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Rural development and environmental protection through the use of biofertilizers in agriculture: An alternative for underdeveloped countries?

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ABSTRACT

Economic momentum of underdeveloped countries derived from the generation and application of their endogenous knowledge is an essential factor toward achieving social welfare. Thus, it is important to understand the development of science and technology within these underdeveloped countries, how the application of that development can address problems in agriculture and food needs, and how that development can offer sustainable options for growth and optimization. In addition, many small farmers in underdeveloped countries are already planting crops based on biotechnological products, which is significant in terms of how these activities influence the development of their lives, particularly with respect to the generation of policies aimed at farming areas. This paper is an exploratory study on the perceptions of peasant producers of the effects of biofertilizers on their environment and their lives. This research is based on a study of peasant producers of the State of Morelos, Mexico, who use biofertilizers produced from endogenous technological assets, i.e., that involve private actors and public research centers. The results facilitate understanding the perceptions of these peasants in addition to the challenges and opportunities that rural areas face and the connections between the involvement of business, academia and government in planning and administration with respect to the management of these innovations.

1. Introduction

Since ancient times, biotechnology has been used to attend the needs of the population. Biotechnology is defined as a science that offers technological solutions from biological organisms, systems and processes related to them, which creates a whole industry in areas such as food, agriculture, and health, among others, and in which the use of technologies employed varies from one application to another in an important manner. Such solutions relate to techniques that go from using fermentation processes to integrating recombinant DNA technology [1–3].

A case study was performed to investigate the effects that endogenously generated technologies have had on the environment and on the lives of the peasant producers who use them. In addition, the challenges and opportunities that lie ahead for the rural environment, business, academia and the government with respect to policy planning and administration for the proper use of these innovations are identified. Specifically, the case for biofertilizers in the area of agricultural biotechnology is affirmed.

To improve understanding of the problem, two theoretical sections are developed. These sections aim to explain, on the one hand, how the theory of development and agriculture is constrained in underdeveloped countries and, on the other hand, how the relationship between technology, agriculture and environmental protection supports rural development in such countries. We begin from the hypothesis that it is possible to generate technologies in local areas of knowledge and that, when managed by small national companies, such technologies can contribute to the sustainable

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development of economies and better conditions for rural producers.

The current economy has been characterized as the unity of time and labor, wherever that unity can occur [4]. However, note that not everything assumes the global scale that, for example, appears in the activities of corporations, whose production and employment generation eventually materialize at the regional level. Technology represents a fundamental element in the explanation of regional development. Thus, successful science and technology policies are aimed toward regions in which there are key actors to generate the process of technological change [5].

De Janvry and Sadoulet [6] argue that technological change can help increase the welfare of those who adopt innovations. This benefit occurs indirectly through the effect of these technologies on, for example, food prices, employment and wages in agriculture. The use of biotechnology has significantly increased in recent years. For example, since the 1980s, the number of intellectual properties (IPs) such as patents in the area of agricultural biotechnology has exponentially increased [7]. Biotechnology applications represent a wide range of opportunities, primarily in areas such as health (human and animal), the agri-food sector (i.e., agriculture, fisheries, forestry and food processing) and the environment (i.e., industrial processing, natural resources, environmental services and platform technologies) [8]. An example is the case of biofertilizers, whose use has been increasing because of the benefits that have been associated with them, i.e., enhancing productivity or addressing problems that arise in the development of multiple crops because of diseases and adverse weather.

Lyson [9] demonstrates how large corporations function as primary creators and disseminators of the most advanced biotechnological advances and that it is through IP mechanisms that these corporations profit from genetically modified products. Thus, the options for underdeveloped countries concerning IP in agricultural biotechnology are related to the use and acquisition of private and public technologies, to the development and protection of national institutional inventions and to the generation of technology transfer alternatives.

In the first and second cases, few underdeveloped countries have IP options for the protection of these inventions. The best alternatives are trade secrets, agreements to transfer these materials, access to technical knowledge, intellectual property rights abroad and the generation of technology transfer mechanisms in line with the technological interests of a given nation [10]. In addition, despite the technical potential of biotechnology to solve various problems, it remains unclear whether social institutions will be able to adopt and use this technology to satisfy the needs of society and improve social welfare [11]. Legal safeguards for endogenous inventions that occur in the agricultural area could be supported by intellectual property mechanisms. Such support becomes necessary with respect to the accumulation of technological capabilities, as represented by the case of biotechnological products and, specifically, biofertilizers in this discussion.

Since the development of new technologies and the increase in the global population, the form of agricultural production has changed. Although the family farm represents a special interest at the micro level, at the macroeconomic level, i.e., as a form of mixed production (crop and animal), the trend in developed countries is the specialization of large-scale crops that support animal production [12].

For example, McMillan, Narin and Deeds [13] explain how biotechnology has spawned a new industry of small companies with strong links to university scientists whereby the latter play a predominant role in the transfer of knowledge from universities to the market or in creating spinoff companies [14]. However, as previously mentioned, the main barriers to the development of a biotechnology industry have been institutional constraints and a lack of skilled human capital in the universities, government research laboratories, and private companies in regional areas [15].

The knowledge and confidence of users concerning the use of agricultural biotechnology are basic elements with respect to the adequate management of the risk perception of these technological assets. Thus, objectivity and transparency in the assessment, management, and communication of knowledge in the area in addition to the inclusion of concerned parties become necessary [16]. Academia, government, business and peasants must work together to overcome technical, legal and operational barriers, not only to increase the availability of food but also to provide for its consumption under conditions of biosafety and availability of information for the population.

As Persley [17] argues, biotechnology is a tool that can contribute to solving food problems. Although the risks are not well understood, to help individuals make better decisions, it is necessary to ensure access to stakeholders through a framework of appropriate information. Thus, it is necessary to provide the best means of access to new technologies, generation of new requirements on public policy matters and necessary institutional arrangements for all stakeholders. These efforts involve social capital in the form of accumulated knowledge in an endeavor to reflect the different perspectives, such as community, institutional, networking and synergy perspectives, that facilitate the improvement of living conditions for the general population through the application of this discipline [18].

Therefore, in-depth studies that ensure the appropriate use of biotechnology applications and their products are required. There has been discussion concerning the social acceptance of biotechnology. It has been demonstrated that a policy concern exists in several countries (primarily in Europe), in which public opinion concerning agricultural biotechnology could impede the progress of such technology. Studies have observed how consumer support can be increased as long as benefits outweigh risks, as in the case of medical biotechnology in Europe, for which the level of acceptance is high in contrast to that of agricultural biotechnology, whose support is low [19].

Addressing the acceptance of biotechnological products by consumers, Aldrich and Blisard [20] performed a case study on the production of a biotechnological food product of animal origin. The authors conclude that consumers doubted the scientific evidence (i.e., perceived the issue as an aspect of food safety and welfare) and scientific results in matters of biotechnology. Thus, controversy was created. However, even when controversy occurs, consumption demand might overcome adverse effects or minimize them. The absence of reports of harm and government regulation could promote acceptance of the results of the use of biotechnology. Another problem is that the development, promotion and application of biotechnology is controlled by large corporations, despite the long history of genetic research in agriculture that has been conducted in underdeveloped countries such as Mexico, Brazil and India [21]. In addition, there are several biotech companies in Latin America, particularly in the health industry, that have achieved success in the market by following innovative strategies that helped them generate competitive advantages [22]. Therefore, similarly, in the area of agricultural inputs, biofertilizers might be an option for the creation of enterprises in underdeveloped countries that, with the cooperation of academia, government and business, create initiatives that favor farming and benefit scientific and technological development in these countries.

Previous empirical analyses of innovation studies have focused on large corporations. However, in recent years, a significant amount of innovative activity has been observed to occur in small businesses, particularly in new industries and emerging areas of knowledge [23]. Thus, in underdeveloped countries, there is a need to study small companies to help them understand their needs and dynamics to enhance their participation and development in domestic and international markets. In addition to the above, in the case of biofertilizer studies, it would be necessary to generate research concerning the perception of peasants in underdeveloped countries with respect to the inclusion of these new inputs in agricultural activities and the effect they have on the peasants' lives. Therefore, it would be necessary to establish actions to incorporate this technology based on local needs arising from the daily activities of producers, thereby generating a synergistic and beneficial effect in terms of technical, social, economic, productivity and environmental stewardship.

