risking human health (Gallegos et al. 2004) such as biological control based on organisms antagonist to pest and pathogens, use of extracts, genetic engineering, and so on.

The expected growth of human population by 2050 signifies a great challenge to state-of-the-art agricultural system. For this reason, agroecology has been highlighted by the United Nations for sustainable farming practices to produce sufficient food without causing injurious effects on the ecosystem (De Schutter 2010). Agroecology is defined as "the integrated study of ecology of entire food systems, including the economic, ecological and social aspects" (Francis et al. 2003). Thus, attention has been paid to the influence of dissimilar agriculture procedures on biodiversity.

In the soil ecosystems exist various types of microbes; these include fungi, bacteria, actinomycetes, protozoans, etc. Its distribution in the adjacent areas of the plant rhizosphere is higher and is more active physiologically (Guetsky et al. 2001). The great difference in biological diversity between a natural ecosystem and an agroecosystem is caused by the decline of biomass in the latter. This reduction is usually caused by a reduction in content of soil organic matter and by the loss of diversity in the plants given by monoculture. The microbial communities that occur naturally in the rhizosphere play a role in the healing of the radical system. This interrelation between the root tissue and the microbial community of the soil is significantly more intense than that found in the plant aerial part (Vilich and Sikora 1998). Different microorganisms that usually act in plant rhizosphere have been reported as effective biocontrol agents. One of the major contrasts of biocontrol for root pathogens is that a biocontrol agent may not provide a good effect, particularly if the biocontrol agent is not adapted to plant rhizosphere. Antagonism operates in a variety of ways: antibiosis, competition, prefiguration, or parasitism. The latter involves of several hydrolytic enzymes production that biodegrade the pathogen cell walls. Some of these hydrolytic enzymes are B-1,3-glucanase and chitinase, which are products of several fungal and bacterial species (Russell et al. 1994).

10.6 Commercial and Market Opportunities of Biological Products

Currently, the global population is increasing breathtakingly fast, and it is expected to reach 9.7 billion by the year 2050 (United Nations 2015). All those people will need to be fed; therefore this close situation will impact in the necessity to increase the production and quality of food. On this expected scenario crop protection, it's a serious issue and should be the main focus of all nations in the world (Moshi and Matoju 2017). The traditional way of ensuring crop protection has been the application of conventional chemical pesticides; however, they are facing important challenges in the present (Maute et al. 2017; Miro Specos et al. 2017). Chief restrictions for application of the chemical pesticides are because of (1) the generation of resistant pests, (2) the death of nontarget organisms, and (3) the residual chemicals on the food and soil (Arora et al. 2016; Eski et al. 2017; Pavela et al. 2017). In short, this puts at risk the human health and ecological balance (Leahy et al. 2014; Matthews 2014). The information mentioned above has been very well known, but the laws have not been stricter until now, since most of the countries are changing its political rules in order to limit the excessive employment of harmful chemical-based pesticides (Desai et al. 2016; Goñi et al. 2017; Hazra et al. 2014).

10.6.1 Market Overview

In the present, the food processors and supermarkets are in the same line with the intention to offer better and healthy products. In terms of economic feasibility, biological products are gaining market, because the development of traditional chemicals (pesticide, fertilizers, and plant growth stimulators) has become harder and more expensive (Thakore 2006). For example, $250 million USD are required to carry out a new agrochemical at commercial level spending 9–10 years for development and regulatory approval, while a biological product only needs $10 million USD and only 3–4 years to put it on the market (Olson 2015; Pucci 2014). All these factors mentioned above plus the demand for sustainable alternatives are driving the trend about research and development of biological products. Analyzing the facts, it is possible to see more increase on the development of biological products, as well as the consolidation of small enterprises and the creation of several start-up companies (Duke et al. 2014). That is a reason to explain the growth of the global agricultural biological market which represents only about 4–5% of the total agroscience market but valued at $5.11 billion USD in 2015 with a growth rate of 13.5% (Technavio 2017). In this segment, it is expected an increase in the market size of $10.05 billion USD for 2020 (Duke et al. 2014; Olson 2015). The segments of the global agricultural biological market are integrated by 45.58% of biopesticides, 38.82% of biostimulants, and 21.60% of biofertilizers (Technavio 2017). In the segment of biopesticides are included bioinsecticides, biofungicides, bioherbicides, bionematicides, and biochemical products (Sudakin 2003). The adjuvants, plant growth regulators, and inoculants in order to enhance the health of crops are classified as biostimulants (du Jardin 2015; Yakhin et al. 2017). In the third section are the biofertilizers that comprise the products for nitrogen fixation, potassium mobilization, and the solubilization of phosphate and other compounds (Kulasooriya and Magana-Arachchi 2016; Sharma et al. 2013). The revenues of each segmentation products are shown in Table 10.5.

