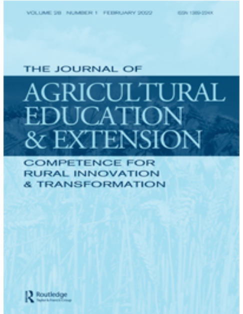

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ABSTRACT

Purpose: The aim of the research was to analyze the impact of the regional innovation system on the efficiency and productivity enterprises dedicated to protected agriculture in Hidalgo, Mexico.
Methodology: The regional innovation system was analyzed by identifying the innovation networks. Subsequently, a typology of enterprises was generated according to the networks in which they participate and an analysis of variance and comparison tests of Scheffé means between clusters.
Findings: In the regional innovation system, the networks were made up of government institutions, teaching and research institutions, and suppliers of inputs and services, where the latter have the highest degrees of articulation. Also, positive effects were identified in the efficiency indicators of the enterprises related to the networks made up of government institutions, teaching and research institutions, and the extension services.
Practical implications: The identification of these interactions is essential for the design of public policies for the promotion of innovation. For example, for the design of a smart extension program that articulates all the actors and that all benefit from their interactions.
Theoretical implications: The study reveals the positive influence of the regional innovation system on enterprises. In addition, it rekindles the discussion on the relevance of the State in the operation of innovation systems, the role of universities in the generation of knowledge and the extension service in the diffusion of new knowledge, information and practices.
Originality/value: The study generates important knowledge about the regional innovation system and about the design of an innovation management strategy.

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1. Introduction

In response to the globalization process and the rapid changes in economic dynamics, innovation is seen as a key aspect to adapt and compete in the markets (O'Regan, Ghobadian, and Sims 2006). In this sense, Bruque and Moyano (2007) consider that the economies of the countries depend on their ability to innovate in new products and processes that become the engine of their economic growth and technological progress. However, innovation is not a simple process to manage and for rural small and medium-sized enterprises it is a difficult and increasingly complex process (Diez 2002).

Innovation and the agents involved in its development and its diffusion have been studied in a wide variety of disciplines, including sociology, economics, marketing, ecology and informatics (Zhang and Vorobeychik 2019). Regarding the study on the adoption of innovations in the agricultural sector, there are two great traditions that have been quite distant from each other (Monge and Hartwich 2008). On the one hand, the sociological tradition in which the diffusion of innovations resembles an epidemic process, by virtue of which the decision to adopt of a certain producer or enterprise leads to the subsequent contagion of others who are in contact or are influenced by it. Contagion occurs basically through the interaction between actors, while the efforts of external agents have an effect on the decision-making of a minority of producers, the pioneers and innovators, who are more attentive to external innovations (Rogers 1995).

On the other hand, among agricultural economics specialists a tradition of individualistic style emerged, according to which producers make the decision to adopt according to the profits they could obtain, in their opinion, derived from such decision (Monge and Hartwich 2008). To do this, each producer rationally analyzes the expected costs and benefits before deciding; and since there is enormous heterogeneity in the individual characteristics and the limitations that each producer faces, a similar dispersion in their decision-making is to be expected (Griliches 1957). This tradition assumed a dominant role in the study of agricultural innovation, giving theoretical and empirical support to many of the policies, programs and systems that have taken place in some countries in order to promote technological change among producers and agricultural development in general (Monge and Hartwich 2008).

For some time, the most interactionist current lost interest among rural sociologists and continued its development in other disciplines (Ruttan, 1996). However, in recent years there has been a growing recognition of the influence of social interactions on individual economic behavior, economic growth, innovation and rural development (Fafchamps 2006; Granovetter 2005). This new interest in social interactions is reflected in different investigations that have emerged in recent decades in relation to social capital, innovation systems, and the evolutionary-institutionalist approach in economics (Dasgupta and Serageldin 2001; Nelson and Nelson 2002). Its drive has slowly extended to the study of agricultural innovation, where studies that consider variables related to these aspects in their models of adoption of innovations are more and more frequent (Katungi, Edmeades, and Smale 2008; Moser and Barrett 2006; Moxley and Brandon Lang 2006).

At present, innovation systems have become more important in almost all sectors of the economy and disciplines. It is possible that the above is due to the fact that it is an integrating vision, in which the two previous approaches converge. It is a model based on the analysis of the agents of innovation and offers two advantages for studying the diffusion of innovation. Firstly, it facilitates the modeling of the heterogeneity of the agents and, secondly, it allows the detailed modeling of the interactions mediated by the networks that constitute them (Zhang and Vorobeychik 2019). The aforementioned makes it possible to propose innovation management schemes, where the rules governing the generation, diffusion and adoption of innovation, and the relationships between the inputs and outputs of the innovation system are clearly perceived (Eito-Brun 2020).

It is pertinent to mention that the networks that arise, evolve and reconfigure as other components of the territories, are the basic elements that, together, go gestating small local innovation systems that, in turn, connect and interact with other systems (regional, national and international) and are the ones which articulate the different agents of innovation. These agents are linked in different segments of the value chain, and involve various and different actors that operate at different scales (Ferreiro and Sousa 2019). Furthermore, these networks cooperate and compete in the same territories and in the same markets, which configures for very complex innovation systems. The aforementioned, in a certain way, determine the effectiveness of all its components, innovative processes are stimulated within the same territory and a high level of competitiveness is generated (Nosova et al. 2018). Consequently, production systems also evolve and transform in order to adapt to new conditions.

This is how protected agriculture emerges, as a relatively new productive system. Protected agriculture or agriculture in controlled environments is a production system developed with the aim of providing plants with the ideal conditions for their development, and thereby express the maximum productive potential (Vargas-Canales et al. 2018). Similarly, it is possible to handle environmental conditions (temperature, relative humidity, nutrition, water, light, etc.) and some other risks (pests and diseases) (Vargas-Canales et al. 2018). The main purpose of this production system is focused on increasing and maintaining productivity in quantity, quality and commercial opportunity (Bastida 2008; Castañeda-Miranda et al. 2007; Moreno, Aguilar, and Luévano 2011). At the same time, allows it more efficient use of resources and inputs (García, Van der Valk, and Elings 2011). In this specific case, it is the production of vegetables in greenhouses. It is important to mention that this type of technology is being rapidly adopted all over the world.

Protected agriculture is conceived as a viable technological means to improve the production of innocuous food and reduce poverty in the rural sector. Because of its importance and transcendence that these production systems represent for the agri-food sector, numerous investigations have been carried out, but their study has focused predominantly on technical aspects. Socioeconomic analysis have focused on identifying the factors that determine innovation (Vargas-Canales et al. 2018; Vargas Canales et al. 2015), the level of technological equipment of the production units (García-Sanchez, Aguilar-Ávila, and Bernal-Muñoz 2011), the profitability of production systems (Terrones Cordero and Sánchez Torres 2011), the technology transfer models (Borbón Morales and Arvizu Armenta 2015) and some aspects related to the effects that protected agriculture has on the rural population (Moulton and Popke 2017).

The study region is a valley surrounded by low elevation hills, with a temperate semi-dry and temperate humid climate, with a temperature range between 10 and 18 ° C, with a precipitation that ranges from 500 to 1,100 mm and is located between 1,600 and 3,100 meters above sea level (INEGI 2014). The rural landscape is defined by economic activities that have developed since colonial times, which allows us to observe a heterogeneous network of crops, buildings, machinery and equipment. The production units are very unevenly distributed throughout the territory. Protected agriculture began in the region at the end of the 90s. Since its introduction there is evidence that shows that protected agriculture is introduced, adapted and reproduced by innovative agents that maintain relationships with universities, public institutions and different actors linked to this technology (Vargas-Canales et al. 2018).

Considering the characteristics of the region and its technological trajectories, the concept of the innovation system stands out as an instrument of analysis and as a public policy tool for the generation and dissemination of science, technology and innovation. Regarding innovation systems, they have been used as an analytical framework for protected agriculture in an aggregate form (García-Sánchez et al. 2018), however, in this way it is difficult to identify the actors that have an effect on the efficiency indicators of the enterprises and, under this vision there is no clarity on the intervention strategies to follow. Derived from the above, the hypothesis of this work suggests that enterprises dedicated to protected agriculture create networks with strategic actors to access more and better innovations and be more efficient. In this sense, the research aimed to analyze the impact of the regional innovation system on the efficiency and productivity enterprises dedicated to protected agriculture in Hidalgo, Mexico, in order to propose strategies that facilitate the generation of innovation. Consequently, the research question was, which actors of the regional innovation system have a positive impact on the efficiency and productivity of protected agriculture?

2. Conceptual framework

Regional innovation systems are a derivation of national innovation systems. The concept first appeared in a book on innovation in Japan, written by Christopher Freeman (Freeman 1987). However, it was Lundvall (1992) who gave body and shape to the concept in a series of articles published later. The concept is of special importance because it allows understanding how a set of institutions, organizations, networks and individuals can interact and use resources to promote innovation around the development of a specific technology (Carlsson et al. 2002; Touzard et al. 2015). In regional innovation systems, the collaboration mechanisms between the different actors of an innovation system (research, public and private services, professional organizations, civil society) that seek to produce knowledge, experiment, learn and/or contribute resources (Faure et al. 2019).

Specifically, the concept of innovation systems focuses on actors, institutions and their relationships, and contributes to a better understanding of both the intrinsic dynamics of innovation, as well as its connections with development processes (Dutrénit et al. 2014). Innovation systems are based on the assumption that understanding the links or relationships between the agents involved in innovation is an essential factor to improve technological performance (Rincón Castillo 2004). In other words, given that innovation and technical progress are the result of a complex series of relationships between the agents that produce, distribute and apply various types of knowledge, the innovative performance of a country or region will largely depend on how those agents, are related to each other as parts or integral elements of a collective system of generation of scientific and technological knowledge (García, Olivé, and Puchet 2014).

It is necessary to mention that the approach evolved rapidly. The concept was taken up by different international organizations and different fields of the social sciences such as economics, sociology, geography, among others. Each of which maintains its particularities. Hence, regional systems, local innovation systems, sectoral innovation systems and even agricultural innovation systems emerged. However, all the visions developed consider that the actors or agents involved are the ones who, through their interactions, trigger innovation processes through the networks that are created between them. In this sense, in the specific case of the rural sector, the region plays an important role. The regional approach considers that the context is significant for the formulation of policies and for the identification of the set of relationships that generate innovations. That is, the important thing is the identification of local actors, those found in the region, and of the institutions and organizations that spread innovations that operate as intermediaries between the components and between the attributes of the system (Cooke 2005; Kauffmann and Tödtling 2001).