2. Economic development and agriculture in underdeveloped countries

Schumpeter [24] states that economic development involves economic history and geography because over time, changes can be observed in industrial organization, methods and quantities of production, technologies, social welfare, and in the appearance of emerging industries and the disappearance of others. Therefore, incentives to invest in infrastructure and human capital become fundamental to development and are coupled with the dissemination and adoption of new techniques, credit institutions, interest rates, exchange rates, prices and wages in agriculture and with coherent policies that support such development [25].

However, a significant number of elements do not allow mitigation of the fight against poverty, such as the inequality in the world, the monopoly of R&D (research and development) by multinational corporations from developed countries and the restricted use of science and technology. In underdeveloped countries, there is a problem related to the lack of efficiency in aspects of production and in the use of new knowledge. Whereas a number of these countries have exhibited progress in the production of high-level knowledge, others are engaged in building capacities that constitute a starting point because the innovation process is characterized by being dynamic but gradual [26,27] and [28].

The development of endogenous technological capabilities and engineering skills, specifically, have been affected by free trade agreements and market deregulation through the substitution of national human resources and the importation of capital goods [29]. Thus, income is distributed to the extent that competencies for the production of complex products that inherently incorporate knowledge are developed. That is, underdeveloped economies should not be limited to production based on natural resources, standardized commodities and cheap labor, which ultimately generates routine mechanisms and does not promote structural change [30]. The search for and exploitation of technological contributions are of great importance, particularly in the agricultural area, in which the needs of underdeveloped countries have important dimensions; such contributions can contribute to improving the lives of millions of peasants who produce food on small and large scales for their own needs and for consumption by the general population, respectively.

There is a need for more balance between technological innovation and social character goals by means of greater collective participation that creates useful support for society in scientific knowledge, for example, when using knowledge produced by the academy because society and technology are integrated as a functional unity. This integration can be achieved through encouraging connection among all parties interested in innovation and knowledge management related to the issue to be addressed [31–34].

How innovation can be translated in terms of competitiveness in rural organizations to increase their profitability has been noted. Everything must be done to match the high competitiveness global framework, which embraces a neoliberal tendency of exclusive nature that has forced people from rural communities to adapt to new circumstances affecting their social and economic environment. Thus, underdeveloped countries need to create agro-industrial enterprises that are competitive and sustainable to help improve rural development [35–37].

A large number of local enterprises in underdeveloped countries have a great vulnerability in encouraging activities focused on science, technology and innovation. This vulnerability can be explained based on the environment in which the activities occur, which is very different to that in developed economies, in which knowledge is their fundamental base for development, a base that has surpassed the value of human resources and production materials. Additionally, in dynamic markets, the innovation process is constantly changing and requires actions to address the competitive forces it creates [38–41].

Although generating technological innovations in the rural context is not a systematic phenomenon, there are important efforts that allow seeing how adoption or absence of different innovations in the agricultural field can encourage or hinder the development of the regions because, on the one hand, these innovations can help make agricultural production more efficient and effective. On the other hand, they might generate larger profits to varying degrees or integrate a larger added value to products such as oil palm, natural rubber, corn, mango, cacao, guava and tomato [42–49].

Poverty and inequality within rural areas in underdeveloped countries have assumed alarming proportions that deserve to be analyzed from the perspective of disadvantaged peasant producers. In this context, it is necessary for governments to promote both economic development in these regions and an increase in the income of the population that is the most vulnerable [50and51]. It has been argued that poverty and rurality are two aspects that show a visible correlation. In regions such as Latin America and the Caribbean, the stress created by these two challenges is among the most obvious in the world. The dynamics of the region in particular show no development that promotes inclusion and sustainability because the rural policies do not consider local histories and their multiple contexts [52and53].

Government support is a key factor in the formation and development of innovation networks, in which the link between private and public components must focus not only on venture capital for R&D development but also on strengthening the sharing of knowledge to generate a competitive advantage [54]. Cooperation should be based on complementarity, learning, speed, flexibility and reciprocity [55], from which it is possible to conceive strategic alliances that facilitate the development of the processes required to generate new products for the market [56].

Sagasti [57,58] notes the importance that the development of science and technology has in underdeveloped countries in preventing disruption and social development costs when technological progress enables these countries to generate, disseminate and use knowledge within the productive and social arenas, thereby counteracting technological dependence when leveraging technology generated abroad. The goal should be to develop capabilities that enable these countries to absorb this knowledge and adapt it to local needs, develop it and export it after the improvements. Such a process would ensure that revenues are distributed to all sectors of the population to improve their quality of life. Therefore, knowledge generation oriented toward understanding social phenomena, an appropriate transformation of the technological base in response to the changing environment, and growth and development of production activities for the benefit of these countries should be considered.

In the specific case of agriculture, traditionally, despite efforts to establish agricultural research systems, these systems are characterized by financial uncertainty in operations, poor links with the private sector, poorly defined strategies, a decrease in quality staff, and bureaucracy, which hinder the satisfaction of technological demands. Thus, research should be conducted through public R&D organizations based on demand, and this research should be more flexible, effective, efficient and open to other forms of financing. Additionally, regional, national and international cooperation should be promoted to decrease dependence upon foreign technology [59]. In terms of productivity and efficiency, the use of biofertilizers has been an important aspect of improving soil conditions and combating various pathogens and pests, environmental factors and diseases of the crops themselves; hence, the quality of their results is a key aspect to address [60–64].

The role of agriculture in economic development is based on the supply of agricultural products required for industry and food, the increase in revenues through exports (particularly during the early stages of development), labor derived from agriculture with potential use in other areas of interest and regional income that can be used to stimulate industrial expansion [65]. After recurrent economic crises and the major crisis that began in 2008, which includes both energy and food crises, this last statement cannot be made with the same confidence as in the past. The population of rural areas has become increasingly vulnerable. The condition of these individuals as marginal producers leaves them in an unfavorable position as consumers. Agricultural research has had a major effect on economic transformation globally. In agricultural policy, efforts have been made, for example, to strengthen intellectual property rights, increase subsidies and incentives, promote research and development at public R&D centers, increase technological regulations, and expand environmental policies [66]. These efforts can succeed in industrialized countries. However, in underdeveloped countries, they tend to increase social inequality; hence, the generation of endogenous developments must be oriented toward the attention of such countries, particularly the most unprotected and vulnerable sector of peasants.

3. Agriculture, technology and environmental protection for rural development in underdeveloped countries

The majority of future population growth will be concentrated in underdeveloped countries, where much of the population will live under conditions of extreme poverty and malnutrition. The situation is exacerbated in rural areas, in which agriculture is the primary source of income and employment. As a result, worldwide, these poorer rural regions are associated with low public and private investment in agricultural activities. This problem leaves the food security of the population unprotected. Food security can be strengthened through investment in scientific research, training and the transfer of knowledge and technologies that will ensure the sound management of resources and the sustainability of the land [67].

An aspect that has damaged rural development the most is migration, which is due to the loss of the younger work force, particularly those in their most active economic stage and who could improve the field's development. The phenomenon is encouraged by the search for better economic conditions for migrants and their families because working in the field does not offer adequate profitability conditions. Families depend increasingly upon remittances or governmental support that promotes abandoning agricultural activities in rural areas where poverty becomes a constant. Thus, a solution to the problem could be a production increase that mitigates poverty conditions and takes advantage of the human capital that is usually lost [68–72].

One of the most important aspects in the innovation process consists of the performance of local actors, in particular, performance related to aspects of connection, investment and learning [73]. In this sense, regional knowledge spaces or environments play an important role in the advancement of these actors and their regions. Casas, De Gortari and Santos [74] conceptualize the term as spaces containing underutilized knowledge in priority areas that can promote the development that occurs when knowledge is shared through the formation of networks.

