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MODEL OF INNOVATION IN AGRICULTURE 4.0 PROCESSES IN THE DEPARTMENT OF CUNDINAMARCA, COLOMBIA

MODELO DE INNOVACIÓN EN PROCESOS DE AGRICULTURA 4.0 EN EL DEPARTAMENTO DE CUNDINAMARCA, COLOMBIA

MODELO DE INOVAÇÃO EM PROCESSOS AGRÍCOLAS 4.0 NO DEPARTAMENTO DE CUNDINAMARCA, COLÔMBIA

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Abstract

Innovation in agriculture plays a fundamental role in the transition of said production towards more sustainable schemes, hence the importance of its study, especially in relation to production processes. The literature shows that although several studies have been carried out that examine the variables that intervene in the innovation processes in the agricultural sector, there is a lack of studies that examine the innovation processes in Colombia. This is why the fundamental objective of this research is to develop a model that explains the main factors that are related to process innovation in the agricultural sector, using concepts derived from organizational innovation process models developed in the literature. The factors identification methodology used a sample of 1,190 Agricultural Production Units (UPA) collected in the National Agricultural Survey, incorporating only producers from the department of Cundinamarca, Colombia. With this sample, and using for the analysis the variables that are developed in the literature, a principal components factorial analysis was carried out, as well as a second-order confirmatory factorial analysis. The factor analysis shows three latent factors, among them “Innovation in Raw Materials”, “Innovation in crops” and “Innovation in management of External Factors”, which, being the most significant for the process innovation process, should be considered as fundamental part of the government's public policies to facilitate its adoption in Colombian agriculture in the future.

Keywords: agricultural research; agricultural development; factor analysis; scientific innovation; agricultural production.

JEL: O30; O13; O31; Q16; Q55

Resumen

La innovación en la agricultura juega un rol fundamental en la transición de dicha producción hacia esquemas más sostenibles, de allí la importancia de su estudio, especialmente en relación con los procesos productivos. La literatura muestra que, si bien se han hecho varios estudios que examinan las variables que intervienen en los procesos de innovación en el sector agrícola, hacen falta estudios que examinen los procesos de innovación en Colombia. Es por esto que esta investigación tiene como objetivo fundamental, desarrollar un modelo que explique los principales factores que se relacionan con la innovación de procesos en el sector agrícola, utilizando conceptos derivados de modelos de procesos de innovación organizacional desarrollados en la literatura. La metodología de identificación de factores utilizó una muestra de 1.190 Unidades de Producción Agropecuaria (UPA) recolectados en la Encuesta Nacional Agropecuaria, incorporando únicamente productores del departamento de Cundinamarca, Colombia. Con esta muestra, y utilizando para el análisis las variables que son desarrolladas en la literatura, se realizó un análisis de tipo factorial de componentes principales, así como también un análisis factorial confirmatorio de segundo orden. El análisis factorial muestra tres factores latentes, entre ellos "Innovación en Materias Primas", "Innovación en cultivos" e "Innovación en manejo de Factores Externos", que al ser los más significativos para el proceso de innovación en procesos, deberían ser considerados como parte fundamental de las políticas públicas del gobierno para facilitar su adopción en el agro colombiano en el futuro.

Palabras clave: investigación agrícola; desarrollo agrícola; análisis factorial; innovación científica; producción agrícola.

JEL: O30; O13; O31; Q16; Q55

Resumo

A inovação na agricultura desempenha um papel fundamental na transição dessa produção para regimes mais sustentáveis, daí a importância do seu estudo, especialmente em relação aos processos de produção. A literatura mostra que embora tenham sido realizados vários estudos que examinam as variáveis que intervêm nos processos de inovação no setor agrícola, faltam estudos que examinem os processos de inovação na Colômbia. É por isso que o objetivo fundamental desta pesquisa é desenvolver um modelo que explique os principais fatores que estão relacionados à inovação de processos no setor agrícola, utilizando conceitos derivados de modelos de processos de inovação organizacional desenvolvidos na literatura. A metodologia de identificação de fatores utilizou uma amostra de 1.190 Unidades de Produção Agropecuária (UPA) coletadas na Pesquisa Agropecuária Nacional, incorporando apenas produtores do departamento de Cundinamarca, Colômbia. Com esta amostra, e utilizando para análise as variáveis desenvolvidas na literatura, foi realizada uma análise fatorial de componentes principais, bem como uma análise fatorial confirmatória de segunda ordem. A análise fatorial mostra três fatores latentes, entre eles "Inovação em Matérias-Primas", "Inovação em culturas" e "Inovação na gestão de Fatores Externos", que, sendo os mais significativos para o processo de inovação de processos, devem ser considerados como parte fundamental das políticas públicas do governo para facilitar sua adoção na agricultura colombiana no futuro.