Table 10.5 Revenue of products by segmentation of the agricultural biological market

	2016		2020	
Segment	Revenue ($ billion USD)	Growth rate (%)	Revenue ($ billion USD)	Growth rate (%)
Biopesticides	2.65	13.98	4.68	16.04
Biostimulants	1.90	13.57	3.31	15.62
Biofertilizers	1.24	12.40	2.06	14.18

10.6.2 Commercial Leaders on Biological Products

Important brands have been established selling this kind of products, from companies such as Agrinos AS, Camson, Vertis USA, Koppert BV, Marrone Bio Innovations, T. Stanes & Company Limited, and Valent BioSciences (Technavio 2017). However, BASF, Bayer CropScience, and Novozymes are the giants of the market who are dominating as the leader players representing 11.60%, 10.10%, and 1.90% in the global agricultural biological market, respectively (Table 10.6). Currently, the key market players are offering different options of environmental friendly products in order to make a sustainable process of crop protection enhancing the production and quality through the combat of weeds, pests, and diseases of crops by the use of bacteria, fungi, and viruses. A very marked tendency is the synergy and acquisition of small companies by the market leaders. This activity has become common in the last 10–15 years, and it is possible to see it easily on the news or the Internet, such as the integration of Becker Underwood with BASF SE, the purchase of Prophyta by Bayer, or the partnership of Monsanto and Novozymes A/S (Seiber et al. 2014; Olson 2015). These movements among companies give them important advantages, in order to make a faster development of biological products, offering more and better options, as well as providing major geographical availability, among others.

10.6.3 Impact of Biological Products on the Health of Soil

The majority of the companies dedicated to the agroscience are continually searching for more attractive biological solutions for pest control, through the area of research and development. As mentioned before, most of their products are focused on biopesticides, biostimulants, and biofertilizers, but also all biological products have a positive effect on the microbial soil populations. In the recent years, the investigations in terms of the soil microbiota incorporating the improvement on crop productivity and the lessening of the hostile and antagonistic consequences of change in climate, among other factors, have attracted more attention. This includes the environmentally friendly agronomic techniques, which can improve yields in agricultural production in a process that is directly linked to soil microbial load. The diversity of the soil microbiota is a very important factor in order to maintain a healthy soil and therefore the development of quality crops. High microbial diversity has a trascendental impact in several beneficial ways, such as (1) the inhibition of pathogens or invader organisms, (2) the high levels of CO_2 trapping, (3) the release of plant growth stimulators, and (4) the improvement in the amount of nutrients in the soil by lytic enzymes production (Li et al. 2017; Sathya et al. 2016; van Elsas et al. 2012; Vishwakarma et al. 2016; Vukicevich et al. 2016). Application of traditional herbicides disrupts the natural nutrients decomposition process, because herbicides also kills the beneficial organisms in the soil, such as earthworms, fungi, and bacteria (Andersen et al. 2013; Vukicevich et al. 2016).

Table 10.6 Business, geographical, and type of products by agrobiological key leaders

Segmentation		BASF SE	Bayer CropScience AG	Isagro SPA	Novozymes A/S
Business		Fungicides	Crop protection/seeds	Fungicides	Crop production
		Herbicides		Stimulants	Microbial solutions
		Insecticides	Environmental science		
		Functional crop care			
Geographical	America	33%	25%	33%	43%
	Europe	35%	30%	37%	38%
	Asia-Pacific	10%	15%	24%	18%
	Rest of the world	23%	29%	6%	–
Products	Biopesticides	Millennium	Serenade	Bio-Tam	Met52 EC
		Nemasys	Sonata	Bioten	
		Vault HP	Requiem	Radix	
		Tricho Plus		Remedier	
		Green Muscle		Tenet	
		Greenguard			
		PL Gold Broadbrand			
		Beta-pro			
		Nogall			
	Biostimulants	BioGain WSP	–	HYT A	Ratchet
				HYT B	RhizoMyco
		BioGain WSP/Sprint 330		HYT C	RhizoMyx
					RhizoPlex
		VigaROOT			Torque

BASF (2017), Bayer CropScience (2017), Isagro SPA (2017), Novozymes A/S (2017), and Technavio (2017)