Similarly, there is a need to develop strategies that support the development of technological capabilities such as product diversification, business alliances, networks related to operation and production elements, coexistence between traditional and modern elements, R&D, external knowledge, organizational culture and training [75]. The specific case of rural development requires the creation of new products and services necessary for the generation of markets and the launching of new technological pathways and more-intensive dynamics to perform whatever is needed for the generation and use of knowledge that will allow cost reduction. Hence, such new products provide viability to a company in the future within the phenomenon of globalization [76and77].

This worldwide generation of new products begins as a part of the search for new alternatives to combat environmental degradation and consequently to migrate to more-friendly technologies. Huang et al. [78], for example, note that the use, abuse and misuse of chemical pesticides in China has poisoned farmers, degraded land, polluted water and increased the amount of these compounds in the food supply. Therefore, the government has regulated the production, marketing and application of these products. Conversely, a number of biotech products have demonstrated their usefulness in increasing productivity, reducing the use of pesticides and decreasing production costs.

Although there are conflicting positions on the acceptance of the use of biotechnology products, data indicate that in 2012, only 17.3 million farmers planted biotech crops, of whom over 90% were poor farmers from underdeveloped countries [79]. Pinstrup-Andersen and Cohen [80] describe how small farmers in underdeveloped countries face a significant number of problems in performing their jobs properly, such as crop losses from pests, diseases and droughts, low soil fertility, lack of access to affordable nutrients, environmental degradation, market problems and problems concerning technical assistance and infrastructure. However, not all biotechnological techniques have generated as much controversy as the case of transgenics in agriculture. That is, there are sectors and areas of expertise in which such techniques are employed regularly and with high acceptance by the public and the scientific community; however, in other areas of expertise, researchers and producers oppose their use. Therefore, the evaluation of the perceptions of all stakeholders on the use of biofertilizers in agriculture is high priority task.

Latin America has been characterized as a region rich in renewable and nonrenewable resources. However, one historical problem in the region has been hunger and rural poverty caused in part by the lack of an efficient agricultural system. In this respect, it has been noted that the modernization of the countryside in the region has undergone mechanization, the introduction of improved seeds (i.e., hybrids) and the use of pesticides and fertilizers. These modernizations have benefited large producers at the expense of peasants, which results in a loss of traditional agricultural knowledge and increases in environmental, social, food self-sufficiency and poverty problems. Thus, processes derived from biotechnological products should be observed carefully to avoid excluding the peasantry. A case in point is the green revolution, which was monopolized by the private sector through its control over the technology assets that were generated at the time and the interest of this sector in cash crops. As a result, local techniques, such as crop rotation, biological pest control and green manuring using vegetables, were abandoned [81].

Thus, it can be understood how in Latin America, various social movements that oppose the widespread use of biotechnology have emerged. In this region, the adoption of modern biotechnology occurred in the early 1990s under neoliberal reforms that influenced the transformation of the agrarian structure of production, the concentration of land ownership, and the reduction of subsidies to the poorest peasants. The issue becomes more relevant when one realizes that agribusinesses in Brazil account for over 40% of its gross domestic product (GDP) and that Brazil and Argentina together represent the largest producers of genetically modified crops in Latin America, commanding an important position in the export of these products in the global market [82]. Consequently, this problem is one not only of endogenous technological development but also of attention to local and regional needs of producers, companies and the population of underdeveloped countries under conditions of autonomy and leadership.

The use of techniques and applications of agricultural biotechnology in Latin America has made considerable progress, particularly in countries such as Brazil and Argentina, in the following areas: a) financial and human R&D resources; b) the use of biotechnological tools; c) government programs; d) regional cooperation programs; e) field trials; f) harvested area; and g) advances in biosafety regulations. In Mexico, the following changes can be observed: a) the government has had a greater share than in countries such as Argentina and Brazil; b) with Brazil, Argentina and Colombia, Mexico has the largest number of scientists in the area; c) support programs exist for infrastructure and research in biotechnology; d) field tests with genetically modified material are underway; e) commercial production of genetically modified crops exists; and f) wide-reaching regulations on biosecurity (including plants, animals and microorganisms) have been developed [83,84].

Thus, the importance of studying these technologies in economies in which economic and social development remains a challenge is clear. It is important to consider the effects on the environment and the benefits for the population. Many factors should be analyzed when a new technology is adopted by users such as its effect on technical and economic development, its productivity and environmental protection factors, and the social development that the technology fosters. The use of biofertilizers has spread and offers alternatives for streamlining productivity. It is important to understand their progress and constraints and address the problems faced by a large number of crops in various regions of the world such as vegetables, mushrooms, tea, soybeans, wheat, bananas, plantago ovata forsk, maize, sunflowers, potatoes, cassava, and cotton [85–99].

Concerning technical and economic development, Marra, Pannell and Ghadim [100] identify the following areas of risk, uncertainty and learning in the adoption of new technologies by farmers: a) learning to improve the ability to implement new technology; b) learning to enable decision making with respect to such technology; c) the present and future perception of the profitability of technology; d) the relationship between the profitability of new and old technologies; e) producer attitudes concerning the risk of adopting new technology; and f) costs incurred by delaying adoption.

With respect to productivity and environmental protection, as previously mentioned, biotechnology is a tool that can help address the problems of food production in conjunction with solving related environmental problems. Microbial techniques have been successfully applied in addressing environmental and agricultural problems, although their functionality has been questioned because of the lack of control of conditions that affect the optimal performance of their metabolic functions. However, these techniques have been accepted as an alternative to chemicals that cause serious environmental concern. Thus, biofertilizers and biopesticides have been associated with the stimulation of plant growth, sustainability and productivity [101].

In terms of social development, De Janvry and Sadoulet [6] argue that technological change can directly help raise the level of social welfare of farmers in poverty conditions who adopt technological innovations and indirectly help farmers in general based on the following factors: the price of food to consumers, the effects on wages and employment within agriculture and other economic sectors through the production and generation of inexpensive raw materials, savings on wages for employers, increased foreign exchange and economic growth.

However, an interesting approach to measure a technology's effect on society is whether it promotes social innovation, i.e., practical ideas that contribute to the achievement of social goals, such as the challenge of controlling climate change, whereby technology will play an important role, although social innovation should generate a behavioral change. Thus, disciplines such as biotechnology must rethink their practices, their production methods and their contribution to achieving these social goals [102].

Gardner, Acharya and Yach [103] note that access to products or services is determined by technological innovation. However, social innovation is responsible for the distribution of technological innovation together with adaptive innovation, which helps contextualize these developments in the local environment, and the organizational innovations required to work, adapt and learn. Mulgan [104] observes that social innovation is encouraged by capable individuals who can identify problems and at the same time provide solutions.

The other benefits associated with the use of microorganisms (i.e., biofertilizers) are as follows: a) acceleration of plant growth, b) increased soil and crop quality, c) improved resistance to diseases and pests through bioactive substances, d) increased productivity and e) decreased costs [105 and 106]. Many studies have noted the benefits of the use and development of these technological assets [107–111], which are increasingly becoming an alternative to chemicals associated with damage to health and the environment. Note that their effect is aimed at generating a framework of productive, economic, technical, social and ecological benefits for rural areas in underdeveloped countries, particularly those populations that are most vulnerable.

4. Study on a company that generates biofertilizers as endogenous linking processes

The proposed method is based on a case study in which qualitative and quantitative evidence is used to identify explanatory factors for understanding the phenomenon under study [112–114]. The first step in conducting the case study was to identify a producer and distributor of biofertilizers in Mexico (which is characterized by the development and commercialization of endogenously developed technology) and to investigate the views of the company and the end users of these products concerning the effect of biofertilizers on the life, activity and environment of peasant producers.