Derived from the above and according to Bellandi and Caloffi (2010), if the objective is to propose strategies to support regional innovation processes, the key aspect is to identify the interactions and the effects that these have on the processes and development of innovation. The notion of interactions for innovation is reflected in many theories that explain the regional grouping of industries such as the network at the regional level and the industrial districts (Markusen 2003). Thus, while networks are clearly important from an innovation systems perspective, it is unclear to what extent governments can harness the power of networks to support innovation as part of a public policy instrument. The understanding of the complexity of the problems in the agri-food sector has led to a demand for policy instruments that make it possible to stimulate the transformation processes of the system (Birner et al. 2009; Leeuwis and Aarts 2011; Rotmans, Kemp, and van Asselt 2001).

In that sense, promoting networks as policy instruments often take the form of projects that involve the formation of new networks or the strengthening of existing networks. Networks can be induced to facilitate the creation of non-existent links between members who do not yet know each other or if it is necessary to incorporate other actors. In the rural sector, network management can be especially useful for the correct functioning of regional innovation systems. The large number and diversity of actors in agriculture offer a greater possibility of forming innovative networks compared to other sectors. However, innovation management is not simply the adoption of an innovation made by farmers, but a process of communication and cooperation between the different agents of innovation (Wu and Zhang 2013). At the institutional level, innovation systems, formed through networks interaction, play a fundamental role in innovation management and regional economic development.

At present, regional innovation systems in the agricultural sector are considered to be a more holistic approach than top-down technology transfer models. It promotes the participation of a wide variety of actors, not only from the agricultural environment and includes the institutions and policies that influence innovation processes (Toillier et al. 2021). This new thinking focuses on innovation, not as the end result of knowledge transfer, but as a continuous process of social, technical and scientific collaboration that affects productivity and performance (Romero-Riaño, Guerrero-Santander, and Martínez-Ardila 2021). In this new paradigm of study of agricultural innovation systems, innovation patterns must be adopted driven by demand, inclusive and receptive to social challenges (Toillier et al. 2021). Under this scheme, the synergy between the various components of agricultural innovation systems has been shown to promote agricultural development and its study serves as an essential input for the design and implementation of innovation strategies (Wang et al. 2018).

In this sense, knowledge is a fundamental enabling factor for agri-food innovation systems and previous management frameworks do not integrate innovation in a pragmatic way and it is essential to think of integrative approaches in which priority is given to the participation of all actors, for the co-design of strategies and the implementation of innovations (Gardeazabal et al. 2021). The agricultural innovation systems approach is a good conceptual and operational tool for planning and implementing development projects. However, it has been found that, in general, there is no alignment between project design and the interests of different stakeholders. Furthermore, research development and universities have been found to remain disconnected from farmers (Ankrah and Freeman 2021). Since the agricultural innovation system approach focuses on the links and interactions of the actors and their roles, the network analysis is ideal to identify the participation of farmer groups, actors developing research, extension, policies and the private sector (Onumah, Asante, and Osei 2021). Derived from the above, in order to design innovation management projects and programs it is necessary to clearly identify the actors involved with the dynamics of production systems and clearly delimit their functions.

Finally, considering different authors who have worked in relation to the actors in charge of the development, management and diffusion of innovation in the agri-food sector, it is possible to identify the group of enterprises or farmers as the central element since this type of actors are those who generate, adopt, adapt and disseminate knowledge, technology and innovation. Actors who act as intermediaries (public institutions), articulators or linkers (extension agents and suppliers of inputs and services), generators of Sciences, Technology and Innovation, Technology Transfer Centers, enablers (credit institutions, standardizing organizations), complementors (related to the value chains) and the market (García-Sánchez et al. 2018; Grovermann et al. 2019; Hermans et al. 2019; Minh 2019; Minh et al. 2014).

In accordance with the foregoing, in this research we define regional innovation system in the agri-food sector as the set of Universities, Institutions, Organizations and Enterprises that interact through networks sharing knowledge, information, practices and experiences on a technology in a specific activity, and involves all operations and transactions in order to satisfy food demands. The foregoing includes all agribusiness linked to the value chain, that is, the actors related to the supply of inputs, primary production, collection, storage, processing, transformation, logistics, and distribution and marketing.

3. Methodology

3.1 . Analysis and location unit

For the analysis of the regional innovation system, small and medium-sized rural enterprises dedicated to protected agriculture were taken as empirical reference. Locateded in

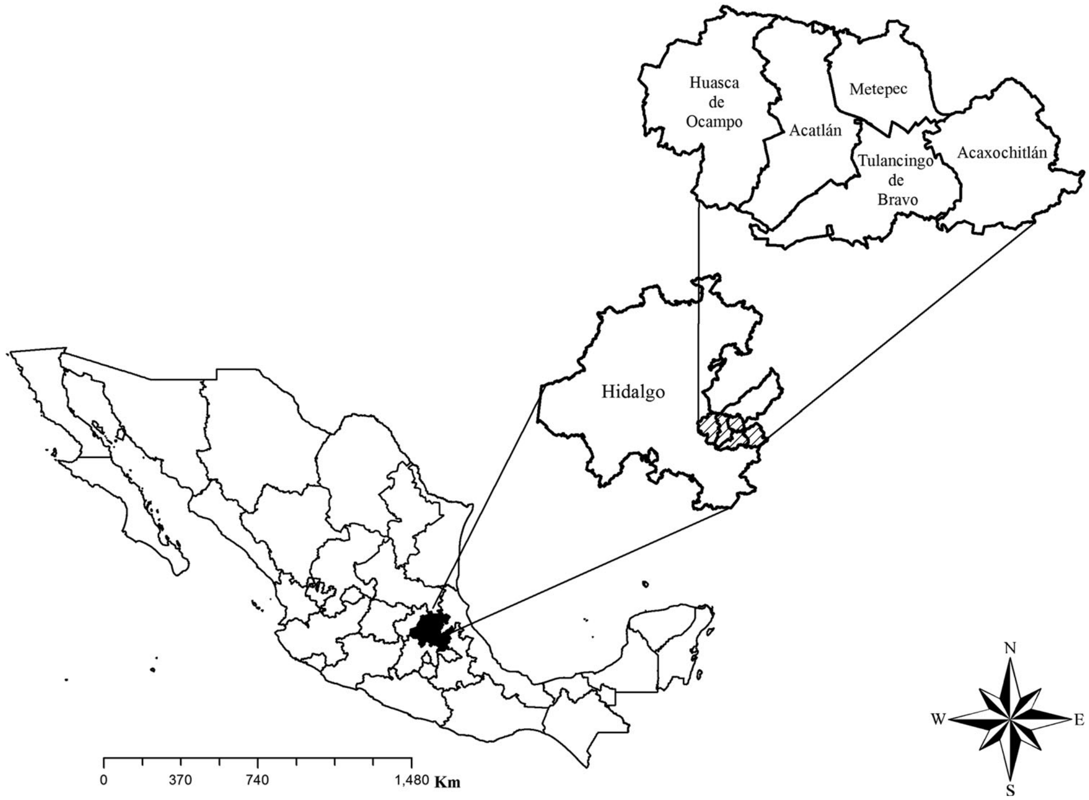

Figure 1 . Geographic location of the study area.

the municipalities of Acaxochitlan, Acatlán, Huasca de Ocampo, Metepec and Tulancingo de Bravo in the state of Hidalgo in Mexico (Figure 1). It is important to mention that this region is one of the most important in the center of the country. Protected agriculture in the region of study began since the end of the 90´s. By 2011 it already had international importance (García, Van der Valk, and Elings 2011), by 2016 it was already considered one of the most important regions of the country (Kuss, Flores, and Harrison 2016) and since then it has maintained significant growth.

3.2 . Collection of the information

To collect the information, a semi-structured survey was applied to 65 enterprises in the region studied from June to December 2016. It is convenient to mention that it was a face-to-face interview between the interviewer and the interviewee. It consists of a conversation in which specific questions (closed and open) defined in advance are answered in accordance with the objectives of the research. In addition, it allows improvising and deepening in some aspects that the researcher considers important (Añorve Guillén 1991). Only the group of enterprises dedicated to protected agriculture were interviewed. The decision was made considering what the most recent literature suggests on how to view and analyze innovation systems. In other words, breaking with the idea of linear models of innovation with a top-down perspective. In addition, it was sought to identify the impact of the links of the different actors of the innovation system in the productive sector specifically.

The questionnaire was divided into three sections: the first section was aimed at obtaining information related to the general characteristics of producers such as age, schooling, years of experience in the activity; the second section was related to the data of the production units such as production area, obtained yields, sale prices and income. The third section was aimed at identifying the networks that make up the regional system of innovation in protected agriculture through the following questions: i) With which educational and research institutions do you have links? (network with teaching and research institutions), ii) With which government institutions do you have links? (network with government institutions), iii) Who provides you with technical advice on your production processes, information on new technologies or practices and information on services related to protected agriculture? (extension network), iv) Who are your main suppliers of inputs? (network of input suppliers), v) From which other enterprises do you learn aspects related to protected agriculture? (inter-enterprise learning network), and vi) Who do you sell your product to? (market network).

The questions were designed considering two fundamental aspects. The first is associated with the characteristics of farmers and their enterprises, in order to identify causal relationships with the networks that make up the regional innovation system and innovative performance analysis. The second is related to the identification of the main actors that have been identified in the innovation systems in the agri-food sector. The aim was to identify the actors that introduce innovations. Innovations were considered as the incorporation of new technologies or better management practices, new knowledge and information that allows enterprises to be more efficient and competitive with the central idea of improving their technical and economic indicators.

3.3 . Sampling

The selection of the information units was made from a non-probability sampling according to the expert's criteria; based on certain characteristics (Muñoz et al. 2004; Pimienta 2000). This technique is widely used by researchers to select representative or typical units or proportions when information on the sample universe is missing. In this case, it was sought to sample representative units and permanence in the activity of at least five years was defined as a selection criterion, which is related to the period of time of reinvestment in the polyethylene cover. In addition, an attempt was made to analyze as many ventures as possible.

3.4 . Analysis and processing of information

For the analysis of the information related to the networks, the first thing that was done was a coding based on the definition of identification keys for the referred actors and the following were used: RE: rural enterprises, EN: rural enterprises not interviewed, EXT: extension, IS: input supplier, SC: Supply Center, LM: local or regional market, GI: government institutions and for teaching and research institutions their acronyms were used.

The information on networks was captured in Notepad, using the DL protocol to describe the data that in this case refers to the list of nodes and their relationships in the Nodelist format (Borgatti 2002). For the design and analysis of the networks, the UCINET® and Key Player® programs were us and to obtain a better design and structure,

Table 1 . Values assigned to relationships according to the type of actor in the regional innovation system for protected agriculture in Hidalgo, Mexico.