Palavras-chave: pesquisa agrícola; desenvolvimento agrícola; análise de fatores; inovação científica; produção agrícola.

JEL: O30; O13; O31; Q16; Q55.

Introduction

Innovation is a very important factor in helping organizations make the transition to environmental and financial sustainability, so much so that it has received considerable attention from regulators, regulators, academics, and policymakers.

In the agricultural industry, innovation often is considered an extremely critical part in the transition of organizations to sustainability. Bedeau et al. (2021) have identified technological innovation as one of the main critical levers (the other components are coherent policies and investments, multiparty collaboration, and data and evidence) to approach the challenges facing agricultural systems. Because of clients and market needs, business in the agricultural industry must constantly innovate at the production process stages.

Innovation in production processes is measured by their effectiveness, its speed of development, and its cost (Voss, 1988). Among the measures of effectiveness, it can be included the number of new production processes improvements per year. This process innovations normally result from continuous improvement activities performed by the organization (Bessant & Buckingham, 1993), reflected in measures that can include the number of suggestions per employee, the percentage of implemented suggestions per employee, or the average annual improvement in process parameters such as quality or cost (Chiesa et al., 1996). Another way to interpret it is through the acquisition of smart farm equipment and devices mediated by cyber-physical systems that can enhance farm management and produce valuable data for the usage on the farm and in the supply chain (Giua et al., 2022).

Although in the agricultural sector there are publications regarding which production processes can be innovated (Heyes et al., 2020; Klewitz & Hansen, 2014; Kopytko, 2019; Long & Blok, 2021; Long et al., 2017; Lubell et al., 2011; Marotta et al., 2017; Martin et al., 2021; Orjuela et al., 2021; Meisch & Stark, 2019; Pancino et al., 2019; Patrício & Rieder, 2018; Pilloni et al., 2020; Ponta et al., 2022; Pontieri et al., 2022), none explains how they can be categorized and the relationship of the variables in the Colombian context, especially in the Department of Cundinamarca.

Within the Departmental Development Plan for the period 2020-2023 called "CUNDINAMARCA, REGION THAT PROGRESSES!", the program "Scientific and innovative Cundinamarca" was contemplated within the strategy line "MORE COMPETITIVENESS", which seeks to develop activities to promote a proper generation of knowledge, the adoption of new technologies, innovation and research activities that improves the capabilities of companies and regions, with environments suitable for the provision of services, favoring the increase in productivity (Gobernación de Cundinamarca, 2022). Consequently, the objective of this study is to establish a model based on multivariate statistics that identifies the relationships that allow us to construct the concept of innovation in agricultural production processes at the departmental level, specifically in the Department of Cundinamarca (Colombia).

Theoretical framework or literature review

Production processes in the agricultural sector are a key element for developing competitiveness in the sector as was proposed by Chiesa et al. (1996) in their postulate on the innovation process. According to the Colombian National Agricultural Survey (in Spanish, Encuesta Nacional Agropecuaria or ENA), developed by the Departamento Administrativo Nacional de Estadística (DANE, 2019), innovation process in the agricultural sector includes variables such as soil suitability and preparation or soil resource management, seed or genetic material selection, sowing practice, crop establishment, crop maintenance, irrigation and water management, fertilization, pest, disease and weed management and harvesting, climate monitoring and waste management.

The selection of the seed or genetic material to be planted is in the first stage of agricultural production processes because the success or failure of the process depends on a good selection according to the production requirements, by time, soil, and pests, among others (Angulo, 2017). Currently, in Colombia, there are two seed supply and production systems: traditional and formal. The traditional system consists of the selection of criollo seeds from the previous harvest or with exchanges within the same community; while the formal system is based on the selection and improvement of specific seeds from programs for the development of hybrid or improved seeds Instituto Agropecuario Colombiano (ICA, 2021).

