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4 Biological Control as a Tool for Sustainable Development: For Increase the Distribution and Income Generation

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Abstract

With a world population of more than 7.5 billion people, today we are able to produce enough food to support the entire population of the planet. However, in the next few years, the population will continue to grow and the challenges are even greater, limitation in expanding new agricultural frontiers, besides the demand of conscious consumers who seek healthy sustainable produced food. In this scenario, the biological control seems to be one solution and one opportunity to reduce the dependence of the oligopoly on agrochemicals. Based on the strategic innovation model of the triple helix, the decentralization of investments in research and innovation, with the approach of universities and research institutes, of the rural producers, fomented by the government, boosts the search of solutions of biological control, supporting the regional development, with the increase the income generation and socioeconomic contributions in diverse countries. This way, we will be able to break the circle of poison.

Keywords

Agricultural production · Bioeconomics · Biological control · Sustainability · Triple helix

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4.1 Introduction

The agriculture as it exists today would not exist without the use of pesticides and chemical fertilizers. With the green revolution that happened after World War II, new technologies and scientific advances allowed today the production of enough food to support the growing population of the planet (FAO 2017a). However, the population will continue to grow, reaching 9.8 billion by 2050, being able to pass the 11 billion in 2100, before it begins to decline (ONU 2013; FAO 2017b). Furthermore, one-third of the food produced in the world is still lost due to the attack of pests and diseases. Allied with the waste and bad distribution of income, they are responsible for chronic hunger and malnutrition that reaches about 10% of the population (one in nine), the vast majority of whom live in developing countries (FAO et al. 2015; OECD/FAO/UNCDF 2016).

Throughout history, several authors have warned over the inability of the Earth's capacity to sustain its growing population. Each time, the crisis has been averted due to technological advances in plant breeding, fertilization, crop protection, and agronomic management (Parnell et al. 2016). Nevertheless, this exponential growth in the world's agricultural production has neglected the consequences of environmental impacts, with excessive deforestation, the irrational use of soil and natural resources.

The indiscriminate use of chemical fertilizers has increased the salinity of soils, mostly in arid and semiarid regions, where it seriously threatens agricultural sustainability and food security (Keswani et al. 2016; Ram et al. 2018; Singh et al. 2016a, 2019). The most limiting soil nutrients for plant growth are nitrogen and phosphorus. Although many soils contain ample quantities of these nutrients, most are not readily accessible for plant growth (Schachtman et al. 1998; Rai 2006). This reinforces the need to find alternative strategies to improve acquisition and use efficiently these nutrients (Laplase et al. 2018). Consequently, microbial products can be developed to increase the availability of nitrogen or phosphorus to crops, thereby maximizing the efficient, sustainable use of nutrients (Parnell et al. 2016).

In addition, the intensification of agriculture, the low diversity of cultivated species, and the excessive agrochemicals used have been increasing in selective pressure, favoring mutations and the propagation of resistant phytopathogenic organisms. On the other hand, billions in investments and decades of research have ensured the discovery and development of new chemical molecules that are capable of controlling the most diverse and resistant unwanted organisms in crops, avoiding billions of dollar losses worldwide (FAO 2017a). However, chemical molecules have shortened their useful lives, with the emergence of the new varieties of pests and diseases, resistant at the newer agrochemical, making unfeasible the billions of investments necessary for its development (Lucas et al. 2015). To break this cycle of resistant organisms and new and more potent chemical products, the biological control arises as an alternative way to control pests and diseases without the emergence of resistance in phytopathogens (Singh et al. 2016b, c, 2017).

On these perspectives, agriculture and food production should increase by 70% to be able to feed all world population until 2100 (FAO 2017b), which will require profound changes and adaptations. In addition, with global development and an increasingly enlightened population that seeks for a healthy diet, it is expected that this increase in agriculture production must be sustained by ecological agriculture linked to environmental preservation. As we face our next challenge, it is critical that we continue to discover new sustainable cropping system solutions to produce more with fewer resources (Parnell et al. 2016).

Concerned about the need to increase the food supply, but without neglecting the risks to the environment and population health, several countries have established stricter legislation over the use of chemical pesticides. The EU has banned the use of various chemical molecules in the territory and reducing the maximum residue limit (MLR) of pesticides in food, water, and soil. They have the strictest regulatory system in the world about pesticides, although the largest pesticide companies are based in European countries (FCEC 2012; European Commission 2017).