Actor-relationship type	Assigned value	Link characteristics
Enterprises - Enterprises	1	These actors are the ones who adopt, adapt and disseminate experience and knowledge about the management of technology.
Enterprises - Market	2	The interaction of these actors is essential since it stimulates the transformation of production systems and technologies through demand according to the tastes, preferences and desires of consumers.
Enterprises – Extension service	5	The interaction of these actors foster collaboration between all actors and disseminate new knowledge, practices and information through technical advice. In this case, they are public and private extension services.
Enterprises - Input supplier	5	Through the interaction of these actors, new products, services and information are disseminated through the sale of machinery, equipment and supplies.
Enterprises - Government institution	7	The interaction of these actors gives support and certainty to the entire innovation system. Through these interactions, public policies and the regulatory framework are operationalized.
Enterprises – Teaching and research institutions	10	These interactions are the least common. Through these, the transfer of science and technology is established directly between the institutions that generate it and the users.

the Gephi® program was used. In this work, five network indicators were analyzed these are commonly assessed in network analysis and us to characterise networks and identify the aspects of interest for the research objectives and are described below:

Most referred or disseminating actors: These are the actors who were the most referred by the respondents. They are generally considered to be the actors that transfer information within the system (Zarazúa, Almaguer-Vargas, and Rendón-Medel 2012).

Fragmentation of the network: These are the actors responsible for strengthening the network. Its disappearance is considered to cause network fragmentation. These actors are responsible for the integration of the network and without their presence the rest of the actors would be isolated.

Density: It is the percentage of existing relations among all the possible ones. High densities manifest broad exchange of available information. The density is expressed as a percentage: a density of 100% indicates that all the actors are related; one of 0% indicates that there is no link (Wasserman and Faust 1999).

Centralization indices: It is known as the difference among the number of links for each node, divided by the maximum amount of difference. A centralized network is dominated by one or very few central nodes (Rendón and Aguilar 2013). In this case, it was divided into the input centralization index and the output centralization index. These indices have different implications and cannot be understood if they are not considered simultaneously. If you have an input centralization index higher than the output one, it is inferred that there are more actors than the system demands and, conversely, if the output centralization index is greater than the input one, it is inferred that there is a lower number of actors than the system needs.

Finally, to analyze the effect of relational capital (Delgado-Verde et al. 2011) or relational assets (Storper 1997) that are generated from the configuration of the regional system of Innovation weighted values were assigned to each link. The value of each link was established considering three fundamental aspects: 1) the functions and roles of each of the actors, 2) the type of knowledge, technology and information they develop and 3) the quality, usefulness and reliability of their contributions to the regional innovation system (Table 1).

Subsequently, a cluster analysis was performed in order to generate a typology of enterprises, for which cumulative hierarchical algorithms were used as a classification method. The squared Euclidean distance was taken as a distance measure and the furthest neighbor as the linking method. This technique avoids inconsistencies and indefiniteness in the formation of clusters (Hair et al. 1999). The total value of links generated by the networks was used as a discriminant variable, according to the assigned values. Finally, an analysis of variance (ANOVA) and the Scheffé contrast test among clusters were performed to identify the means that have a significant difference, a method used for unbalanced models, as is the case. The SPSS® program was used for statistical analyzes.

4. Results

4.1 . General characteristics of the production system

Protected agriculture in the study region consists of agricultural production in medium-technology greenhouses (Costa and Giacomelli 2005). It is characterized because most of the greenhouses are built of metal structure, covered with polyethylene and have a passive ventilation and heating system. They have simple control panels for fertigation, soil-based production, and long production cycles established for eight months from transplant to harvest (Vargas-Canales et al. 2018). At present, derived from its evolution and adaptation, practically 100% of the enterprises focus on the production of tomato (*Solanum lycopersicum* L.). It is convenient to mention that it is a region that has specialized in tomato production and is one of the most important producing regions in the center of the country. The general characteristics of the enterprises dedicated to protected agriculture indicate that they are producers with an average age of 44.4 years, schooling of 9.1 years, with an experience in production of 8 years. The average surface of 5147.6 m^2, sale price of \$ 6.5 Kg, annual average returns of 24.0 (kg m^2) and income of

Table 2 . Descriptive statistics of rural enterprises dedicated to protected agriculture in Hidalgo, Mexico.

Variables	Minimum	Mean	Maximum	Standard error n = 65	Standard deviation	Variance
Age (years)	18.0	44.4	67.0	1.2	10.4	109.1
Producer education (years)	0.0	9.1	16.0	0.4	3.2	10.4
Producer experience (years)	1.0	8.0	18.0	0.6	4.9	24.7
Production area (m^2)	400.0	5147.6	25000.0	552.1	4451.7	19818471.1
Sale price (\$)	3.5	6.5	9.0	0.1	1.1	1.3
Yields obtained (kg m^2)	10.0	24.0	40.0	0.8	7.07	50.0
Total income (\$ m^2)	52.5	159.8	300.0	6.8	55.52	3083.2
Links with teaching and research institutions	0.0	2.6	30.0	0.8	6.67	44.6
Links with government institutions	0.0	8.6	28.0	0.9	7.8	60.8
Links with extension	0.0	3.3	10.0	0.3	3.2	10.3
Links with input suppliers	5.0	9.8	20.0	0.5	4.0	16.3
Links between enterprises	0.0	1.8	9.0	0.2	1.7	3.2
Links with markets	2.0	2.6	6.0	0.1	1.0	1.0
Total Links	7	28.9	67	1.8	14.8	220.3

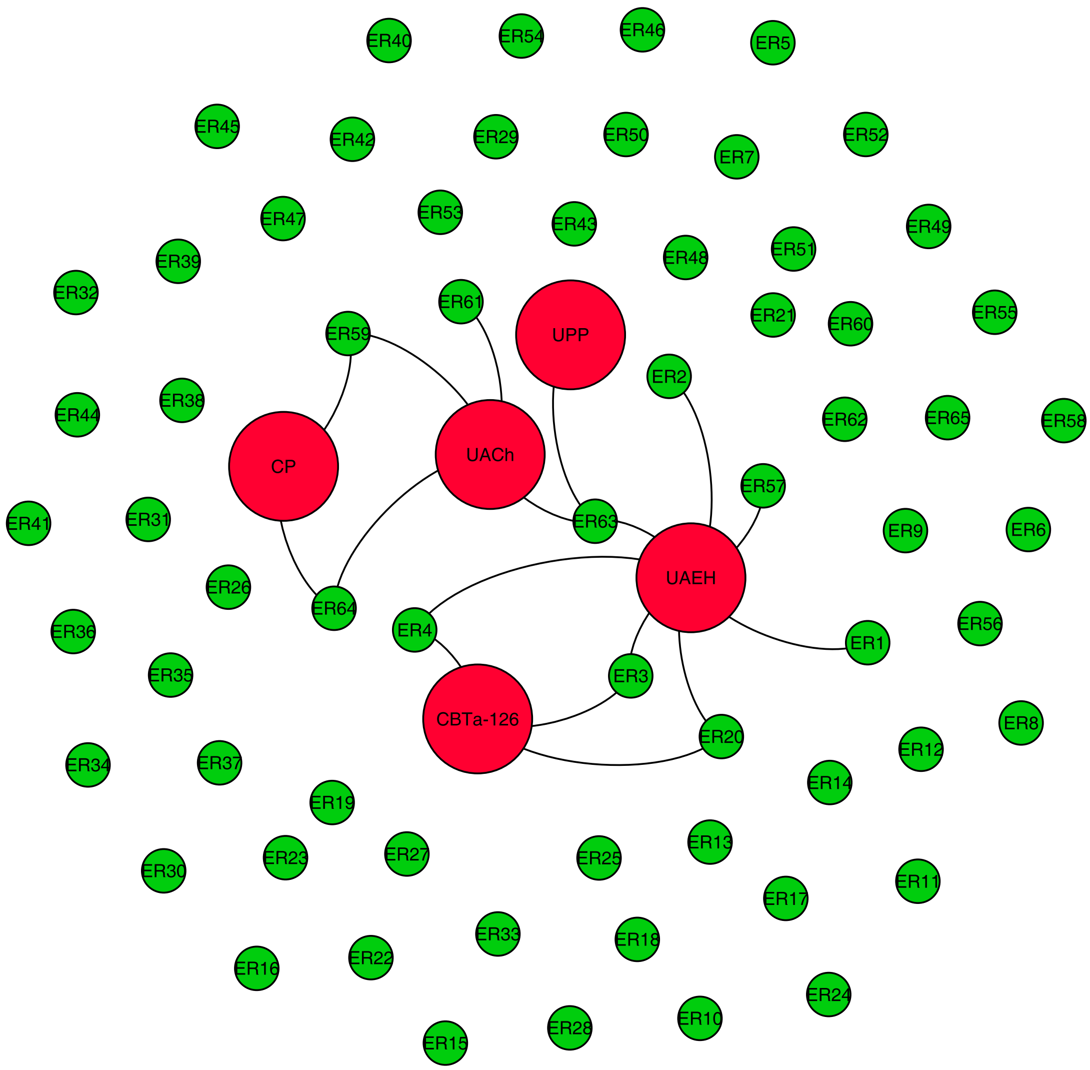

Figure 2 . Network with teaching and research institutions of the regional innovation system of protected agriculture in Hidalgo, Mexico.

159.8 ($ m^2). In relation to the links, they create with Teaching and Research Institutions, the average is 2.6, links with Government Institutions 8.6, links with input supplier 9.8, links with markets 2.6, links with extension agents 3.3, links with other similar enterprises 1.8 and the total links 28.9 (Table 2).

4.2 . Regional innovation system

4.2.1 . Networks with teaching and research institutions

The network of teaching and research institutions is characterized by having few links with enterprises dedicated to protected agriculture (Figure 2). The most referenced teaching and research institutions in this network were the Centro de Bachillerato Tecnológico Agropecuario 126 (CBTa 126), the Universidad Autónoma del Estado de Hidalgo (UAEH) and the Universidad Autónoma Chapingo (UACh). These three actors concentrate 14.9% of the connections with enterprises. It is important to mention that these actors are linked, mainly, through research carried out in the region. The fragmentation value indicates that, if these three actors did not exist, the network would be dismantled by 0.4%, this is because the network is generally disarticulated. The value obtained on density of 0.3% suggests that it is not very cohesive, since the score in this variable was the lowest in all networks. Finally, the centralization index of entry (9.9%) and exit (4.0%) indicate that there is a greater supply of educational institutions than the system demands.