After selecting the seed or genetic material, the soil preparation in agricultural production processes is the key to allow the adequate distribution of the propagation and nutritional elements necessary for planting. This process demands a high energy expenditure and must be carried out according to the type of planting system used, considering aspects such as sustainable and economic production. Currently, there are two ways of preparing soils: the conventional soil preparation system and the conservationist technology system.

Soil preparation, regardless of the methodology, must take into account the following aspects: Soil structure, the arrangement of soil particles, which is modified by tillage so that soil porosity allows good air circulation; Soil aeration, which refers to the amount of air and gas circulation existing in the soil due to its porosity; Compaction, This problem occurs in certain types of soils due to factors such as gravity, rain and high traffic over the sown area. This problem causes the porosity to decrease and consequently the circulation of air in the soil; Organic matter, increases aggregation, improves soil structure, and reduces the negative effects of compaction; Soil moisture is one important factor since it decides whether it is easy to be penetrated when tilling the soil. The soil should not be too wet, as this hinders the displacement of the plowing machines, nor too dry, as this quality makes the soil very hard and difficult to till (Inostroza & Méndez, s.f.; Vallejo et al., 2018).

Thus, the use of one or the other seed supply system also varies between the type or size of production, with the formal system being preferred by industries, while the traditional system is maintained among farmers both because of the familiarity of the process already used and the lack of resources and information (Herrera et al., 2002).

Once the seed and the soil are prepared, the fertilization in agricultural production is one of the parts that has the greatest impact on the yield of a crop because it helps to have a better-conditioned soil for the product that is planted. Likewise, fertilization affects water efficiency in agriculture, since a crop with more nutritious roots also has a greater capacity to extract water from its surroundings (Martínez, 2020). In the case of Colombia, technical fertilization in different forms (with low potassium, without boron, with additional calcium), and traditional fertilization have been used (Gordillo et al., 2004). In addition, in recent years, biofertilization and its effects on chili bell pepper crops have been experimented with and used as a complement to other fertilization methods with promising results (Rodríguez et al., 2010).

When planting crops, several factors should be considered that will indicate the success of the crop. To begin with, the spatial arrangements and planting density for the plantation must be considered. For this, the altitude and thickness of the plant product must be known to determine its planting location. On the other hand, the variety, quality, and origin of the seed must be considered to identify the best conditions for it.

Once the crop is established, factors that influence planting should be taken into account, such as identification of water bodies that will keep the roots of the crop in contact with water for proper hydration (Vallejo, 2013); tillage systems according to the land and the crops bordering it (Gómez et al., 2018); fertilizer used that satisfies the nutrients demanded by the plant during its germination and development process; as well as a pest control plan according to the crop and its ecology. The success of the above-mentioned will determine the amount of harvest as well as the economic and sustainability indexes of the crop.

During the productive periods of a crop, it is necessary to consider how it will provide the desired results at the end. Therefore, crop maintenance is fundamental (Alcívar & Mutre, 2015). For this, the requirements must be considered, for example: irrigation systems, weeding; harvesting of plant products; selection of defective crops and elimination; and management of crop biodiversity and its bacterial microbiota (Jarvis et al., 2010).

Farmers must approach these processes responsibly and sustainably. Purely manual work does not optimize harvesting, usability, and time utilization. Therefore, automation processes implemented in these parts of the process will reduce execution times, optimize processes, reduce costs, and incorporate the farmer into the technology contributing to market optimization and improved competition (Franco, 2018).

Pests in agricultural production are the main challenge to product utility and food security. Without timely pest management in crops, production yields decrease along with crop sustainability (Melgar et al., 2014). For this reason, several safer and ecosystem-friendly methods have been developed to combat them. Some examples are biological control (Medina, 2019), the use of pheromones, genetic modification, and precision technologies, among others (Sandoval et al., 2022).

In recent years, the methods have been unified to optimize the management of agricultural production by integrating electronic, telecommunication, and computer technologies specialized in the needs of the crop, called precision technologies in crop management (Leiva, 2003). For this purpose, several factors are considered that can alter pest cycles, such as heat waves, humidity percentage, human intervention in biological cycles, host transmission, and organism migration, among others.