On the other hand, the main world food producers (USA, China, and Brazil) have less restrictive legislation regarding the use of chemical pesticides (more flexible and tolerant). In Brazil, the world's largest consumer of agrochemicals (19% of the world market), despite being only the third largest food producer, 30% of chemical pesticides used are banned in the EU. In addition, the MRLs are 400 times higher for food and 5000 times higher for glyphosate in drinking water (Bombardini 2017).

The permissibility and flexibility of these large global food producers have effects around the world, characterizing the circle of poison. Many European countries that are the largest pesticide producers are also among the larger importers of agricultural commodities (Galt 2008; Bombardini 2017). However, despite the fact that many pesticide residues return to these countries through food, we cannot forget that the greatest damage is caused by residues that remain in the soil and water, affecting the biodiversity and health of the population, in countries such as Brazil, which pride themselves on being the world's breadbasket. Thus, we become simple producers of commodities, putting our land, our people, our natural wealth, and our biodiversity at the service of those who can pay for what they do not want to produce. We swap tons of commodities for grams of poison.

Today, with the current knowledge, we cannot maintain the same developmental line of the last century. We need to look for means of agricultural production integrated with the environment and sustainability, respecting nature to serve our production. Nevertheless, we understand that agriculture will not change dramatically in a short time, nor definitively leave aside the use of chemical pesticides. Agriculture is gradually evolving, incorporating new technologies such as integrated pest management, assessment of the level of economic damage for rational and conscious use of agrochemicals, even as the use of biological control agents, which together will be the key to sustainable food production.

4.2 Biological Control and the Global Market for Agrochemicals

Biological control can be defined as the use of an organism to reduce the population density of another organism, and this includes the control of animals, weeds, and diseases (De Bach 1964; Bale et al. 2008). Thus, biopesticides are products developed with biocontrol organisms, which can be microorganisms (fungi, bacteria, and viruses), microscopic animals (nematodes), and macroorganisms (predatory parasites, insects, and mites) or natural products derived from living organisms, used for the protection of plants or animals (Bettiol 2011).

Compared to most of the current chemical pesticides, the biopesticides have a more complex mode of action, carved by billions of years of development. They are able to control pests and diseases in crops without the emergence of resistance (Hubbard et al. 2014; Senthil-Nathan 2015). This happens because the biological control reduces rather than eradicates pests, making the pest and natural enemy remain in the agroecosystem at low densities. A number of important pests can be kept at a low population density by biological control over long periods of time. In other cases, populations of pests are significantly reduced by natural enemies, but repeated releases or additional methods are needed to achieve an adequate level of control. These methods include, for example, resistant plants, cultural techniques, physical barriers, semiochemicals, and, as a last resource, the use of selective chemicals; this is the fundamental philosophy of integrated pest management (Bale et al. 2008).

In general, biological control can be classified as the form of occurrence, but, firstly, it needs to be distinguished from natural control. The biological control is the use by men of an organism to reduce the population density of another organism, whereas natural control is the reduction in numbers of the population of a species by a naturally occurring natural enemy with no human intervention. Thus, there are three main techniques of biological control:

(1) *Classical* – when an exogenous species is introduced into a new ecosystem, imported from another region or country. It is used mainly against "exotic" pests that have established in new countries or regions of the world.
(2) *Augmentative* – refers to all forms of biological control in which natural enemies are periodically introduced and usually requires the commercial production of the released agents.
(3) *Conservative* – refers to the use of indigenous biological control agents, usually against native pests. Various measures are implemented to enhance the abundance or activity of the natural enemies (Bale et al. 2008; Polanczyk and Pratissoli 2009; Roderick et al. 2012).

The techniques of biological control *classical* and *augmentative* requires the development of products that guarantee the delivery of the agent in the field. For their development, several steps are required: collect, isolation, selection, identification, characterization of the microorganism, production optimization, production scale-up, product formulation and application studies, shelf life, registration, and commercialization of the product. However, despite this long process to get to the market, the cost of developing biopesticides is much less expensive than the development of new chemical molecules, which can cost hundreds of millions of dollars and take decades of research (Cumagun 2014).

Biological control, despite being known and studied for more than 100 years, still presents low diversity and availability of products in the market. However, the interest in biopesticides has increased, because the use of biological control agents as part of the IPM program represents a change in the model of agriculture being practiced in the country. If these technologies were considered a myth in the universe of large plantations, today MIP is a rational method for pest and disease control, perfectly aligned with the use of biological control agents (Bueno et al. 2012; Faria 2017).