4.2.2 . Network with government institutions

The network of government institutions is characterized by maintaining a large number of links with enterprises dedicated to protected agriculture (Figure 3). In this network the most referenced institutions were the Comité Estatal de Sanidad Vegetal del Estado de Hidalgo (GI1), the Delegación de la Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (GI2) and the Secretaría de Desarrollo Agropecuario del estado de Hidalgo (GI3). These three actors concentrate 62.3% of connections with

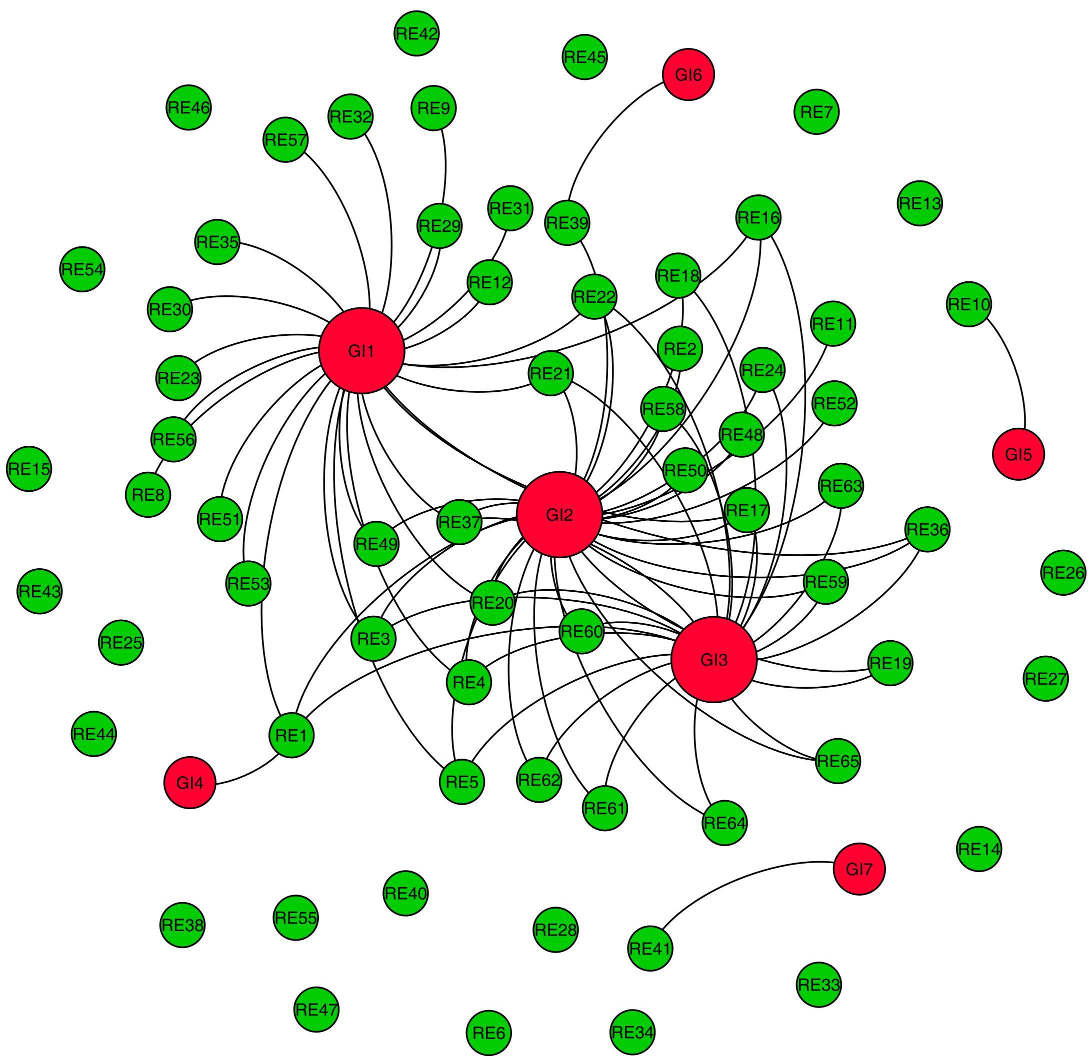

Figure 3 . Network with government institutions of the regional innovation system of protected agriculture in Hidalgo, Mexico.

enterprises. There are other government institutions as part of the innovation system, however, they are linked to very specific issues and therefore have low articulation. The fragmentation value indicates that if these three actors did not exist, the network would dismantle by 1.5%, greater than the previous ones because the links are more concentrated in this network. The value obtained on density of 1.5% suggests that it is a network with little cohesion. Lastly, the centralization index of entry (39.8%) and exit (4.1%) indicate that there is a greater institutional supply than what the system demands.

4.2.3 . Network with the extension service

The extension network is characterized by maintaining few connections and many apparently isolated actors (Figure 4). Only a few small subsets are observed, made up of seven extension agents who maintain links with the enterprises. In this regard,

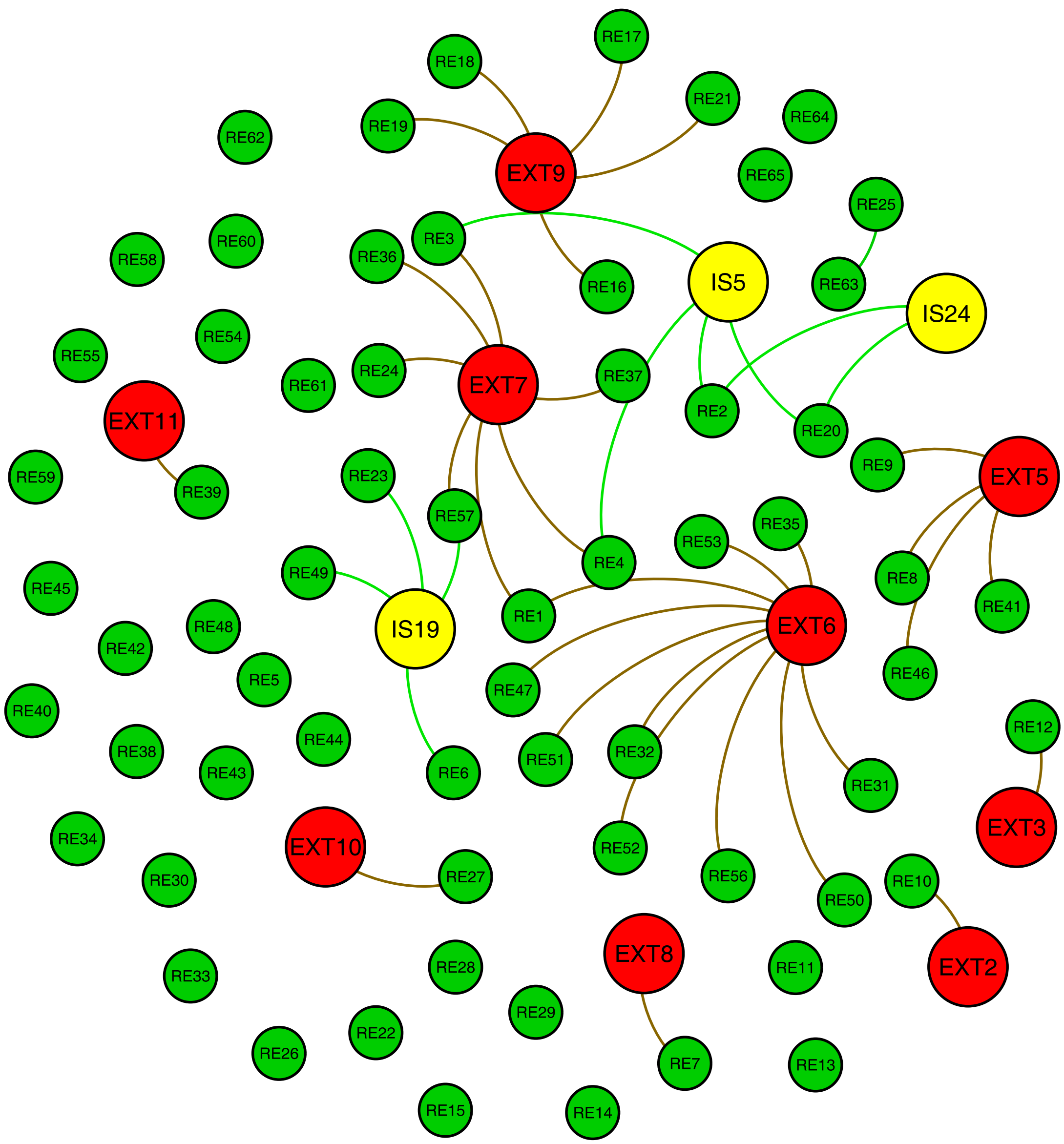

Figure 4 . Network with the extension service of the regional innovation system of protected agriculture in Hidalgo, Mexico.

extension agents 6, 7 and 9 stand out as the most referred actors since their services have a coverage of 28.3% of the network. As it is possible to observe, there are other actors that carry out extension functions and even fulfill other roles (input supplier: IS), however, the influence on the innovation system is very low due to its low linkage. The fragmentation value indicates that if these three actors did not exist, the network would decouple by 0.4%. This low impact is explained by the disarticulation of the network. The density of 0.7% suggests that the network has little cohesion. Lastly, the centralization rate of entry (12.1%) and exit (1.9%) indicate that there is a greater supply of the service than the system demands.

4.2.4 . Network with input suppliers

The input supplier network is characterized by the existence of many actors and a large number of connections (Figure 5). In this network, the most referenced supplier are the Cosecha Servicios Profesionales enterprise located in Acatlán, Hgo. (IS2), ETSOL - Distribuidora y Comercializadora de Fertilizantes y Agroquímicos located in Tulancingo,