To this end, a questionnaire was developed based on a conceptual framework that was divided into two sections. In the first section, closed and open questions were integrated to characterize population data such as a) age, b) gender, c) education, d) place of residence, e) whether the interviewee was an independent producer or worked for an employer, f) crop type and cultivation area in hectares, g) which company's biofertilizers the interviewee used and for how long, h) whether production increased and whether the interviewee would use biofertilizers again and recommend them and i) the specific benefits to social development obtained through using biofertilizers.

The second section was intended to measure the perception of peasant producers of the effect of biofertilizers in the following three categories: a) technical and economic development, b) productivity and environmental protection, and c) social development. Categorical statements in an affirmative form were included in each category to measure the degree of agreement or disagreement using a Likert scale with the following options: 1. Strongly disagree, 2. Disagree, 3. Undecided, 4. Agree, and 5. Strongly agree. The higher the score was, the greater the degree of agreement with the expressed statements (Table 1).

Haladyna [115] has expressed the importance of validity in the development of questions and the answers that are obtained from them. In fact, to ensure its validity, the questionnaire was evaluated by a panel of three university experts on issues of research methods and agricultural biotechnology. The experts evaluated the general content and how the questions were presented to ensure that the questions were commensurate with the educational level of the participants and focused on the research goal. They provided suggestions that helped improve the questionnaire's form and substance.

5. Analysis of results

The selected company was characterized by its strong connection with academia. Among the entities with which it has had connections, the following stand out: a) the Research Center on Nitrogen Fixation (now known as the Center for Genomic Sciences) of the National Autonomous University of Mexico (UNAM), b) the Institute of Biotechnology – UNAM, c) the Biomedical Research Institute – UNAM, and d) the National Laboratory of Genomics for Biodiversity (LANGEBIO). In fact, several of the products sold by this company were created within the university, and their development has been sought through participation of the government.

Based on an interview with company officials, it was established that in these activities, the company has participated with the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) in a program focused on the use of biofertilizer in corn production in fields of more than 10,000 ha. Because of this program, an approximately 15% production increase was obtained (with other crops, for example, cane, the increases can vary from 20 to 30%). Based on the results, twice the number of hectares of maize used during the first phase was proposed. In addition, the development of projects with the National Council of Science and Technology (CONACYT) to promote further advances in the link between academia and business was promoted.

One problem that the organization describes is the emergence of other products on the market that do not meet appropriate quality standards, a problem that has significantly affected the image of biofertilizers. It should be considered that although a quality biofertilizer cannot always replace the use of agrochemicals, it can reduce the use of such chemical by up to 50% and thereby increase productivity, lower production costs and mitigate environmental impact. Additionally, the cost of fertilizing a hectare with biofertilizers involves an investment that is one-tenth or less that required for fertilization that only employs chemical fertilizers. However, for the company, technology transfer has not been easy. It was described as a long, slow, expensive process with dissemination problems.

The company undergoes constant innovation. Among its most important advances because of the establishment of its ongoing relationship with academia is the development of two biofertilizers in liquid form, which increases the shelf life of these products. Research is also being conducted on the development of new biofertilizers, improved compost and biofertilizers with a high concentration of microorganisms per milliliter. The company has various certifications, including an approval from the Federal Commission for the Protection against Sanitary Risks (COFEPRIS) that provides a guarantee against risks and SAGARPA certification of biological effectiveness.

The target population of this study uses two of the company's biofertilizers, which were isolated by selecting the best strains. No genetic modification was performed in either case. The first of these biofertilizers is based on the arbuscular mycorrhizal fungus *Glomus intraradices*, which is used for all types of crops and primarily stimulates root growth. Thus, the biofertilizer enhances the absorption of nutrients necessary for root development, promotes the uptake of nitrogen and water and promotes the production of hormones that stimulate the growth of the plant and its resistance to, e.g., disease, drought, and soil salinity. The second biofertilizer was developed based on the *Azospirillum brasilense* bacterium that is used in most perennial agricultural crops and in ornamental plants. The bacterium transfers nitrogen from the air to the plant, producing hormones that stimulate plant growth and compete with root pathogens.

The study sample belongs to a group of producers located in the State of Morelos, Mexico, in which the company has had the greatest effect and presence. More than 70 peasant producers were

Table 1
Statements concerning the effect of the use of biofertilizers for each category.

I: Technical and economic development	
1	Since using these biofertilizers, the profits I receive from the produced crops have improved.
2	The use of biofertilizers has been of greater economic benefit for me than, for example, chemical fertilizers.
3	Biofertilizers produce the same or better results year after year regardless of changes in climate.
4	Learning to use biofertilizers has been simple and their cost highly affordable.
5	I consider that using biofertilizers involves minimal risk to me, both technically and economically.
6	I am sure that biofertilizers have more advantages than disadvantages.
II: Productivity and environmental protection	
7	Biofertilizers are a technology that does not harm the environment and increases the quantity and quality of crops.
8	Using biofertilizers, I have noticed that the quality and recovery of the land have improved significantly.
9	If I use biofertilizers, I receive a higher yield per hectare than if I only use chemical fertilizers.
10	The use of biofertilizers is less risky for me and for the soil than chemicals.
11	Using biofertilizers enables the plant to grow faster and become more resistant to pests and weather changes.
III: Social development	
12	I believe that since using biofertilizers, the profits I have received enable me to increase my welfare and that of my family.
13	The use of biofertilizers has improved my social status and obtained greater benefits for my family and/or me.
14	Thanks to the benefits of production and the ease of use of biofertilizers, I have had more free time for my family and myself.

Authors' elaboration

interviewed and surveyed. Given the size and scope of the company's market study, the sample was not random and the inclusion of the participants in the study was undertaken by invitation. In total, contact was established with individuals from nine regions of the state: 1. Cuautla, 2. Quilamula, Tlaquiltenango, 3. Achichipico, Yecapixtla, 4. Ocuituco, 5. Zacatepec, 6. Tlayacapan, 7. La Tigra, Puente de Ixtla, 8. Ayala, and 9. Atotonilco, Tepalcingo.

Many of the interviewed peasant producers were not native to the studied localities. In these places, there are important problems, such as lack of quality basic services, housing, and education, which hinder the economic and social development of the population. Overall, the environment in which they pursue their agricultural activities exhibits signs of vulnerability because what is grown is a result of harvests that are obtained by heavy rain rather than by irrigation. However, a few of the interviewed producers had better infrastructure and greater technical and financial resources, which enabled them to more clearly perceive the benefit of using biofertilizers. The most important characteristics of the surveyed population are provided in Table 2.

Subsequently, and based on the results obtained from the second part of the questionnaire, a matrix of 14 columns by 71 rows was generated to calculate the average for each of the questions and to determine the perception (favorable or unfavorable) concerning these technological assets for each of the statements included in the three previously described categories. The average for each of the three categories and the overall average were also calculated (Table 3).

Overall, the results reveal a positive perception of the effect of biofertilizers in each of the proposed categories. At the level of each question, a value greater than 4.3 is observed in most cases. Only in Question Three was a value of 3.9 obtained, possibly because in an important number of cases, the period of use of both products was short. Therefore, it was difficult to determine the behavior of the biofertilizers over time. However, if the overall average is considered, it can be broadly argued that the perception was positive.

To measure in greater detail the perception of the effect of biofertilizers in the previously noted categories, a scale of measurement was proposed that is more accurate for determining the percentage of respondents who have developed a more positive or negative perception of the use of biofertilizers according to the following scheme. On a scale of 1–10, it was found that for those participants who in the evaluation of their overall perception awarded a minimum score of eight, the perception tended to be positive, whereas those who awarded a score less than eight tended to have a more negative evaluation.

To perform this measurement, a frequency analysis was conducted in which the maximum possible obtained value was 70 points. Next, a scale was established that adopted as reference an equivalence of 70 points for a score of 10. Thus, in the frequency analysis, the lowest recorded value was 46 points, and the highest value was 70 points (Table 4).

According to the results, the cutoff point for determining a positive perception was a value greater than eight. Thus, based on this parameter, it was observed that most of the studied population had a positive perception of the effect of biofertilizers (Fig. 1). However, the population that displayed a lower acceptance did not

Table 2
Main characteristics of the surveyed population.