The global biopesticide market in 2013 was estimated at approximately USD 3 billion, or 5% of total crop protection market, and it is expected to grow more than USD 4.5 billion by 2023 (Olson 2015; Kumar et al. 2018), whereas the global pesticides market, in 2017, estimated at USD 61 billion. This was achieved with a growth above 15% a year from 2011, and today, in Brazil, from the total sales of agricultural defenses, it is estimated that only 1–2% are represented by biopesticides. In the USA biological control products already represent 6% of the market and in Europe 14–16%, and it is being used in more than 50% of the planted area in the system of agroecological of production of Cuba (Altieri and Funes-Monzotefr 2012; Abcbio 2016; Locatelli et al. 2018).

With an eye on this growing market, the largest agrochemical companies have invested in the development of new biopesticides, which can be evidenced by patent registrations in this area. The major companies follow the *classical* biological control, searching for one species, through selection or genetic manipulation, capable of controlling several pests and diseases, in different cultures in different regions of the world. Unlike the agrochemical, the biological control agents present peculiarities when used in the field. Their efficiency can be influenced by seasonal and intrinsic characteristics of the soil. Biological control agents that have high efficiency in pest control in a given region may not be as effective in another country or region.

In addition, many questions were not answered about biological control agents. Can this biological agent introduced into a new ecosystem generate environmental imbalances? Can it destroy native species of nontarget organisms? Can they cross with nearby species? Can this introduction of a new species in another region cause a reduction of genetic biodiversity (Roderick et al. 2012)? Thus, how to ensure the safety in the use of biological control and increase your participation in the world agrochemicals market?

Usually, beneficial and pathogenic organisms are naturally present in the soil, living in balanced conditions that do not cause economic damage at crops, but some factors may favor the onset of a pest or disease. From the environmental perspective, it is more sustainable and safe the development of personalized or regionalized bio-defensives, based on the concept of *augmentative* and *conservative* biological control. Thus, seeking to isolate the environment where the disease occurs, the natural enemy present in that ecosystem is able to control the disease, without the need of introducing a new species from another region to control pests. Therefore, we benefit from millions of years of coevolution between biological control agent and phytopathogenic organism. It is smarter, more economical, and safer to search for the biological control agent at the very site of disease manifestation, developing a personalized product for the disease that is occurring in that region or country. This model can be better understood with the example of Cuba agroecological agriculture.

4.2.1 Cuba as Reference in Agroecological Agriculture

Cuba is today a reference in agroecological agriculture. With economic embargoes imposed on Cuba and especially after the collapse of trading relations with the former Soviet Bloc in 1989, Cuba restricted its access to chemical pesticides and agricultural inputs. Then they had to look for another way for agricultural development and food production to support its population, converting its modern conventional agriculture to semi-organic farming on a large scale. Thus, a country with a highly industrialized agricultural system technologically similar to that in California (dominated by monocultures) has had to dramatically increase food production without significantly affecting earnings from export agriculture, all virtually without the chemical inputs and machinery on which it had become dependent (Rosset 1997; Altieri and Funes-Monzotefr 2012).

The strategy adopted by the government was to mobilize Cuba's substantial scientific infrastructure – both physical and human resources. Since 1982 Cuba has focused on integrating pest management (IPM), with an emphasis on biological control. This meant biopesticides and natural enemies to combat insect pests, resistant varieties, crop rotations, and microbial antagonists to combat phytopathogens. The chemical fertilizers were replaced by biofertilizers (microbial products) and other forms of compounds and other organic fertilizers (Rosset 1997; Nicholls et al. 2002).

The Cuban program involves decentralized regional laboratories, territorial plant protection centers scattered throughout the country, more than 200 units of the Center for Reproduction of Entomophages and Entomopathogens, guaranteeing the use of biological control in more than 50% of the country's agricultural area (Shishkoff 1993; Rosset 1997; Almeida et al. 2001) which, for example, was able to increase its production by 145% to general vegetables and 351% to beans, same with a decrease in agrochemicals of 72% and 55% for both crops, respectively. Cuba has sufficient land to produce enough food with agroecological methods to satisfy the nutritional needs of its 11 million inhabitants (Nicholls et al. 2002; Altieri and Funes-Monzotefr 2012).

A rich knowledge of agroecology science and practice exists in Cuba, the result of accumulated experiences promoted by researchers, professors, technicians, and farmers. This legacy is based on the experiences within rural communities that contain successful "agroecological lighthouses" from which principles have radiated out to help build the basis of an agricultural strategy that promotes efficiency, diversity, synergy, and resiliency (Altieri and Funes-Monzotefr 2012). We leave aside the political and economic discussions, to verify the success of this agroecological system. This model can serve as a basis for the construction of strategies to increase the participation of biological control agents in the world market of agrochemicals.