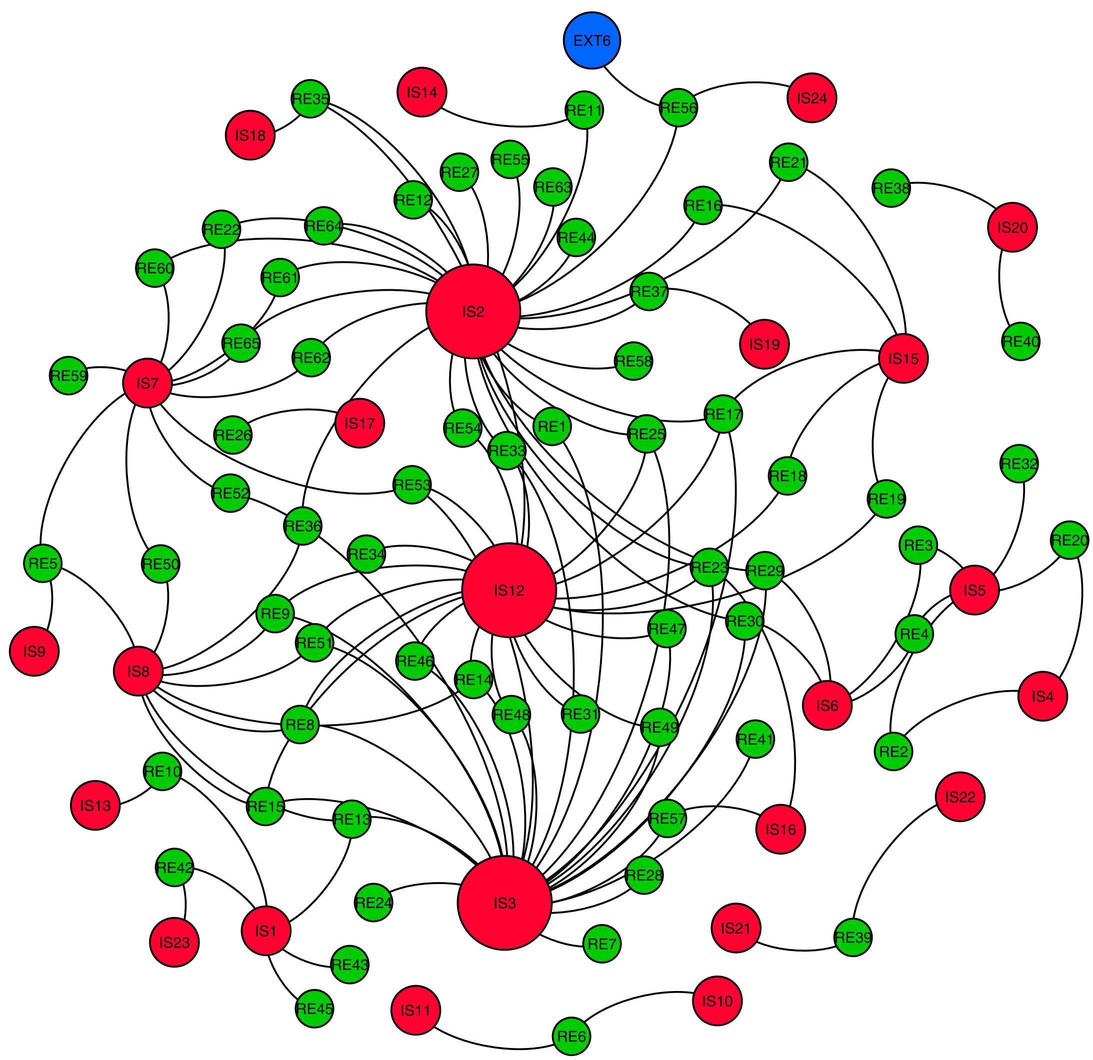

Figure 5 . Network with input suppliers of the regional innovation system of protected agriculture in Hidalgo, Mexico.

Hgo. (IS12) and Central Agrícola del Valle located in Tulancingo, Hgo. (IS3). These three actors supply 56.3% of enterprises. It is worth mentioning that in the region this type of actors increased concurrently to the increase in the area dedicated to this activity and generally has two or three branches distributed in the region. The fragmentation value indicates that if these three actors did not exist, the network would dismantle by 0.9%, a value that can be considered low and is explained by the existence of other actors of this type. For its part, the 1.6% density suggests that the network has little cohesion. Lastly, the centralization index of entry (29.0%) and exit (2.9%) indicate that there is a greater supply of products than what the system demands.

4.2.5 . Business-to-business learning network

The learning network is characterized by being the one with the fewest links (Figure 6). Enterprises RE17, RE3, RE22 stand out in this network, accounting for 25.3% of

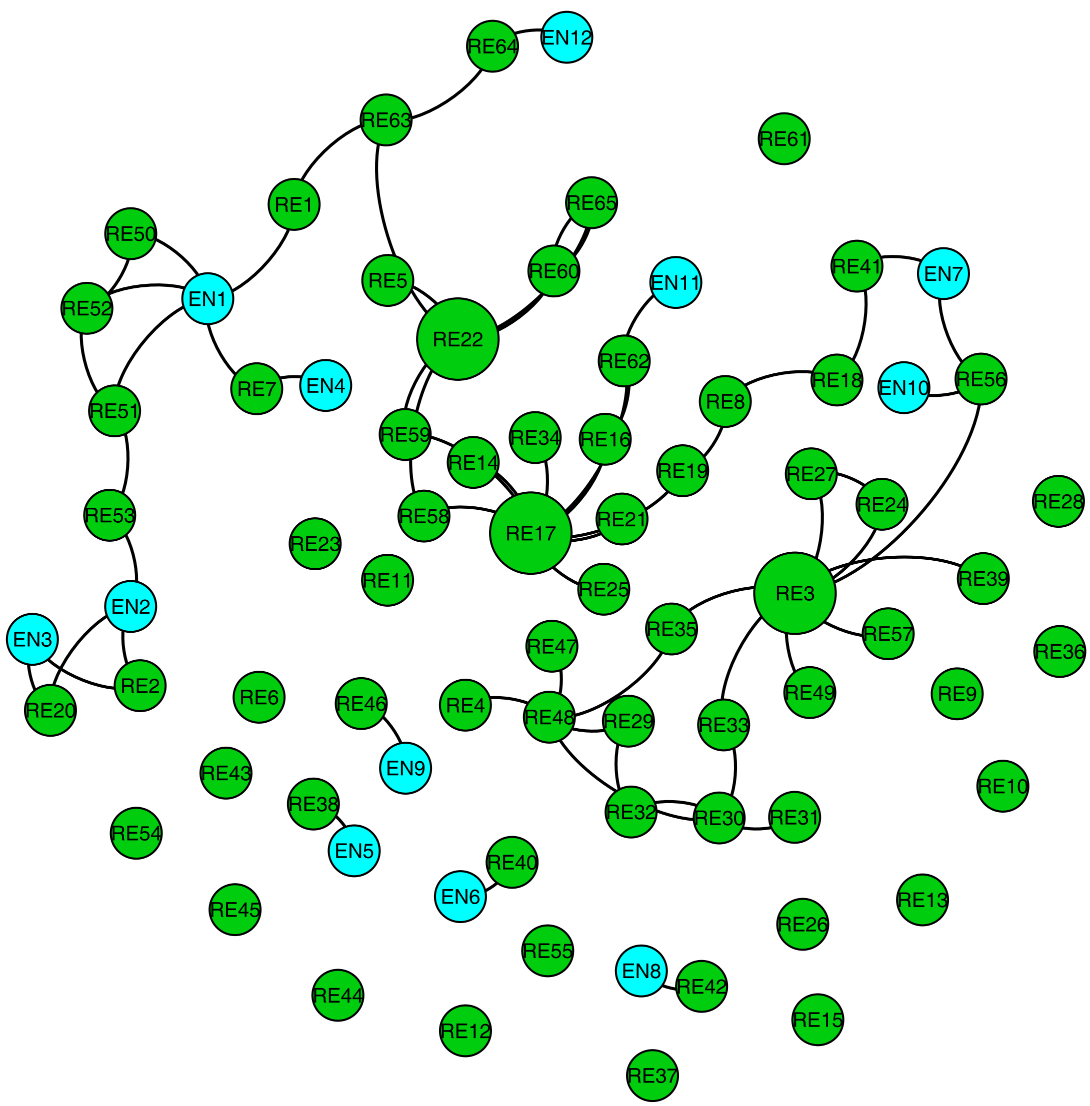

Figure 6 . Network of learning among enterprises of the regional innovation system of protected agriculture in Hidalgo, Mexico.

connections with enterprises. In this case, it is possible to observe that the link between enterprises is very low, however, most enterprises link to clearly defined small groups in which they share information, knowledge and experiences. Regarding fragmentation, the value obtained indicates that if these three actors did not exist, the network would only break up by 0.8%. The value obtained over 1.0% density suggests that it is a network with low cohesion. Lastly, the centralization index of entry (9.6%) and exit (2.4%) indicate that there is a greater offer of information providers than what the system demands.

4.2.6 . Network with the markets

The product marketing network is characterized by maintaining a large number of connections (Figure 6). A very large subset is observed that defines the Supply Center of Tulancingo (SC-TUL) as the main market and other smaller ones structured around the Supply Center of Mexico City (SC-CDMX) and Jitomates la Güera (LM3). The 61.2% of enterprises are concentrated in these three markets. Also, it is observed that

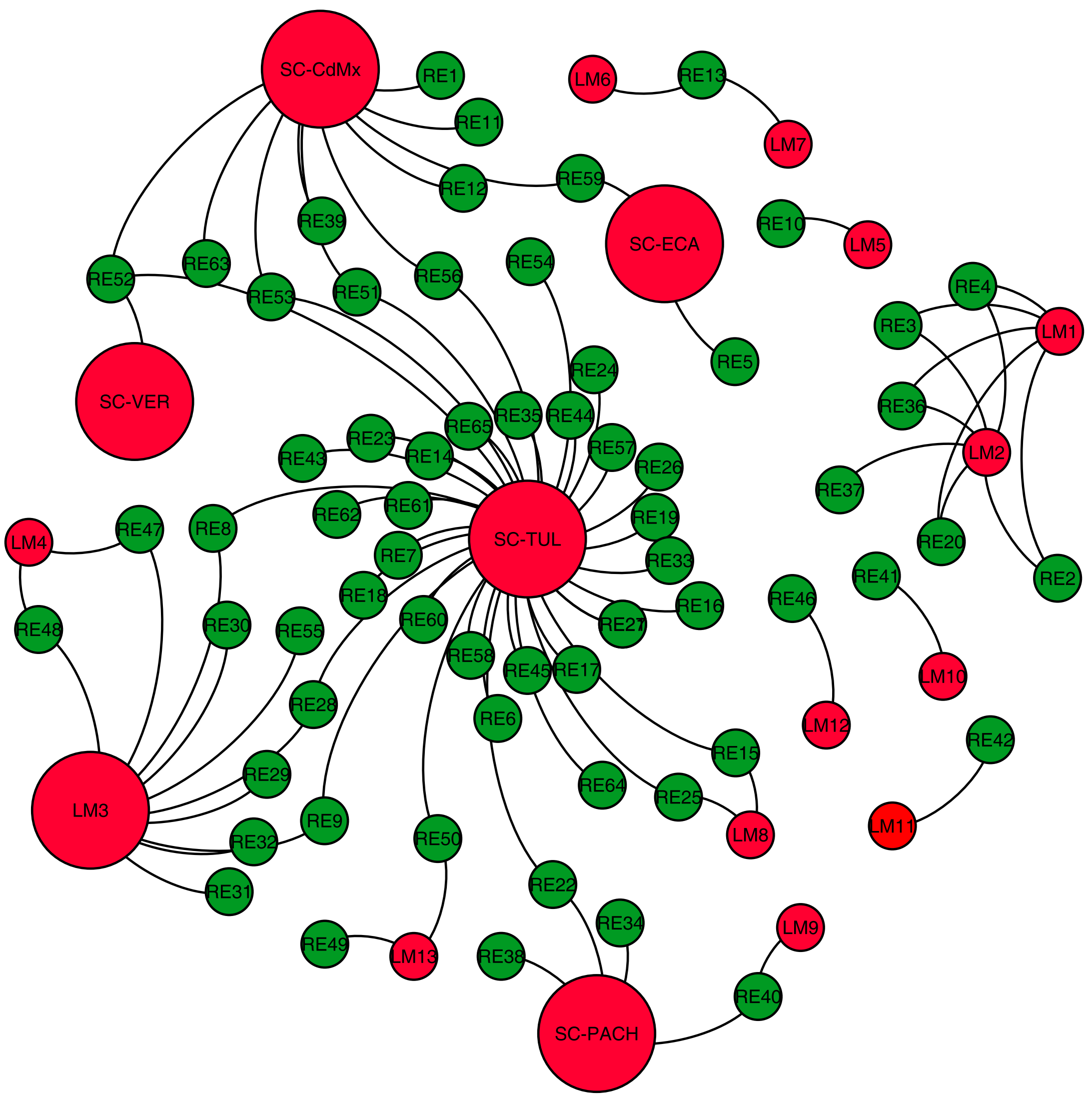

Figure 7 . Network with the markets of the regional innovation system of protected agriculture in Hidalgo, Mexico.

a significant number of enterprises sell their products to local markets. The fragmentation indicates that if these three actors did not exist, the network would decouple by 0.9%, this value is low due to the existence of local markets. The value obtained on density of 1.2% suggests that there is little cohesion. Finally, the centralization index of entry (43.1%) and exit (2.4%) indicate that there are more market options than what the system demands for optimal operation (Figure 7).