No.	Characteristics
1	The education level is low in the interviewed individuals: 7.04% did not receive any formal education, 54.93% completed or abandoned primary school, 22.54% completed or abandoned secondary school studies, 14.08% completed or abandoned high school studies, and only 1.41% completed undergraduate studies.
2	A small number of young individuals involved in agricultural activities was observed. The minimum age recorded was 19 years and the maximum was 86 years, although the average age was 49.4 years.
3	An insufficient surface area. One of the interviewed producers had 230 ha. However, excluding this case from the sample, the average number of hectares used by each farmer was 5.5.
4	The male population represented the largest agricultural workforce, with 77.5% of the share compared with 22.5% for women.
5	Poor crop rotation and consequently a strong predominance of maize. A total of 93% of the farmers sow corn alone or in combination with one or more crops, often sorghum. Crops with a lower presence included sugarcane, hominy, kidney beans, tomatoes, cucumbers, alfalfa, improved pasture (i.e., gamba grass), criollo chilies, pumpkin and chia.
6	The period during which the interviewees used biofertilizers varied from one to seven years, although most of the sampled population relapses into a period of use that ranges from one to three years.
7	All of the producers were independent; i.e., they do not work for any employer, and they use their production for their own consumption and/or for sale.
8	The form of tenure of the productive lands includes small proprietors, commons, the temporary tenant of common land and often the tenant.
9	The entire surveyed population replied that it would use and recommend biofertilizers. Only 7% did not report an increase in production, and in several cases, less yield was obtained per hectare. However, it was observed that the economic benefits increased in any case through the savings that were obtained from the application of biofertilizer and the subsequent decrease in chemical fertilizer.
10	Because of the characteristics of the surveyed population, there was more-detailed inquiry concerning the area's social development. The inquiry had the following results: improvements in its economy, lower production costs (e.g., savings achieved through the decreased use of chemical fertilizers), smaller technical problems (e.g., fewer pests and weeds), less work with more time for other activities and benefits such as the ability to purchase, for example, livestock and plastic sheets, which improve household budgets and increase access to education.

Authors' elaboration

Table 3
Obtained averages by question, category and overall.

Categories													
I: Technical and economic development						II: Productivity and environmental protection					III: Social development		
Obtained averages for the questions													
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4.3	4.5	3.9	4.5	4.4	4.6	4.5	4.3	4.5	4.6	4.5	4.3	4.4	4.4
Averages by category													
4.3						4.5					4.4		
Overall average													
4.4													

Authors' elaboration

Table 4
Frequency analysis and determination of equivalences.

Values	Frequency	Percentage	Cumulative percentage	Equivalent rating
46	1	1.4	1.4	6.6
49	1	1.4	2.8	7.0
50	3	4.2	7	7.1
51	1	1.4	8.5	7.3
52	4	5.6	14.1	7.4
53	2	2.8	16.9	7.6
54	3	4.2	21.1	7.7
55	2	2.8	23.9	7.9
56	4	5.6	29.6	8.0
57	1	1.4	31	8.1
58	3	4.2	35.2	8.3
59	3	4.2	39.4	8.4
60	1	1.4	40.8	8.6
61	2	2.8	43.7	8.7
62	3	4.2	47.9	8.9
63	5	7	54.9	9.0
64	1	1.4	56.3	9.1
65	2	2.8	59.2	9.3
66	7	9.9	69	9.4
67	4	5.6	74.6	9.6
68	3	4.2	78.9	9.7
69	7	9.9	88.7	9.9
70	8	11.3	100	10.0

Authors' elaboration

strongly reject the effect of this biotechnology. Additionally, the results continue to correlate with adverse circumstances from a technical, social, environmental and economic approach.

Additionally, during fieldwork, the producers exhibited concern about factors that limit the performance of biofertilizers and their feasibility of use, which at some point might hinder the use of this technology. Therefore, another objective was to generate a discussion that would facilitate the development of policies and programs that would help mitigate these problems in the future. On this basis and as part of fieldwork, in-depth interviews were conducted with various individuals affiliated with government programs, technicians and farmers concerning the favorable aspects and the obstacles that they have encountered since adopting biofertilizers.

The main problems that can limit the benefits obtained from the use of biofertilizers included the following: 1. The economic benefit obtained from a crop depends upon the crop type and the extent of the cultivated land. 2. If other major inputs (i.e., seed and irrigation) were absent, the expected benefits might be limited. 3. In many cases, it is necessary to conduct soil studies and, if required, apply the relevant treatment. 4. Training to apply fertilizers is important, and its lack affects yields. 5. Infrastructure is lacking. 6. The price of products on the market is low, and their positioning is difficult. 7. Government support for small-scale producers is lacking.

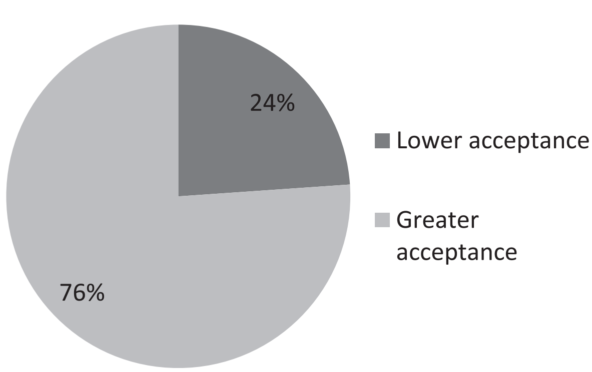

Fig. 1. Percentage of acceptance or rejection of the favorable effect of biofertilizers. Authors' elaboration

6. Discussion and conclusions

The results were positive, which indicate that biofertilizers contribute to improved land productivity, decreased environmental impact and improved social development. It was generally observed that the perception of the effect of biofertilizers on the environment and on the lives of farmers was favorably accepted. However, it is also true that those producers with more education and greater technical and financial resources have been able to use the benefits derived from this biotechnology in a more comprehensive manner. Therefore, the lack of technical skills and the economic conditions characteristic of the rural environment limit the majority of peasant producers in their use of these new technological options.

In planning and administration policy for the management of these innovations, action is required from the government, academia, business and the peasant producer. These actions include the following: 1. promoting connections among all stakeholders; 2. the planning and administration of programs to stimulate innovation in line with reality and the needs of underdeveloped countries; 3. the generation of *ad hoc* programs that include small-scale producers to promote the modernization of the countryside and address the needs of these producers; 4. the generation and facilitation of technology transfer mechanisms; and 5. the construction of diffusion, awareness and training mechanisms on the use of these biotechnologies.

Although this study is only one approach to understanding the problem, it is possible to conclude in principle that the use of biofertilizers in underdeveloped countries is a valid option for peasant producers because these fertilizers contribute to rural development and environmental protection. It is important to emphasize the need to promote this type of biotechnology based on endogenous scientific and technological knowledge and the interests and needs of its potential users.

The users should not be limited to using innovations from developed economies and their adaptation to the local environment. The formulation of policies and programs that promote and enable the development of this area of knowledge and other scientific and technological disciplines that provide solutions and benefits to the field of underdeveloped countries is required. All of these goals must be pursued within a monitoring framework that ensures the biosafety and food security of peasant producers and the general population.

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References

[1] M. Knockaert, S. Manigart, S. Cattoir, W. Verstraete, A perspective on the economic valorization of gene manipulated biotechnology: past and future, Biotechnol. Rep. 6 (2015) 56–60.

[2] E. Fraser, et al., Biotechnology or organic? Extensive or intensive? Global or local? A critical review of potential pathways to resolve the global food crisis, Trends Food Sci. Tech. 48 (2016) 78–87.