Likewise, the progress of agricultural practices is related to climatic factors. These determine the productive results of the crop in terms of leaf area, stem, mass, roots, fruits, and flowers. For this reason, climate change can have consequences that will change crop production. For example, it has been found that with the El Niño and La Niña phenomena, cob crops in the Atlantic increase their productivity in flowering and fruiting compared to other seasons during the year (Ruíz y Pabón, 2013). Therefore, it is important to carry out monitoring to determine changes in productivity versus climatic changes to provide crops with the most favorable conditions.

It should be noted that with good monitoring it is possible to evaluate in what periods the climatic continuity was lost, which as a consequence generates outbreaks of plant diseases, pests, crop damage due to drought or fire, excess humidity favoring the growth of decomposer fungi, changes in soil pH and salinity, erosion and/or soil fragmentation that do not allow crop compaction (Petzoldt & Seaman, 2005).

In all process agricultural residues are materials from livestock, forestry, and agriculture activities that have no economic value or are not used for their initial purpose (Alvarez et al., 2018). These residues are also called biomass and are currently used for multiple purposes, to take advantage of them and therefore increase the profitability of agricultural processes. Among its applications, we can mention: Composting, biofuels, animal feed, and bio ferments. These supply the functions of chemical fertilizers, highly harmful to the soil, fossil fuels, developed from non-renewable resources, and compounds that allow a biochemical route in fermentation processes capable of producing natural and better-quality metabolites without affecting human or animal health (Coronado & Valencia,2014).

Additionally**,** water management is fundamental in the biological cycle of crops. It provides energy and allows plant germination. For this purpose, there are different irrigation systems: drip, sprinkling, pumping, and gravity. Good irrigation management avoids contamination of water bodies, excessive consumption costs, and optimization of the energy used. Likewise, inadequate water uses results in soil erosion, waterlogging that leads to epidemics, and waterlogging that leads to changes in pH and salinity, among others.

The automation and advancement of irrigation systems imply changing intensive systems for more efficient systems that unfortunately imply higher energy consumption and therefore high operating costs (Sánchez et al., 2006). For this reason, irrigation technologies that improve the distribution of water and fertilizer are being developed and applied to improve the utilization of the plant product (Díaz et al., 2008).

Finally, harvesting is one of the last stages of agricultural processes and one in which more technological development has been produced and accepted. In the case of Colombia, the methods used range from manual methods for fruit selection to the use of vibrators and machine vision for harvesting. In addition, with the support of precision technology and data analysis, an improvement in fruit harvesting has been occurring, decreasing the possibility of crop loss by harvesting unripe or very ripe fruit (Mora y Soto, 2018). Currently one of the most widely used methods is that of vibration harvesting, in which approximately 90% of the fruits of a tree or shrub can be harvested. Such a device despite needing one to two operators and one to two pickers facilitates manual labor and decreases average harvesting times (Oliveros et al., 2005).

Methodology

Geographic area of study

The department of Cundinamarca, Colombia, was the one chosen for this research. This area is in the central part of Colombia, in the Andean area. According to the ENA, this Department has a population of 11,157 UPAs. Cundinamarca produces 20.2% of the tropical fruits exported by Colombia, representing 1.4% of total exports of the Department. Proximity to Bogota and climate diversity facilitates Cundinamarca to produce a wide variety of fruits and vegetables.

Characteristics of the population and sample

The target population in this study included the 11,157 UPAs (Agricultural Productive Units) belonging to the Department of Cundinamarca from which a sample of 1,190 was taken. Over the last decade, agricultural systems and producers in the Department of Cundinamarca have been influenced by the impacts on process innovation and the application of technology 4.0. Therefore, in this research, the population included farmers dedicated to a wide variety of crops, with different land ownership and land sizes, to increase generalizability of the results to various types of Colombian farmers.