4.3 . Effects of the regional innovation system

The cluster analysis allowed creating a taxonomy of enterprises based on the links it maintains with other enterprises and institutions that configure the regional innovation system. Cluster 1 is the largest, made up of 30 enterprises that are characterized by being the largest. This group concentrates producers of intermediate age, lower levels of schooling and with higher levels of experience in the activity. Producers belonging to this cluster obtain the lowest sales prices and the lowest yields and incomes. Regarding the links that it has with other enterprises and institutions, it is the group that presents the lowest levels, with the exception of the links with input suppliers that are the highest (Table 3).

Cluster 2 is made up of 29 enterprises that are characterized by being medium in size. It concentrates the younger producers, with medium educational levels and with the lowest levels of experience in the activity. They get average sales prices, the highest returns and an average income level. Regarding the links that this group has with other enterprises and institutions, they present average levels, with the exception of the links with other enterprises, which are the highest values (Table 3). Cluster 3 is the smallest group, is made up of only 6 enterprises and is characterized by being smaller in size, concentrating producers with the oldest age, with higher levels of education and experience in middle activity. They get higher sales prices, high returns, and higher incomes. Regarding the links that this group has with other enterprises and institutions, they present the highest levels, with the exception of links with other enterprises (Table 3).

Table 3 . Typology of enterprises developed from the networks that it creates with other actors in the regional innovation system of protected agriculture in Hidalgo, Mexico.

Variables	Cluster 1	Cluster 2	Cluster 3
Number of enterprises	30	29	6
Age (years)	48.6 a	38.2 b	54.0 a
Producer education (years)	8.8 a	9.3 a	10.0 a
Producer experience (years)	10.1 a	5.6 b	8.8 ab
Production area (m^2)	5443.3 a	5072.4 a	4033.3 a
Sale price ($)	6.0 b	6.7 ab	7.8 a
Yields obtained (kg m^2)	19.6 b	27.7 a	26.8 a
Total income ($ m^2)	121.4 b	185.3 a	210.3 a
Links with teaching and research institutions	0.0 b	3.1 b	13.3 a
Links with government institutions	7.2 b	7.7 b	19.8 a
Links with extension	2.8 b	2.5 b	9.1 a
Links with input suppliers	11.6 a	7.9 b	10.0 ab
Links between enterprises	2.4 a	1.4 a	1.3 a
Links with markets	2.2 b	2.9 ab	3.6 a
Total Links	24.9 b	27.1 b	57.3 a

Note: Means with different letters in rows indicate significant differences ($P \leq 0.05$), according to the Scheffe test.

It is important to highlight that Cluster 3 presents the best indicators in most of the variables. This group presents significant differences in terms of the sale prices it obtains in the market, harvest yields and income. In other words, this Cluster presents the best efficiency and productivity indicators (Table 3). According to the analysis, the best results are related to the participation of three networks that make up the regional innovation system: networks with educational and research institutions, networks with government institutions and networks with extension agents, which also show differences significant.

5. Discussion

The system of protected agriculture production shows, in accordance with its general characteristics, a considerable development in the region. More and more enterprises are engaged in this activity and they are also growing in relation to their surface area and the yields obtained, which are greater than those previously found (García-Sánchez et al. 2018; Vargas-Canales et al. 2018; Vargas Canales et al. 2015). It can be inferred that this is an activity that has been successfully inserted and positioned in the markets and that has the potential to generate sustained development in the region, despite being a relatively new activity, compared to other activities traditional agricultural activities such as corn production (Vargas-Canales et al. 2018).

In the regional innovation system are all the actors and elements necessary to trigger innovation processes, even more than those required by the system according to the centralization indices (Rendón and Aguilar 2013). In this case, if any of the actors present in the region were excluded or left, it would apparently not generate significant fragmentation in the networks. However, this apparent stability in turn has a possible explanation in the density of the networks, that is, in that the actors are little related to each other (Wasserman and Faust 1999). In addition, the links they maintain are few, as in the case of the network with educational and research institutions and the networks formed with extension service, a situation that coincides with results found in other investigations (Ankrah and Freeman 2021). In the case of relations between enterprises, it is possible to observe small agglomerations, however, it is a very disjointed network.

The effect of the regional innovation system on the efficiency of enterprises engaged in protected agriculture is related, first of all, to links with educational and research institutions and government institutions. In this sense, Cluster 3 presents significant differences related to obtaining the highest returns, prices and income, which coincides with different investigations (Franco and Esteves 2020; Hermans et al. 2019; Philipson 2020; Roldán-Suárez et al. 2019). As in other regional innovation systems, these actors seem to be essential to encourage the dynamism of the system (Pyka, Kudic, and Müller 2019). In this sense, it is important to strengthen ties with educational institutions because knowledge is a fundamental enabling factor for agri-food innovation systems (Gardeazabal et al. 2021).

In relation to the links with extension service, the results show a positive effect on the efficiency of the enterprises, which coincide with those reported by other investigations (Aguilar-Gallegos et al. 2015; Roldán-Suárez et al. 2019; Skaalsveen, Ingram, and Urquhart 2020; Vargas-Canales et al. 2018). Derived from the above, through extension, it is possible to encourage the participation of groups of farmers, actors who develop research and the private sector (Onumah, Asante, and Osei 2021). On the other hand, the networks with input supplier show significant differences with Cluster 1, which is the one with the lowest parameters. The results differ from those reported in the region (García-Sánchez et al. 2018), a situation that could improve due to the fact that they play an important role in the diffusion of new technologies in agri-food systems (Hornum and Bolwig 2021).

Apparently, there is no effect of inter-enterprise learning networks on their own efficiency due to poor network articulation. Proper management could substantially improve its operation. According to what was found by Skaalsveen, Ingram, and Urquhart (2020), interpersonal networks are important to farmers and influence learning and decision-making since farmers often make them as their main source of information. In relation to market networks, the results indicate that those who access the most markets are Clusters 1 and 2. The market also pours information into the innovation system since it transmits the tastes and preferences of consumers, which forces them to search and continually introduce improvements in production systems to meet their demands.

The method used allows us to identify causal correlations between belonging to networks and the efficiency of enterprises. This can help define strategies for strengthening the regional innovation system. In this sense, relational capital, business coordination, social relations and the use of the technological infrastructure available in the region must be taken into account (Arias and Alarcón 2019), in addition to the natural resources and the skills, experiences and capacities of the societies that develop in the territories. The foregoing in is in order to promote an intelligent regional specialization that focuses on identifying the central and potential competencies that the region has in order to make the innovation process more efficient (Asheim 2019; Vlčková, Kaspříková, and Vlčková 2018).

On the other hand, the method does not capture the potentially negative externalities associated with intensive monoculture such as genetic erosion, subordination to the market, generates a significant environmental burden (overexploitation of resources) and causes changes in patterns food and transforms territories without considering their characteristics and evolution (Vargas-Canales et al. 2020). In addition, these new technologies represent different social conflicts as a new form of governance of the population, with which new types of affective relationships and agrarian subjectivities are generated (Moulton and Popke 2017) and as a result strong social asymmetries develop.

The research clearly shows the impacts of teaching and research institutions and that of government institutions on the efficiency of enterprises, however, their functions and capacities are limited. Derived from the above, the extension services can play a fundamental role in the construction of new networks that strengthen the operation of the regional innovation system. The extension services should be considered as intermediaries of systematic and formal innovation, creating and maintaining innovation networks (Poncet, Kuper, and Chiche 2010). Furthermore, they can access institutional resources to provide the advisory service and function as a link and act as moderators between the different actors in the system (Skaalsveen, Ingram, and Urquhart 2020).

Consequently, it is necessary to reassess the role of public extension, it is convenient to mention that it is inadequate and there is great uncertainty about its operation, little attention from the state and a continuous decrease in resources. Extension is key because it is the direct intermediary between the academy and the productive sector. In this sense, it is opportune to rethink the policy on extension and its role in the development of the productive sector. In short, it is pertinent to promote a smart extension that is based on scientific and technological development, with a greater social and environmental awareness, more critical and reflective about its roles and functions and at the same time more proactive and creative to generate innovative solutions to the problems of the agri-food sector.

6. Conclusions

The network analysis allowed identifying the main actors of the regional innovation system and clearly observing the structure of the relationships established among them. Government, teaching and research institutions and input supplier stand out in this activity as key actors for the development of the regional innovation system since they are the ones with the highest degrees of articulation.

Regarding the regional innovation system, it is important to mention that, in theory, the necessary actors are present so that the innovation processes develop dynamically. However, a low articulation between actors is revealed that needs to be addressed. It becomes evident that the networks of enterprises with strategic actors such as teaching and research institutions, with government institutions and with extension agents, allow them to be more efficient in their production systems according to the results obtained. The findings suggest that it is through these networks that relevant information, technologies and reliable knowledge have been disseminated and that in most cases they have been previously verified.