[3] G.S. Burrill, The biotechnology industry: an engine of innovation, in: C. Shimasaki (Ed.), Biotechnology Entrepreneurship. Starting, Managing, and Leading Biotech Companies, Academic Press-Elsevier, United States of

America, 2014, pp. 21–44.
[4] M. Castells, The Rise of the Network Society, second ed., Blackwell Publishers, Great Britain, 2000.
[5] D. Dohse, Technology policy and the regions-the case of the BioRegio contest, Res. Policy 29 (9) (2000) 1111–1133.
[6] A. De Janvry, E. Sadoulet, Rural poverty in Latin America determinants and exits paths, Food Policy 25 (4) (2000) 389–409.
[7] D.G. Graff, et al., The public-private structure of intellectual property ownership in agricultural biotechnology, Nat. Biotechnol. 21 (9) (2003) 989–995.
[8] B. Van Beuzekom, A. Arundel, OECD Biotechnology Statistics-2006, Organisation for Economic Co-operation and Development, Paris, 2006.
[9] T.A. Lyson, Advanced agricultural biotechnologies and sustainable agriculture, Trends Biotechnol. 20 (5) (2002) 193–196.
[10] J. Van Wijk, J.I. Cohen, J. Komen, Intellectual Property Rights for Agricultural Biotechnology. Options and Implications for Developing Countries, Research Report 3, IBS-ISNAR, Netherlands, 1993.
[11] P.W.B. Phillips, Biotechnology in the global agri-food System, Trends Biotechnol. 20 (9) (2002) 376–381.
[12] J.-P. Chavas, On the economics of agricultural production, Aust. J. Agric. Resour. Ec 52 (4) (2008) 365–380.
[13] G.S. McMillan, F. Narin, D.L. Deeds, An analysis of the critical role of public science in innovation: the case of biotechnology, Res. Policy 29 (1) (2000) 1–8.
[14] M. Meyer, Academic entrepreneurs or entrepreneurial academics? Research-based ventures and public support mechanisms, R&D Manage. 33 (2) (2003) 107–115.
[15] D.B. Audretsch, The role of small firms in U.S biotechnology clusters, Small Bus. Econ. 17 (1–2) (2001) 3–15.
[16] J.D. Wolt, R.K.D. Peterson, Agricultural biotechnology and societal decision-making: the role of risk analysis, AgBioForum 3 (1) (2000) 39–46.
[17] Persley, G. Agricultural biotechnology and the poor: promethean science. In: Persley G.J. and Latin M.M. (Editors). Agricultural Biotechnology and the Poor. Proceedings of an International Conference. Consultative Group on International Agricultural Research, Washington, pp. 3–21.
[18] M. Woolcock, D. Narayan, Social capital: implications for development theory, research, and policy, Word Bank. Res. Obser 15 (2) (2000) 225–249.
[19] A. Arundel, Biotechnology Indicators and Public Policy. OECD Science, Technology and Industry Working Papers-OECD Publishing, Paris, 2003.
[20] L. Aldrich, N. Blisard, Consumer acceptance of biotechnology lessons from the rbST experience. Current Issues in Economics of Food Markets, Agric. Inf. Bull. 747–01 (1998) 1–5.
[21] H. Eakin, M.C. Lemos, Adaptation and the state: Latin America and the challenge of capacity-building under globalization, Glob. Environ. Chang. 16 (1) (2006) 7–18.
[22] J.L. Solleiro, R. Castañon, Technological strategies of successful Latin American biotechnological firms, Electron J. Biotechnol. 2 (1) (1999) 26–35.
[23] D.B. Audretsch, M.P. Feldman, Small-firm strategic research partnerships: the case of biotechnology, Technol. Anal. Strateg. 15 (2) (2003) 273–288.
[24] J. Schumpeter, Seventh Chapter. The theory of economic development, in: J. Backhaus (Ed.), The Economy as a Whole (Translation from 1912), Kluwer Academic Publishers, Netherlands, 2003, pp. 61–116.
[25] W.A. Lewis, The state of development theory, Am. Econ. Rev. 74 (1) (1984) 1–10.
[26] R. Arocena, P. Senker, Technology, inequality, and underdevelopment: the case of Latin America, Sci. Technol. Hum. Val. 28 (1) (2003) 15–33.
[27] R. Arocena, B. Göransson, J. Sutz, Knowledge polices and universities in developing countries: inclusive development and the "developmental university", Technol. Soc. 41 (2015) 10–20.
[28] R. Padilla-Pérez, Y. Gaudin, Science, technology and innovation polices in small and developing economies: the case of Central America, Res. Policy 43 (4) (2014) 749–759.
[29] M. Cimoli, J. Katz, Structural reforms, technological gaps and economic development: a Latin American perspective, Ind. Corp. Chance 12 (2) (2003) 387–411.
[30] M. Cimoli, S. Rovira, Elites and structural inertia in Latin America: an introductory note on the political economy of development, J. Econ. Issues XLII (2) (2008) 327–347.
[31] F. Tula Molina, Consumo tecnológico y educación tecnológica: fundamentos filosóficos para un proyecto futuro, Sociologias 13 (26) (2011) 154–175.
[32] H. Thomas, Los estudios sociales de la tecnología en América Latina (Social studies of technology in Latin America), Íconos 37 (2010) 35–53.
[33] M.E. Di Bello, Investigadores académicos, conocimientos científicos y utilidad social, Redes 19 (36) (2013) 51–78.
[34] R. Rendón-Medel, J. Díaz-José, B. Hernández-Hernández, T.C. Camacho-Villa, Modelos de intermediación en la extensión agrícola (Models of intermediation in agricultural extension), Rev. Mex. Ciencias Agrícolas 6 (1) (2015) 139–150.
[35] M. Muñoz Rodríguez, J. Aguilar Ávila, R. Rendón Medel, J.R. Altamirano Cárdenas, Análisis de la Dinámica de Innovación en Cadenas Agroalimentarias, Universidad Autónoma Chapingo–CIESTAAM/PIIAI and others, Estado de México, 2007.
[36] A. Espinoza-Ortega, E. Espinosa-Ayala, J. Bastida-López, T. Castañeda-Martínez, C.M. Arriaga-Jordán, Small-scale dairy farming in the highlands of central Mexico: technical, economic and social aspects and their impact on poverty, Expl. Agric. 43 (2) (2007) 241–256.