Research instrument, data collection, and quantitative methods

A structured questionnaire was developed for data collection. It used the selected variables: soil suitability and preparation (also known as soil resource management), genetic material selection, fertilization, planting and crop practice, crop maintenance, water management, pest, disease and weed management, harvesting, climate monitoring, and residue management. The questionnaire consisted of 10 items, rated on a five-point Likert-type scale (where 1 means completely disagree and 5 means completely agree), that was previously approved by a group of experts in the area, that included two mechatronic engineers who are experts in 4.0 technologies, two industrial engineers who are experts in processes and agribusiness, an economist who is an expert in business innovation and an expert administrator in agro-chains, all with a master's or doctorate degree in the area and experience in the object of study. The reliability of the instrument was tested by employing the total item correlation coefficients. Based on the test, items with correlation coefficients below 0.5 were not used in the final data set (Chatterjee, 2021; Hair et al., 2010; Sharma, S. 1996).

The phenomenon of innovation in the agricultural sector is a complex issue. For that reason, a methodology that could identify the dimensions of complexity was used. The methodology categorized sub-indicators as more abstract factors, also called dimensions, allowing to identify the factor structure, using the IBM SPSS software. For this phase, Principal component factor analysis (PCFA) was used. The study applied the VARIMAX form of rotation, due to correlation between factors and dimensions (Kalantari, 2018). Importantly, while interpreting factors may involve some degree of subjectivity, Principal Component Analysis remains a valuable tool for exploring underlying patterns in data and reducing the dimensionality of complex datasets.

The research used two Kaiser-Meyer-Olkin (KMO) indicators and Bartlett's sphericity to evaluate the suitability of the data for the factor analysis, being KMO an important criterion for evaluating adequacy of the data, and the Statistic value should be greater than 0.7 in an adequate data set (Nunnally & Bernstein,1994). Bartlett's test ensured that the correlation matrix was not zero in the population, given that for factor analysis is an important assumption (Habibpour & Safari, 2012).

Results

The main objective of this research was to stablish the main factors associated with the innovation process in the agricultural sector related to the ENA. Based on the information in this section, the 9 concepts listed below were chosen (Table 1).

Table 1

Concepts extracted from the ENA

Concepts extracted from the ENA
Soil suitability and preparation or soil resource management
Fertilization
Pest, disease, and weed management
Residue management
Crop maintenance
Climate monitoring
Planting practice and crop establishment
Harvesting and harvesting
Irrigation and water management
Seed or genetic material selection

Source: own elaboration

Factorial structure of the scale

A KMO value of 0.8351 (Table 2) means that the used data sed have an adequate correlation between the variables and the use of the PCFA is justified according to the literature (Howard, 2016). Likewise, the significance (sig.) of 0.002 indicates that Bartlett's test of sphericity rejects the null hypothesis showing statistical evidence to affirm that the variables are correlated in the population (Howard, 2016).

Table 2

Estimation, KMO and Bartlett's statistics.

Factors Identified	KMO	Sig.
3	0.8351	0.002

Source: own elaboration

Table 3 shows the results of the principal component factor analysis (PCA) for the unrotated and rotated factors (Kaiser, 1960). The eigenvalues are a measure of the variance in the data that is explained by each factor. In general, eigenvalues greater than 1 indicate that the factor is significant and can explain a substantial amount of the variance.

Table 3

Extracted latent variables, eigenvalues, and percentage of variance explained.

	Unrotated factors			Rotated factors		
Factors / Latent Variable	eValue	Percentage of variance explained	% accumulated	eValue	Percentage of variance explained	% accumulated
factor 1	3.4569	32.65%	32.66%	3.1842	31.84%	31.84%
factor 2	2.8745	29.15%	61.81%	2.2905	22.90%	54.74%
factor 3	1.2702	14.20%	76.02%	2.1269	21.26%	76.01%

Source: own elaboration

In the table, three factors have eigenvalues greater than 1 and explain 76.02% of the variance. Factor 1 has the highest eigenvalue, thus being the most important factor in explaining the variance. Together, factors 1 and 2 explain more than 60% of the variance, suggesting their importance in explaining the data (Mansoorfar, 2018; Kaiser, 1960).

Rotated factors are often used to simplify the factor structure and make the factors more interpretable. In this case, Varimax rotation was used, which seeks to maximize the variance of the squares of the factor loadings. After rotation, the first three factors explain 76.017% of the total variance in the data. The percentages of variance explained for each factor are similar to those of the unrotated factors, but the factor loadings are different.

Table 4 shows the results of the factor analysis, which identified that each item or indicator loaded on one of the three factors. The factor loading values represent the correlation between each item and the corresponding factor and provide information about the underlying dimensions or constructs being assessed.