The results obtained allow us to affirm that it is desirable to manage the regional innovation system based on an extension program capable of developing solutions to regional problems, spreading new technologies and innovations, and effectively articulating all the actors in the system. A policy that modifies the structure of the system and increases its level of interconnection would favor the flow of knowledge and experiences through the network and with this, a greater number of actors would benefit from their interactions. Finally, some of the shortcomings of this research are related to the lack of interviews with other types of actors in the innovation system, the evaluation of environmental impacts and the analysis of development asymmetries generated by protected agriculture.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

Aguilar-Gallegos, N., M. Muñoz-Rodríguez, H. Santoyo-Cortés, J. Aguilar-Ávila, and L. Klerkx. 2015. “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.” *Agricultural Systems* 135: 122–132. https://doi.org/10.1016/j.agsy.2015.01.003

Ankrah, D. A., and C. Y. Freeman. 2021. “Operationalizing the Agricultural Innovation System Concept in a Developing Country Context – Examining the Case of the MiDA Programme in Ghana.” *The Journal of Agricultural Education and Extension* 0 (0): 1–20. https://doi.org/10.1080/1389224X.2021.1915828

Añorve Guillén, M. A. 1991. “La Fiabilidad en la Entrevista: La Entrevista Semi Estructurada y Estructurada, un Recurso de la Encuesta.” *Investigación Bibliotecológica* 5 (10): 29–37. https://doi.org/10.22201/iibi.0187358xp.1991.10.3793

Arias, M. E., and S. Alarcón. 2019. "Sistemas Regionales de Innovación Agroalimentarios de Colombia: Un Análisis Factorial y de Clúster Para la Industria." *Cuadernos de Desarrollo Rural* 16 (84): 1–22. https://doi.org/10.11144/Javeriana.cdr16-84.sria.

Asheim, B. T. 2019. "Smart Specialisation, Innovation Policy and Regional Innovation Systems: What About new Path Development in Less Innovative Regions?" *Innovation: The European Journal of Social Science Research* 32 (1): 8–25. https://doi.org/10.1080/13511610.2018.1491001

Bastida, T. A. 2008. *Los Invernaderos en México*. Chapingo, México: Universidad Autónoma Chapingo.

Bellandi, M., and A. Caloffi. 2010. "An Analysis of Regional Policies Promoting Networks for Innovation." *European Planning Studies* 18 (1): 67–82. https://doi.org/10.1080/09654310903343534

Birner, R., K. Davis, J. Pender, E. Nkonya, P. Anandajayasekeram, J. Ekboir, A. Mbabu, et al. 2009. "From Best Practice to Best Fit: A Framework for Designing and Analyzing Pluralistic Agricultural Advisory Services Worldwide." *The Journal of Agricultural Education and Extension* 15 (4): 341–355. https://doi.org/10.1080/13892240903309595

Borbón Morales, C. G., and M. Arvizu Armenta. 2015. "Contraste Empírico de Modelos de Transferencia de Tecnología: Los Casos de Tres Empresas de Agricultura Protegida en México." *Nova Scientia* 7 (15): 364. https://doi.org/10.21640/ns.v7i15.99

Borgatti, S. P. 2002. *NetDraw: Graph Visualization Software*. Lexington, KY: Harvard, Analytic Technologies.

Bruque, S. S., and J. Moyano. 2007. "Organisational Determinants of Information Technology Adoption and Implementation in SMEs: The Case of Family and Cooperative Firms." *Technovation* 27 (5): 241–253. https://doi.org/10.1016/j.technovation.2006.12.003

Carlsson, B., S. Jacobsson, M. Holmén, and A. Rickne. 2002. "Innovation Systems: Analytical and Methodological Issues." *Research Policy* 31: 233–245. https://doi.org/10.1016/S0048-7333(01)00138-X

Castañeda-Miranda, R., E. Ventura-Ramos, R. del R. Peniche-Vera, and G. Herrera-Ruiz. 2007. "Análisis y Simulación del Modelo Físico de un Invernadero Bajo Condiciones Climáticas de la Región Central de México." *Agrociencia* 41 (3): 317–335.

Cooke, P. 2005. "Regionally Asymmetric Knowledge Capabilities and Open Innovation: Exploring "Globalisation 2" - A new Model of Industry Organisation." *Research Policy* 34 (8): 1128–1149. https://doi.org/10.1016/j.respol.2004.12.005

Costa, P., and G. Giacomelli. 2005. "Los Planes del éxito. Agricultura Protegida: Productividad Basada en el Nivel Tecnológico." *Productores de Hortalizas Para Centroamérica (USA)* 7 (1): 42–44.

Dasgupta, P., and I. Serageldin. 2001. *Social Capital: A Multifaceted Perspective*. Washington, DC: World Bank Publications.

Delgado-Verde, M., G. Martín-de-Castro, J. E. Navas-López, and J. Cruz-González. 2011. "Capital Social, Capital Relacional e Innovación Tecnológica. Una Aplicación al Sector Manufacturero Español de Alta y Media-Alta Tecnología." *Cuadernos de Economía y Dirección de La Empresa* 14 (4): 207–221. https://doi.org/10.1016/j.cede.2011.04.001

Diez, R. J. 2002. "Metropolitan Innovation Systems: A Comparison Between Barcelona, Stockholm, and Vienna." *International Regional Science Review* 25 (1): 63–85.

Dutrénit, G., J. Sutz, R. Arocena, and L. Navas-Aleman. 2014. *National Innovation Systems, Social Inclusion and Development*. Cheltenham: The Latin American Experience. Edwar Elgar Publishing.

Eito-Brun, R. 2020. "Synergies Between Web-Based Open Innovation Platforms and Open Information Infrastructures." In *Information Systems Architecture and Technology: Proceedings of 40th Anniversary International Conference on Information Systems Architecture and Technology - ISAT 2019. ISAT 2019,* edited by Z. Wilimowska, L. Borzemski, and J. Świątek, 254–261, Vol. vol 1052. Cham: Springer.

Fafchamps, M. 2006. "Development and Social Capital." *Journal of Development Studies* 42 (7): 1180–1198. https://doi.org/10.1080/00220380600884126

Faure, G., A. Toillier, S. Audouin, S. Mathé, B. Triomphe, and L. Templen. 2019. "Evaluación de los Sistemas de Innovación Agropecuaria Para el Diseño de Políticas Públicas: Una Revisión de la Literatura." In *Sistemas y Políticas de Innovación Para el Sector Agropecuario en América Latina*, edited by F. Goulet, J.-F. Le Coq, and O. Sotomayor, 1–20. Rio de Janeiro: E-papers.

Ferreiro, M., and C. Sousa. 2019. "Governance, Institutions and Innovation in Rural Territories: The Case of Coruche Innovation Network." *Regional Science Policy & Practice* 11 (2): 235–250. https://doi.org/10.1111/rsp3.12147

Franco, M., and L. Esteves. 2020. "Inter-clustering as a Network of Knowledge and Learning: Multiple Case Studies." *Journal of Innovation & Knowledge* 5 (1): 39–49. https://doi.org/10.1016/j.jik.2018.11.001

Freeman, C. 1987. "Technology, Policy, and Economic Performance: Lessons from Japan." *Frances Printr*: 155.

García, J. C., L. Olivé, and M. Puchet. 2014. "Hacia un Modelo de Innovación Intercultural." In *Perspectivas Latinoamericanas en el Estudio Social de la Ciencia, la Tecnología y el Conocimiento*, edited by P. Kreimer, H. Vessuri, L. Velho, and A. Arellano, 433–446. México: Siglo XXI.

García, V. N., O. Van der Valk, and A. Elings. 2011. *Mexican Protected Horticulture Production and Market of Mexican Protected Horticulture Described and Analysed. Rapport GTB-1126*. Wageningen: Wageningen Academic Publishers.

García-Sanchez, I. E., J. Aguilar-Ávila, and R. Bernal-Muñoz. 2011. "La Agricultura Protegida en Tlaxcala, México: La Adopción de Innovaciones y el Nivel de Equipamiento Como Factores Para su Categorización." *Teuken Bidikay* 2: 193–212.

García-Sánchez, E. I., J. M. Vargas-Canales, M. I. Palacios-Rangel, and J. Aguilar-Ávila. 2018. "Sistema de Innovación Como Marco Analítico de la Agricultura Protegida en la Región Centro de México." *Cuadernos de Desarrollo Rural* 15 (81): 1–24. https://doi.org/10.11144/Javeriana.cdr15-81.sima

Gardeazabal, A., T. Lunt, M. M. Jahn, N. Verhulst, J. Hellin, and B. Govaerts. 2021. "Knowledge Management for Innovation in Agri-Food Systems: A Conceptual Framework." *Knowledge Management Research & Practice* 00 (00): 1–13. https://doi.org/10.1080/14778238.2021.1884010

Granovetter, M. 2005. "The Impact of Social Structure on Economic Outcomes." *The Journal of Economic Perspectives* 19 (1): 33–50.

Griliches, Z. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica, Journal of the Econometric Society* 25 (4): 501–522.

Grovermann, C., T. Wossen, A. Muller, and K. Nichterlein. 2019. "Eco-efficiency and Agricultural Innovation Systems in Developing Countries: Evidence from Macro-Level Analysis." *PLoS ONE* 14 (4): 1–16. https://doi.org/10.1257/0895330053147958

Hair, J., R. Aanderson, R. Tatham, and W. Black. 1999. *Análisis Multivariante (5a Edición)*. Madrid: Prentice Hall.

Hermans, F., F. Geerling-Eiff, J. Potters, and L. Klerkx. 2019. "Public-private Partnerships as Systemic Agricultural Innovation Policy Instruments – Assessing Their Contribution to Innovation System Function Dynamics." *NJAS - Wageningen Journal of Life Sciences* 88 (October 2018): 76–95. https://doi.org/10.1016/j.njas.2018.10.001

Hornum, S. T., and S. Bolwig. 2021. "A Functional Analysis of the Role of Input Suppliers in an Agricultural Innovation System: The Case of Small-Scale Irrigation in Kenya." *Agricultural Systems* 193 (November 2020): 103219. https://doi.org/10.1016/j.agsy.2021.103219

INEGI. 2014. Instituto Nacional de Estadística y Geografía. http://www.inegi.org.mx.

Katungi, E. M., S. Edmeades, and M. Smale. 2008. "Gender, Social Capital and Information Exchange in Rural Uganda." *Journal of International Development* 20: 35–52. https://doi.org/10.1002/jid

Kauffmann, A., and F. Tödtling. 2001. "Science-Industry Interaction in the Process of Innovation: The Importance of Boundary Crossing Between Systems." *Research Policy* 30: 791–804.

Kuss, E., D. Flores, and T. Harrison. 2016. *Mexico Tomato Annual Mexico Continues to Expand Greenhouse Tomato Production. GAIN Report Number: MX6021*. 1–9. http://gain.fas.usda.gov/Recent GAIN Publications/Tomato Annual_Mexico City_Mexico_6-1-2016.pdf.