[37] R. Dagnino, H. Thomas, Latin American science and technology policy: new scenarios and the research community, Sci. Technol. Soc. 4 (1) (1999) 35–54.
[38] H. Thomas, R. Dagnino, Efectos de transducción: una nueva crítica a la transferencia acrítica de conceptos y modelos institucionales (Effects of transduction: a new criticism to the acritical transference of concepts and institutional models), Cienc. Docencia Tecnol. 31: XVI (2005) 9–46.
[39] M. Muñoz Rodríguez, V.H. Santoyo Cortés, I. Capítulo, Del extensionismo a las redes de innovación, in: J. Aguilar Ávila, J. Reyes Altamirano Cárdenas, R. Rendón Medel (coordinadores), V.H. Santoyo Cortés (Eds.), Del Extensionismo Agrícola a las Redes de Innovación Rural, Universidad Autónoma Chapingo-CIESTAAM-FAO-CYTED, México, 2010, pp. 31–69.
[40] J.M. Ekboir, M. Muñoz, J. Aguilar, R. Rendón Mendel, J.G. García Muñiz, J.R. Altamirano Cárdenas, ISNAR Discussion Paper 7. On the Uneven Distribution of Innovative Capabilities and Why that Matters for Research, Extension and Development Policies, International Service for National Agricultural Research (ISNAR) Division, USA, 2006.
[41] M. Muñoz Rodríguez, R. Rendón Medel, J. Aguilar Ávila, J.G. García Muñiz, J.R. Altamirano Cárdenas, Redes de Innovación, Un Acercamiento a su Identificación, Análisis y Gestión para el Desarrollo Rural, Universidad Autónoma Chapingo-Fundación PRODUCE Michoacán, A.C., México, 2004.
[42] N. Aguilar-Gallegos, M. Muñoz-Rodríguez, H. Santoyo-Cortés, J. Aguilar-Ávila, L. Klerkx, Information networks that generate economic value: a study on clusters of adopters of new or improved technologies and practices among oil palm growers in Mexico, Agric. Syst. 135 (2015) 122–132.
[43] J. Díaz-José, R. Rendón-Medel, J. Aguilar-Ávila, M. Muñoz-Rodríguez, Análisis dinámico de redes en la difusión de innovaciones agrícolas (Dynamic analysis of networks in the diffusion of agricultural innovations), Rev. Mex. Cienc. Agríc. 4 (7) (2013) 1095–1102.
[44] J.A. Zarazúa, G. Almaguer-Vargas, R. Rendón-Medel, Capital social. Caso red de innovación de maíz en Zamora, Michoacán, México, Cuad. Desarro. Rural 9 (68) (2012) 105–124.
[45] A.V. Ayala-Garay, G. Almaguer-Vargas, N.K. De la Trinidad-Pérez, I. Caamal-Cauich, R. Rendón, Competitividad de la producción de mango (Mangifera indica l.) en Michoacán, Rev. Chapingo Ser. Hortic. 15 (2) (2009) 133–140.
[46] O. Díaz-José, J. Aguilar-Ávila, R. Rendón-Medel, V. Horacio Santoyo-Cortés, Current state of and perspectives on cocoa production in Mexico, Cien. Inv. Agric. 40 (2) (2013) 279–289.
[47] J.A. Zarazúa, J.L. Solleiro, R. Altamirano Cárdenas, R. Castañón Ibarra, R. Rendón Medel, Esquemas de innovación tecnológica y su transferencia en las agroempresas frutícolas del estado de Michoacán, Estud. Sociales 17 (34) (2009) 38–71.
[48] B. Ortiz Jiménez, et al., Nivel de adopción de tecnologías para la producción de jitomate en productores de pequeña escala en el estado de Oaxaca (Level of technology adoption of small-scale tomato producers in the state of Oaxaca), Rev. Mex. Ciencias Agrícolas 4 (3) (2013) 447–460.
[49] J.M. Vargas Canales, M.I. Palacios Rangel, J.H. Camacho Vera, J. Aguilar Ávila, J.G. Ocampo Ledesma, Factores de innovación en agricultura protegida en la región de Tulancingo, México (Innovation factors in protected agriculture in the region of Tulancingo, Mexico), Rev. Mex. Ciencias Agrícolas 6 (4) (2015) 827–840.
[50] M.Q. Dao, Poverty, income distribution, and agriculture in developing countries, J. Econ. Stud. 36 (2) (2009) 168–183.
[51] M.Q. Dao, Rural poverty in developing countries: an empirical analysis, J. Econ. Stud. 31 (6) (2004) 500–508.
[52] A. Rodríguez-Pose, D. Hardy, Addressing poverty and inequality in the rural economy from a global perspective, Appl. Geogr. 61 (2015) 11–23.
[53] J.A. Berdegué, J. Escobal, A. Bebbington, Explaining spatial diversity in latin american rural development: structures, institutions, and coalitions, World Dev. 73 (2015) 129–137.
[54] M. Dodgson, J. Mathews, T. Kastelle, M. Chih Hu, The evolving of Taiwan's national innovation system: the case of biotechnology innovation networks, Res. Policy 37 (3) (2008) 430–445.
[55] J. Senker, M. Sharp, Organizational learning in cooperative alliances: some case studies in biotechnology, Technol. Anal. Strateg. 9 (1) (1997) 35–52.
[56] F. Rothaermel, D.L. Deeds, Exploration and exploitation alliances in biotechnology: a system of new product development, Strateg. Manage. J. 25 (3) (2004) 201–221.
[57] F.R. Sagasti, Underdevelopment, science and technology: the point of view of the underdevelopment countries, Sci. Stud. 3 (1) (1973) 47–59.
[58] F. Sagasti, Knowledge and Innovation for Development, Edward Elgar Publishing Limited, Great Britain, 2004.
[59] R.G. Echeverría, Agricultural research policy issues in Latin America: an overview, World Dev. 26 (6) (1998) 1103–1111.
[60] S.S. Dudeja, N.P. Singh, P. Sharma, S.C. Gupta, R. Chandra, B. Dhar, R.K. Bansal, G.P. Brahmaprakash, S.R. Potdukhe, R.C. Gundappagol, B.G. Gaikawad, K.S. Nagaraj, Chapter 3. Biofertilizertechnology and pulse production, Soil biology Volume 28 (Series Editor Varma A.), in: A. Singh, N. Parmar, R.C. Kuhad (Eds.), Bioaugmentation, Biostimulation and Biocontrol, Springer, Heidelberg Dordrecht London New York, 2011, pp. 43–63.
[61] J.S. Singh, V.C. Pandey, D.P. Singh, Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development, AgrEcosyst Environ. 140 (3–4) (2011) 339–353.
[62] E. Malusá, L. Sas-Paszt, J. Ciesielska, Technologies for beneficial microorganisms inocula used as biofertilizers, Sci. World J. 2012 (2012) 1–12.