In factor 1, the items "waste management", "seed selection", "fertilization" and "harvesting" have factor loadings of 0.8933, 0.8521, 0.8940, and 0.8269 respectively. These items are related to the efficiency of farming practices to maximize crop yield and minimize waste, which could reflect the efficiency of farming practices to reduce costs and increase profitability.

In factor 3, the items "soil suitability", "sowing", "crop maintenance" and "irrigation and management" have high factor loadings of 0.8824, 0.8805, 0.8797, and 0.8658 respectively. These items are related to the agricultural production process and could reflect the effectiveness of agricultural practices in maintaining healthy and productive soil. This suggests that these items are strongly associated with the first factor which was named IMP.

In factor 2 labeled CI, the items "pests", "climate monitoring" and residue management have factor loadings of 0.8354 0.8887, and 0.8933 respectively. These items are strongly related to risk management and could reflect the effectiveness of agricultural practices to control crop pests and diseases and to adapt to changing climatic conditions.

Table 4

Factor loadings.

	Factor 1	**Factor 2**	**Factor 3**
Soil adaptation	0.8824		
Sowing	0.8805		
Crop maintenance	0.8797		
Irrigation and management	0.8658		
Pests		0.8354	
Climate monitoring		0.8887	
Residue management		0.8933	
Seed selection			0.8521
Fertilization			0.8940
Harvesting			0.8269

Source: own elaboration

Table 5 contains information related to the loading factors, significance levels, and fit indices of the scale measurement models. It also presents composite reliability measures, an analysis of the average variance extracted, and Cronbach's alpha coefficient.

Factor loading values are quite high, indicating a good relationship between the observed variables and the underlying factors. The composite reliability coefficients and Cronbach's alpha coefficient exceed the minimum values recognized by the literature, suggesting good validity consistency and internal reliability of the scale.

Table 5

Convergent validity and reliability analysis.

	Factor 1	Factor 2	Factor 3	Composite reliability index	Analysis of the average variance extracted	Cronbach's Alpha
Soil adaptation	0.8824					
Sowing	0.8805					
Crop maintenance	0.8797			0.8000	0.7694	0.9012
Irrigation and management	0.8658					
Pests		0.8354				
Climate monitoring		0.8887		0.7498	0.7364	0.8219
Residue management		0.8933				
Seed selection			0.8521			
Fertilization			0.8940	0.7498	0.7619	0.8432
Harvesting			0.8269			
Cronbach's Alpha	0.9012	0.8219	0.8432			

Source: own elaboration

When assessing internal consistency, the composite reliability must be greater than 0.7, and the average variance extracted must be greater than 0.5. However, several studies (Shyu et al., 2013; Cheung & Wang, 2017) have established that values greater than 0.4 are also appropriate. Thus, it is straightforward to conclude that all dimensions have adequate convergent validity considering the data shown in Table 5.

In addition, adequacy indices were used to assess the quality of the scale, as shown in Table 6. Overall, the results showed that the Goodness of Fit Index (GFI) and the Adjusted Goodness of

Fit (AGFI) exceeded the desired value of 0.9 (GFI = 0.961; AGFI = 0.917). In addition, the Normalized Fit Index (NFI) and the Comparative Fit Index (CFI) also showed an acceptable level (0.921 and 0.911 respectively), which theoretically should be higher than 0.9. Therefore, these results indicate the adequacy of the fit between the data and the proposed model.

Table 6

Scale goodness-of-fit index

Index	**RMSEA**	**AGFI**	**GFI**	**NFI**	**CFI**	**χ2/df**	**χ2**	**Df**
Value	0.061	0.917	0.961	0.921	0.918	2.301	418.62	182

Source: own elaboration

In addition, it can be noted that the root mean squared error (RMSEA) of the developed scale was 0.061, which is an acceptable value in the literature being less than 0.08. It was also identified that the Chi-square (χ2) value normalized by the degree of freedom (df) was 2.301, less than the required value of 3.