Leeuwis, C., and N. Aarts. 2011. "Rethinking Communication in Innovation Processes: Creating Space for Change in Complex Systems." *The Journal of Agricultural Education and Extension* 17 (1): 21–36. https://doi.org/10.1080/1389224X.2011.536344
Lundvall, B-Å. 1992. *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning*. London: Anthem Press.
Markusen, A. 2003. "Fuzzy Concepts, Scanty Evidence, Policy Distance: The Case for Rigour and Policy Relevance in Critical Regional Studies." *Regional Studies* 37 (6–7): 701–717. https://doi.org/10.1080/0034340032000108796
Minh, T. T. 2019. "Unpacking the Systemic Problems and Blocking Mechanisms of a Regional Agricultural Innovation System: An Integrated Regional-Functional-Structural Analysis." *Agricultural Systems* 173 (January): 268–280. https://doi.org/10.1016/j.agsy.2019.03.009
Minh, T. T., R. Friederichsen, A. Neef, and V. Hoffmann. 2014. "Niche Action and System Harmonization for Institutional Change: Prospects for Demand-Driven Agricultural Extension in Vietnam." *Journal of Rural Studies* 36: 273–284. https://doi.org/10.1016/j.jrurstud.2014.09.008
Monge, P. M., and F. Hartwich. 2008. "Análisis de Redes Sociales Aplicado al Estudio de los Procesos de Innovación Agrícola." *REDES-Revista Hispana Para El Análisis de Redes Sociales* 14 (2): 1–31. https://doi.org/978-950-34-0513-0.
Moreno, R. A., D. J. Aguilar, and G. A. Luévano. 2011. "Características de la Agricultura Protegida y su Entorno en México." *Revista Mexicana de Agronegocios* 15 (29): 763–774.
Moser, C. M., and C. B. Barrett. 2006. "The Complex Dynamics of Smallholder Technology Adoption: The Case of SRI in Madagascar." *Agricultural Economics* 35 (3): 373–388. https://doi.org/10.1111/j.1574-0862.2006.00169.x
Moulton, A. A., and J. Popke. 2017. "Greenhouse Governmentality: Protected Agriculture and the Changing Biopolitical Management of Agrarian Life in Jamaica." *Environment and Planning D: Society and Space* 35 (4): 714–732. https://doi.org/10.1177/0263775816679669
Moxley, R. L., and K. Brandon Lang. 2006. "The Importance of Social Context Influences on new Farm Technology Sustainability: Community and sub-Community Characteristics in Jamaica." *Technology in Society* 28 (3): 393–406. https://doi.org/10.1016/j.techsoc.2005.08.005
Muñoz, R. M., M. R. Rendón, A. J. Aguilar, M. J. García, and C. J. Altamirano. 2004. *Redes de Innovación: Un Acercamiento a su Identificación, Análisis y Gestión Para el Desarrollo Rural*. Chapingo, México: Universidad Autónoma Chapingo.
Nelson, R., and K. Nelson. 2002. "Technology, Institutions, and Innovation Systems." *Research Policy* 31 (2): 265–272. https://doi.org/10.1016/S0048-7333(01)00140-8
Nosova, S. S., S. V. Makar, V. Z. Chapljuk, A. M. Medvedeva, and A. N. Semenova. 2018. "Collaborative Nature of Innovative Economy." *Espacios* 39 (41): 1–32.
Onumah, J. A., F. A. Asante, and R. D. Osei. 2021. "Actor Roles and Linkages in the Agricultural Innovation System: Options for Establishing a Cocoa Innovation Platform in Ghana." *Innovation and Development* 0 (0): 1–22. https://doi.org/10.1080/2157930X.2021.1965752
O'Regan, N., A. Ghobadian, and M. Sims. 2006. "Fast Tracking Innovation in Manufacturing SMEs." *Technovation* 26 (2): 251–261. https://doi.org/10.1016/j.technovation.2005.01.003
Philipson, S. 2020. "Sources of Innovation: Consequences for Knowledge Production and Transfer." *Journal of Innovation & Knowledge* 5 (1): 50–58. https://doi.org/10.1016/j.jik.2019.01.002
Pimienta, L. R. 2000. "Encuestas Probabilísticas vs . no Probabilísticas." *Política y Cultura* 13: 263–276.
Poncet, J., M. Kuper, and J. Chiche. 2010. "Wandering off the Paths of Planned Innovation: The Role of Formal and Informal Intermediaries in a Large-Scale Irrigation Scheme in Morocco." *Agricultural Systems* 103 (4): 171–179. https://doi.org/10.1016/j.agsy.2009.12.004
Pyka, A., M. Kudic, and M. Müller. 2019. "Systemic Interventions in Regional Innovation Systems: Entrepreneurship, Knowledge Accumulation and Regional Innovation." *Regional Studies* 53 (9): 1321–1332. https://doi.org/10.1080/00343404.2019.1566702
Rendón, M. R., and Á. J Aguilar. 2013. Gestión de redes de innovación en zonas rurales marginadas. CIESTAAM/UACh.

Rincón Castillo, E. L. 2004. "El Sistema Nacional de Innovación : Un Análisis Teórico-Conceptual." *Opción: Revista de Ciencias Humanas y Sociales* 20 (45): 94–117. https://dialnet.unirioja.es/servlet/articulo?codigo = 2476831.

Rogers, E. M. 1995. *Diffusion of Innovations*. New York: Newyork Free Press.

Roldán-Suárez, E., A. Islas-Moreno, J. Sánchez-Gómez, and R. Rendón-Medel. 2019. "Innovation Networks in Milpa Production Systems." *Revista de Geografía Agrícola* 63: 45–62. https://doi.org/10.5154/r.rga.2019.63.09

Romero-Riaño, E., C. D. Guerrero-Santander, and H. E. Martínez-Ardila. 2021. "Agronomy Research co-Authorship Networks in Agricultural Innovation Systems." *Revista UIS Ingenierías* 20 (1): 161–175. https://doi.org/10.18273/revuin.v20n1-2021015

Rotmans, J., R. Kemp, and M. van Asselt. 2001. "Emerald Article: More Evolution Than Revolution: Transition Management in Public Policy." *Foresight (los Angeles, Calif)* 3 (1): 15–31. https://doi.org/10.1108/14636680110803003

Ruttan, V. W. 1996. "What Happened to Technology Adoption-Diffusion Research?." *Sociologia Ruralis* 36 (1): 51–73. https://doi.org/10.1111/j.1467-9523.1996.tb00004.x

Skaalsveen, K., J. Ingram, and J. Urquhart. 2020. "The Role of Farmers' Social Networks in the Implementation of no-Till Farming Practices." *Agricultural Systems* 181 (January): 102824. https://doi.org/10.1016/j.agsy.2020.102824

Storper, M. 1997. "Las Economías Regionales Como Activos Relacionales." *Ekonomiaz* 41: 10–45.

Terrones Cordero, A., and Y. Sánchez Torres. 2011. "Análisis de la Rentabilidad Económica de la Producción de Jitomate Bajo Invernadero en Acaxochitlán, Hidalgo." *Revista Mexicana de Agronegocios* 15 (29): 752–761.

Toillier, A., S. Mathé, A. Saley Moussa, and G. Faure. 2021. "How to Assess Agricultural Innovation Systems in a Transformation Perspective: A Delphi Consensus Study." *The Journal of Agricultural Education and Extension* 0 (0): 1–23. https://doi.org/10.1080/1389224X.2021.1953548

Touzard, J.-M., L. Temple, G. Faure, and B. Triomphe. 2015. "Innovation Systems and Knowledge Communities in the Agriculture and Agrifood Sector: A Literature Review." *Journal of Innovation Economics* 17 (2): 117. https://doi.org/10.3917/jie.017.0117

Vargas Canales, J. M., M. I. Palacios Rangel, J. H. H. Camacho Vera, J. Aguilar Ávila, and J. G. Ocampo Ledesma. 2015. "Factores de Innovación en Agricultura Protegida en la Región de Tulancingo, México." *Revista Mexicana de Ciencias Agrícolas* 6 (4): 827–840.

Vargas-Canales, J. M., G. Carbajal-Flores, T. I. Bustamante-Lara, J. H. Camacho-Vera, J. Fresnedo-Ramírez, M. I. Palacios-Rangel, and B. Rodríguez-Haros. 2020. "Impact of the Market on the Specialization and Competitiveness of Avocado Production in Mexico." *International Journal of Fruit Science* 20 (S3): S1942–S1958. https://doi.org/10.1080/15538362.2020.1837711

Vargas-Canales, J. M., M. I. Palacios-Rangel, J. Aguilar-Ávila, J. G. Ocampo-Ledesma, P. Kreimer, and G. Ortiz-Martínez. 2018. "Technological Innovation in a Case of Protected Agriculture in Mexico." *Revista de Geografía Agrícola* 61 (2): 9–38. https://doi.org/10.5154/r.rga.2017.61.02

Vargas-Canales, J. M., M. I. Palacios-Rangel, J. Aguilar-Ávila, J. G. Ocampo-Ledesma, and S. E. Medina-Cuellar. 2018. "Efficiency of Small Enterprises of Protected Agriculture in the Adoption of Innovations in Mexico." *Estudios Gerenciales* 34 (146): 52–62. https://doi.org/10.18046/j.estger.2018.146.2811

Vlčková, J., N. Kaspříková, and M. Vlčková. 2018. "Technological Relatedness, Knowledge Space and Smart Specialisation: The Case of Germany." *Moravian Geographical Reports* 26 (2): 95–108. https://doi.org/10.2478/mgr-2018-0008

Wang, D., X. Du, J. Sun, X. Guo, and Y. Chen. 2018. "Synergy of National Agricultural Innovation Systems." *Sustainability* 10 (10): 3385. https://doi.org/10.3390/su10103385

Wasserman, S., and K. Faust. 1999. "Social Network Analysis in the Social and Behavioral Sciences." In *Social Network Analysis. Methods and Applications. Structural Analysis in the Social Sciences*, edited by S. Wasserman, and K. Faust, 3–27. Cambridge: Cambridge University Press.

Wu, B., and L. Zhang. 2013. “Farmer Innovation Diffusion via Network Building: A Case of Winter Greenhouse Diffusion in China.” *Agriculture and Human Values* 30 (4): 641–651. https://doi.org/10.1007/s10460-013-9438-6

Zarazúa, J. A., G. Almaguer-Vargas, and R. Rendón-Medel. 2012. “Capital Social. Caso red de Innovación de Maíz en Zamora, Michoacán, México.” *Cuadernos de Desarrollo Rural* 9 (68): 105–124.

Zhang, H., and Y. Vorobeychik. 2019. “Empirically Grounded Agent-Based Models of Innovation Diffusion: A Critical Review.” *Artificial Intelligence Review* 52 (1): 707–741. https://doi.org/10.1007/s10462-017-9577-z