[63] S. Sharma, R. Gupta, G. Dugar, A.K. Srivastava, Chapter 4. Impact of application of biofertilizers on soil structure and resident microbial community structure and function, in: D.K. Maheshwari (Ed.), Bacteria in Agrobiology: Plant Probiotics, Springer, Heidelberg New York Dordrecht London, 2012, pp. 65–77.
[64] D. Bhardwaj, M.W. Ansari, R.K. Sahoo, N. Tuteja, Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity, Microb. Cell Fact. 13 (66) (2014) 1–10.
[65] B.F. Johnston, J.W. Mellor, The role of agriculture in economic development, Am. Econ. Rev. 51 (4) (1961) 566–593.
[66] D.A. Sumner, J.M. Alston, J.W. Glauber, Evolution of the economics of agricultural policy, Am. J. Agric. Econ. 92 (2) (2010) 403–423.
[67] R.L. Naylor, et al., Biotechnology in the developing world: a case for increased investments in orphan crops, Food Policy 29 (1) (2004) 15–44.
[68] Y. Du, A. Park, S. Wang, Migration and rural poverty in China, J. Comp. Econ. 33 (4) (2005) 688–709.
[69] T.M. Aide, H.R. Grau, Globalization, migration, and Latin American ecosystems, Science 305 (5692) (2004) 1915–1916.
[70] B.D. Jokisch, Migration and agricultural change: the case of smallholder agriculture in highland Ecuador, Hum. Ecol. 30 (4) (2002) 523–550.
[71] C. Ashley, S. Maxwell, Rethinking rural development, Dev. Policy Rev. 19 (4) (2001) 395–425.
[72] X. Irz, L. Lin, C. Thirtle, S. Wiggins, Agricultural productivity growth and poverty alleviation, Dev. Policy Rev. 19 (4) (2001) 449–466.
[73] L.K. Mytelka, Local systems of innovation in a globalized world economy, Ind. Innov. 7 (1) (2000) 15–32.
[74] R. Casas, R. De Gortari, M.J. Santos, The building of knowledge spaces in Mexico: a regional approach to networking, Res. Policy 29 (2) (2000) 225–241.
[75] R. Casas, Between traditions and modernity: technological strategies at three tequila firms, Technol. Soc. 28 (3) (2006) 407–419.
[76] J.D. Van der Ploeg, et al., Rural development: from practices and policies towards theory, Sociol. Rural. 40 (4) (2000) 391–408.
[77] M. Song, J. Noh, Best new product development and management practices in the Korean high-tech industry, Ind. Mark. Manag. 35 (3) (2006) 262–278.
[78] J. Huang, R. Hu, C. Pray, F. Qiao, S. Rozelle, Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China, Agric. Econ. 29 (1) (2003) 55–67.
[79] International Service for the Acquisition of Agri Biotech Applications –ISAAA-. Farmers First. Feedback from the Farm. Biotech Communication Series: 5, ISAAA, Philippines, 2013.
[80] P. Pinstrup-Andersen, M.J. Cohen, Agricultural biotechnology: risks and opportunities for developing country food security, Int. J. Biotechnol. 2 (1/2/3) (2000) 145–163.
[81] M.A. Altieri, Sustainable agricultural development in Latin America: exploring the possibilities, Agric. Ecosyst. Environ. 39 (1–2) (1992) 1–21.
[82] P. Newell, Trade and biotechnology in Latin America: democratization, contestation and the politics of mobilization, J. Agrar. Change 8 (2–3) (2008) 345–376.
[83] E.J. Trigo, et al., Agricultural Biotechnology and Rural Development in Latin America and the Caribbean Implications for IDB Lending, Sustainable Development Department Technical Papers Series, Inter-American Development Bank, Washington, D.C, 2000.
[84] C. James, Global Status of Commercialized Biotech/GM Crops, ISAAA Brief No. 44. ISAAA, Ithaca, NY, 2012.
[85] C. Baum, W. El-Tohamy, N. Gruda, Increasing the productivity and product quality of vegetable crops using arbuscular mycorrhizal fungi: A review, SciHortic-Amsterdam 187 (2015) 131–141.
[86] A. Zaidi, E. Ahmad, M.S. Khan, S. Saif, A. Rizvi, Role of plant growth promoting rhizobacteria in sustainable production of vegetables: current perspective, Sci. Hortic-Amsterdam 193 (2015) 231–239.
[87] G. Seneviratne, G.A. Peyvast, J.A. Olfati, A. Kariminia, Rhizobia as biofertilizers for mushroom cultivation, Curr. Sci. 96 (12) (2009) 1559.
[88] Z. Bai, C. Zhou, Xu S. CaoJ, S. Wu, D. Li, Effects of bacillus amyloliquefaciens biofertilizer on tea yield and quality, Agric. Sci. Technol. 15 (11) (2014) 1883–1887.
[89] D. Mahanta, R.K. Rai, S.D. Mishra, A. Raja, T.J. Purakayastha, E. Varghese, Influence of phosphorus and biofertilizers on soybean and wheat root growth and properties, Field Crop Res. 166 (2014) 1–9.
[90] Z. Shen, S. Zhong, Y. Wang, B. Wang, X. Mei, R. Li, Y. Ruan, Q. Shen, Induced soil microbial suppression of banana fusarium wilt disease using compost and biofertilizers to improve yield and quality, Eur. J. Soil Biol. 57 (2013) 1–8.
[91] I. Haneef, S. Faizan, R. Perveen, S. Kausar, Impact of bio-fertilizers and different levels of cadmium on the growth, biochemical contents and lipid peroxidation of plantago ovata forsk, Saudi J. Biol. Sci. 21 (4) (2014) 305–310.
[92] Lévai L. Gajdos É, S. Veres, B. Kovács, Effects of biofertilizers on maize and sunflower seedlings under cadmium stress, Commun. Soil Sci. Plan. 43 (1–2) (2012) 272–279.
[93] M. Kumar, L.K. Baishya, D.C. Ghosh, M. Ghosh, V.K. Gupta, M.R. Verma, Effects of organic manures, chemical fertilizers and biofertilizerson growth and productivity of rainfed potato in the eastern Himalayas, J. Plant Nutr. 36 (7) (2013) 1065–1082.
[94] A.C. Hridya, G. Byju, R.S. Misra, Effect of biocontrol agents and biofertilizers on root rot, yield, harvest index and nutrient uptake of cassava (Manihot esculanta Crantz), Arch. Agron. Soil Sci. 59 (9) (2013) 1215–1227.
[95] M. Amjad, J. Akhtar, M.S. Rashid, Evaluating the effectiveness of biofertilizer on salt tolerance of cotton (*Gossypium hirsutum* L.), Arch. Agron. Soil Sci. 61 (8) (2015) 1165–1177.
[96] M.K. Abbasi, M. Yousra, Synergistic effects of biofertilizer with organic and chemical N sources in improving soil nutrient status and increasing growth and yield of wheat grown under greenhouse conditions, Plant Biosyst. 146 (1) (2012) 181–189.
[97] Z.M. El-Sirafy, H.J. Woodard, E.M. El-Norjar, Contribution of biofertilizers and fertilizer nitrogen to nutrient uptake and yield of Egyptian Winter Wheat, J. Plant Nutr. 29 (4) (2006) 587–599.
[98] U. KantaBehera, S. KantaRautaray, Effect of biofertilizers and chemical fertilizers on productivity and quality parameters of durum wheat (Triticum turgidum) on a Vertisol of Central India, Arch. Agron. Soil Sci. 56 (1) (2010) 65–72.
[99] M.A.S. Abdel Monem, H.E. Khalifa, M. Beider, I.A. El Ghandour, Y.G.M. Galal, Using biofertilizers for maize production: response and economic return under different irrigation treatments, J. Sustain Agric. 19 (2) (2001) 41–48.
[100] M. Marra, D.J. Pannell, A.A. Ghadim, The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? Agric. Syst. 75 (2–3) (2003) 215–234.
[101] J.S. Singh, V.C. Pandey, D.P. Singh, Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development, Agric. Ecosyst. Environ. 140 (3–4) (2011) 339–353.
[102] G. Mulgan, S. Tucker, R. Ali, B. Sanders, Social innovation. What it is, why it matters and how it can be accelerated, Working paper, Skoll Centre for Social Entrepreneurship-The Basingstoke Press-Oxford Said Business School- The Young Foundation, London, 2007.
[103] C.A. Gardner, T. Acharya, D. Yach, Technological and social innovation: a unifying new paradigm for the global health, Health Aff. 26 (4) (2007) 1052–1061.
[104] G. Mulgan, The process of social innovation, Innov 1 (2) (2006) 145–162.
[105] T. Higa, J.F. Parr, Beneficial and Effective Microorganisms for a Sustainable Agriculture and Environment, International Nature Farming Research Center Atami, Japan, 1994.
[106] I.R. Kennedy, R.J. Roughley, The inoculant biofertiliser phenomenon and its potential to increase yield and reduce costs of crop production: the need for quality control, in: I.R. Kennedy, A.T.M.A. Choudhury (Eds.), Biofertilisers in Action. A Report for the Rural Industries Research and Development Corporation. Australia, Rural Industries Research and Development Corporation, 2002, pp. 4–10.
[107] Y. Bashan, Inoculants of plant growth-promoting bacteria for use in agriculture, Biotechnol. Adv. 16 (4) (1998) 729–770.
[108] G. Seneviratne, L.H.J. Van Holm, E.M.H.G.S. Ekanayake, Agronomic benefits of rhizobial inoculant use over nitrogen fertilizer application in tropical soybean, Field Crop Res. 68 (3) (2000) 199–203.
[109] L.E. Fuentes-Ramírez, J. Caballero-Mellado, Chapter 5. Bacterial biofertilizers, in: Z.A. Siddiqui (Ed.), PGPR: Biocontrol and Biofertilization, Springer, Netherlands, 2006, pp. 143–172.
[110] J.A. Álvarez, M.D. Herrera, R.J. Soto, M.R. Ávila Marioni, O. Ramírez Valle, Interactions between Bio-fertilizers and the Production of Oats without Irrigation in Chihuahua, Mexico. In19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 2010.
[111] M. Faheem, W. Raza, W. Zhong, Z. Nan, Q. Shen, Y. Xu, Evaluation of the biocontrol potential of Streptomyces goshikiensis YCXU against fusarium oxysporum f. sp, Niveum. Biol. Control 81 (2015) 101–110.
[112] K.M. Eisenhardt, Building theories from case study research, Acad. Manage. Rev. 14 (4) (1989) 532–550.
[113] R. Yin, The case study crisis: some answers, Admin. Sci. Quart. 26 (1) (1981) 58–65.
[114] R.K. Yin, Case study research: design and methods, in: 3 editionApplied Social Research Methods Series, Vol. 5, Sage Publications, United States of America, 2003.
[115] T.M. Haladyna, Developing and Validating Multiplechoice Test Items, L. Erlbaum Associates, Mahwah, N.J, 2004.

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