Conclusions

The development and validation of this scale revealed three latent factors: Innovation in Raw Material (IMP), Innovation in Exogenous Factors (IFE), and Innovation in Crop (IC). Results showed that the three latent factors found can explain innovation in production processes in the era of Agriculture 4.0. These three factors need to be considered in future agriculture programs to facilitate technology acquisition and training for farmers. Innovation in Raw Material (IMP) and Innovation in Exogenous Factors (IFE) were the strongest determinants in the scale of innovation in production processes in the agricultural sector.

The dimension of innovations in Raw Materials is composed of selection of seed or genetic material, fertilization, harvesting, and harvesting, which are variables observed with the greatest impact on the process innovation model in the agricultural sector of Cundinamarca, Colombia.

Likewise, innovation in exogenous factors such as pest management, climate monitoring, and waste management are agricultural processes for which the search for cooperation between different type of government agencies to establish adequate predictive systems is fundamental, given the fact that previous insufficient investments in meteorological information, entomology and environmental sustainability by the government and the private sector have a high impact. Meteorological organizations often lack coordination with program planning, and not provide accurate meteorological forecasts to farmers, being both barriers in the policy dimension (Valizadeh et al., 2021).

Crop innovation, according to this research has components such as soil suitability and preparation, planting practice and crop establishment and crop maintenance, as well as irrigation and water management. Precision agriculture uses a variety of sensors to be implemented in fields, plants, crops and equipment. Therefore, the lack of professional sensors is an obstacle to detailed agricultural monitoring, especially in plant phenotyping biosensors. To tackle this problem, is needed to design and develop high quality and reliable agricultural sensors for sensing agricultural production environments and plant physiological signs.

Governmental entities need to develop a scale of innovation applicable to agricultural production processes that would allow them to focus their efforts, given the need to have reliable instruments in the field of innovation for the agricultural sector worldwide. Different actors in the agricultural sector, including not only farmers, government entities, technical assistance entities, among others, need precise information on the variables that influence innovation in agricultural production processes to make the right decisions. Despite that, in several cases, actors don’t have access to the rights tools and, therefore, may make incorrect decisions in which representative capital is wasted. Furthermore, the wrong policies may be adopted since the level of influence of the factors in this area is not known.

The limitations of this study include that the Likert-type scale, which was used in the instrument of this research, despite having the great advantage of allowing multivariate analysis to be carried out, has the limitation of not being able to capture opinions or experiences specific to farmers, which were not addressed in this study. Future studies for the region or country could address the topic of innovation from a mixed perspective, in order to explore in depth, the factors found in this study in terms of opinions and experiences that enrich the research results.

Continuing with the limitations of the statistical analysis used, despites it is clear that the KMO and Bartlett tests are useful to evaluate the suitability of the data in the factor analysis, these tests, similar to other multivariate analysis techniques, have as one of their assumptions the linearity and normality of the data, an assumption that can be fulfilled within the sample, but that does not necessarily reflect the reality of many study phenomena. This conclusion implies that the study, when using an analysis technique that is based on this assumption, may not present the same results at the population level. Future analyzes with different and larger samples could help to validate the capacity of generalization of this study.

Lastly, a limitation of the study is related with the specificity of the geographical area covered by the analysis. The geography of the country covers a wide range of diverse regions that favors the emergence not only of diverse types of crops but also of diverse practices by farmers, who live in different socioeconomic conditions and who in turn coexist with multiple ecosystems and face multiple challenges caused by climate change depending on their location (Fajardo, 2009; Andrade et al., 2018). This is important because the aforementioned diversity and heterogeneity makes any exercise of generalization of the findings of this study problematic, which is why it is necessary to carry out similar studies in other regions of the country to understand if there are patterns that are repeated in other territories, or if the geographical and socioeconomic differences of the productive units in different regions leads to different results.

Ethical considerations

The present research did not require ethical endorsement because it was based on governmental documents.

Conflict of interest

The authors declare that there is no conflict of interest related to the article.

Authors' contribution statement

Carlos Alberto Almanza Junco: Conceptualization, Methodology, Software, Validation, Formal analysis, Research, Data curation, Writing - Original draft, Visualization, Acquisition of funds. Yenny Katherine Parra Acosta: Formal Analysis, Research, Resources, Writing - Original Draft, Supervision, Project Management, Funding Acquisition.

Mauricio Sabogal Salamanca: Research, Writing - Original Draft, Writing: Review and Editing, Visualization, Supervision.

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