4.3 Strategies for Increasing the Use of Biopesticides in a Global Market Dominated by Agrochemicals

Before we delineate a strategy that allows greater participation of biological control in the market of agrochemicals, we must know some concepts:

Strategy – can be defined as the determination of the long-term goals and objectives of an enterprise and the adoption of courses of action and the allocation of resources necessary for carrying out these goals (Chandler 1962).

Innovation – the concept of innovation from the economic perspective was defined by Schumpeter (1943), as "an innovation was something that changed the marketplace in a profound way. The innovating organization was, thus, likely to become the new market leader and to gain an immense advantage over its competitors." Already Drucker (1985) defined innovation as "the act that endows resources with a new capacity to create wealth". This way the "innovation transforms insight and technology into novel products, processes and services that create new value for stakeholders drive economic growth and improve standards of living" (González 2004).

Based on these concepts, we can understand the concept of innovation strategy, which can be defined as the strategy that generates innovation within a company or organization because, although we can talk about accidental technical inventions, we can hardly use the same qualification for innovations, which requires a continuous and complex effort to develop a new product, process, or service. Such an effort requires a long-term vision, commitment of resources and time, and an integrated structure of decisions. That is, innovation needs a strategy (Porto 2013).

Thus, the innovation strategy applied by Cuba to reach its goals of productivity and food self-sufficiency based on agroecological crops were diversification and decentralization. They made available the physical and intellectual structure of the research institutes and universities of the rural producers. This generated disruptive innovations that allowed the breakdown of the dependence of inputs (agrochemicals and fertilizers) of the monopoly of large companies that dominate the sector, besides increasing the productivity of several crops and guaranteed self-sufficiency in food for its population.

This innovation model seeks to convert academic knowledge, generated in universities and research institutes, in applications that bring social and economic development, which translates the concept of the triple helix. Government and industry, the classic elements of public-private partnerships, have been recognized as important spheres of society since the eighteenth century. The triple helix model is that the university is no longer having a secondary social role, though important, of providing higher education and research, but is assuming a primordial role equivalent to that of industry and government as the generator of new industries and enterprises. Thus, the University has an almost governmental performance, as an organizer of local or regional technological innovation. This triad model of innovation and development allows the presence of a conciliator in the individual's interests, giving greater sustainability to the cooperation between the parties (Dzisah and Etzkowitz 2008; Porto 2013; Etzkowitz and Zhou 2017).

In the model exemplified by the success of agroecological agriculture in Cuba, we have research institutes and universities as protagonists of innovation, rural producers in the role of industry, transforming knowledge into product generation, and government in its role of mediator and foster of innovations. Leaving aside the economic policy adopted by the country, this model can perfectly foster the economical niche of biological control products, increasing participation in the agrochemical market. That would be capable of creating jobs, generating and distributing income mainly in underdeveloped countries, such as Brazil. The disruptive innovation generated by the niche of biological control will allow decrease of the dependence of products and inputs imported from developed countries, which produce the agrochemicals, but prohibit the application, of the great majority, in their soils. This way, we will be able to break the circle of poison.

4.4 Final Considerations

In this way, it seems clear that the decentralization of investments, to foment different strategies of the use of agents of biological control, bringing together innovation agents, favors the emergence of agribusiness' start-ups. This will allow the increase in the participation of biological control agents in the agricultural defensive market. Start-ups have more flexibility to maintain close relations with the farmers and cooperatives, in the search of innovative solutions, and directed to the solutions of local problems.

However, this requires that each helix of the triple model do its part, the government as a mediator of interests and research financer, guaranteeing a greater plurality of investments in research and development, with the aim of knowing the biodiversity, the problems, and challenges of regional agriculture. The university as a research center and teaching, to generate and disseminate knowledge, which along with producers or companies acted as agents of innovation, transforming knowledge generated in products that solve problems and lead to social development.

Agricultural cooperatives or large independent producers, in partnerships with universities and research institutions, can identify and isolate biological control agents present mainly where the disease is occurring. Many biological control agents, whether microorganisms or insects, can be multiplied and produced by simple methods with a small structure; as an advantage in Brazil and other countries, the multiplication of a biological control agent for own use does not require registration with the official control entities.

The correct triple helix circulation to the proposed niche increases the offer of biological control products, diversity of companies and solutions, reducing the dependence of agribusiness of the dominance of few agrochemicals companies. Thus, the bioeconomy – the set of economic activities relating to the invention, development, production, and use of biological products and processes – became an important tool for major socioeconomic contributions in diverse countries, which contributes to the plan by policy agenda from OECD to Bioeconomy to 2030 (OECD 2009).

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