10.6.4 Current Researches and Future Perspectives

The beneficial effects mentioned in the last section have been supported by several authors, such as Bernard et al. (2014), who reported an increment of the microbial community on a potato field through the combination of three different sustainable disease management practices: (1) compost amendment improving the chemical, biological, and physical characteristics of cultivable soil; (2) biocontrol organisms using *Bacillus subtilis*, *Trichoderma virens*, and *Rhizoctonia solani* Rhs1A1 as biocontrol agents; and (3) disease-suppressive rotation. Crop rotation and composting are a good complements in order to increase the microbial populations. Commonly crop rotation is used to increase the nitrogen-fixing bacteria that have been used for biocontrol of pathogens infecting plants, like *Fusarium* species (Yang et al. 2017). Conversely, the employment of compost in agriculture and horticulture is important because is a natural nutrient as well as energy and carbon source for the microorganism's development. Moroever, the compost also contributes in the recycling of organic waste and minimizing the application of chemical fertilizers Since, compost is a natural source of biological control microbiota, several beneficial microorganisms have been isolated from this material (López-González et al. 2015). In the case of Suárez-Estrella et al. (2013), they reported more than 126 different effective strains against important phytopathogens such as *F. oxysporum*, *Fusarium melonis*, *R. solani*, *P. ultimum*, *Pectobacterium carotovorum* subsp. *carotovorum*, *Pseudomonas syringae* subsp. *syringae*, and *Xanthomonas campestris*. Trichoderma spp. is one of the potential biocontrol agents that proliferate by compost application, the commonly applied efficient species are *Trichoderma harzianum* and *Trichoderma asperellum*. These fungal genera have shown great effectiveness against pathogens of plants such as *Phytophthora nicotianae*, *R. solani*, *Sclerotinia sclerotium*, *B. cinerea*, and *Alternaria alternata,* among others (De la Cruz Quiroz et al. 2015; Ros et al. 2017). Despite the improvement of soil health depending on several factors, the addition or fortification of beneficial microbial populations is the fastest way to obtain better results (Larkin and Tavantzis 2013; Lenc et al. 2015).

The trends are very clear; the market is growing by leaps and bounds including its three sections; biopesticides, biostimulants, and biofertilizers. Despite the presence of four big established companies in agroscience, there are still challenges to attend to, such as the high or sufficient production, the widespread distribution, the maintenance of long shelf life of bioproducts, and the overhead costs. Therefore, it is a great opportunity for start-ups to reach to the places less attended with this type of products, as well as generate technological development in the weak points of the current products, such as the high variability in efficiency of biopesticides, the tracking of adverse effects of fungicides on biopesticides, and a more deep exploration with the aim to offer less limited results from bioassays. In the case of soil amendment, all kinds of biological products have shown improving activities mainly with the increase of diversity in the microbiota; however an integrated pest management is highly recommended integrating practices of preventive cultures, such as monitoring crop fields, mechanical controls, and responsible and low use of chemical pesticides, among others.

10.7 Future Perspectives

Biocontrol is very significant and imperative in the present situation of crop production. This is a compelling alternative to increase soil productivity and reduce the consequences of climate change. However, its wide benefits are not being fully exploited; new scientific research should be proposed to assess the effects of biocontrol on the crop produce where it has not yet been evaluated and the effect of the use of endemic microorganisms in the increase of the fertility of the soil.

Governments must also articulate clear strategies to strengthen the commercialization of bioagents. Since the biocontrol products that are marketed have not been used efficiently by the farmers due to the lack of information on their use. There is also an urgent need to mass produce biological agents, to evaluate their synergistic effect with other alternatives such as compost, to understand the mechanisms of action, to evaluate environmental factors that favor the growth of biocontrol agents, and to evaluate symbiotic microorganisms in environments where they were found.

Countries should generate government alternatives for small farmers to receive a bonus in exchange for contributing to the reduction of greenhouse gases using good production practices. This alternative guarantees stability in the prices of the products and improves the eco-efficiency in the production.

10.8 Conclusion and Final Remarks

Biological control agents contained into microbial biopesticides offer a very wide spectrum of opportunities in order to control or inhibit huge insect pests. Despite most of them are so specific in the action against the pest. They also offer the possibilities to use with different combinations of agricultural products, which increases its efficeincy to controls pests and also enhance the health of the agricultural soils. Also, a number of papers founded about yeasts and nematodes as biopesticides are scarce or limited only to a few species. However taking into account the results published by some authors, they also have a high potential to offer to the agro-industries a very deep strategy to control more efficiently.

The use of biopesticides could enhance the results on soil amendment, if they are integrated into a well-studied strategy, such as the integrated pest management where it is included the monitoring and the application of physical controls. Also, it is important that the main objective is not destroying the whole population of pests but the reduction of the damages caused by them, creating a balance.

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