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Agronomy research co-authorship networks in agricultural innovation systems

Redes de coautoría en investigación sobre agronomía en sistemas de innovación agrícola

Efrén Romero-Riaño [1], Cesar Darío Guerrero-Santander [2], Hugo Ernesto Martínez-Ardila [3]

[1] Innotec, Doctorado en Ingeniería, Universidad Autónoma de Bucaramanga, Colombia. Orcid: 0000-0002-3627-9942. Email: eromero21@unab.edu.co
[2] Grupo Tecnologías de Información, Dirección de Investigaciones, Universidad Autónoma de Bucaramanga, Colombia. Orcid: [a] 0000-0002-3286-6226. Email: cguerrer@unab.edu.co
[3] Innotec, , Escuela de Estudios Industriales y Empresariales, Universidad Industrial de Santander, Colombia. Orcid: 0000-0001-6893-0819. Email: hemarti@uis.edu.co

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Abstract

Increasingly, Agricultural Innovation Systems, AIS, have been recognized as fundamentals pathways for agricultural science impact. This new thinking focuses on innovation, not as the end of pipe outcome of knowledge transfer, but as a continuous process of social, technical and scientific collaboration at regional and higherlevel systems that impacts on productivity and innovation performance. This paper surveys the agricultural innovation system in Colombia. We analyze collaboration between authors, institutions and countries from the perspective of social network analysis to introduce a descriptive review of the scientific collaboration in terms of links (discipline structure) and nodes (actors). A mixed methodology is implemented based on co-authorship bibliometric mapping using VOS VIEWER and social network analysis based on the software UCINET. Whereas exogenous authors and institutions are the most connected in terms of interaction, they have lower influence than endogenous authors.

Keywords: agricultural innovation systems; collaboration; social network analysis; bibliometrics; coauthorship; scientific visualization; VOS viewer; UCINET.

Resumen

Cada vez más, los Sistemas de Innovación Agrícola, SIA, han sido reconocidos como vías fundamentales para el impacto de la ciencia agrícola. Este nuevo pensamiento se centra en la innovación, no como el resultado final de la transferencia de conocimientos, sino como un proceso continuo de colaboración social, técnica y científica en los sistemas regionales y de nivel superior que repercute en la productividad y el rendimiento de la innovación. En el presente documento se examinan los documentos de agronomía de Colombia como una rama de todo el sistema de innovación agrícola. Analizaremos la colaboración entre autores, instituciones y países desde la perspectiva del análisis de las redes sociales para introducir las principales características de los vínculos (estructura de la disciplina) y los nodos (actores). Se implementa una metodología mixta basada en la visualización de redes de co-autoría con Vos viewer y el análisis de redes sociales basado en el software UCINET. Si bien los autores e instituciones exógenas son los más conectados en términos de interacción, tienen una menor influencia que los autores endógenos.

Palabras clave: sistemas de innovación agrícola; colaboración; análisis de redes sociales; bibliometría; coautoría; visualización científica; VOS viewer; UCINET.

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1. Introduction

The promotion of Agricultural Innovation Systems, AIS, in Colombia, is relatively recent and its implication comes from the Ministry of Agriculture and Rural Development and from the main agricultural research and extension center in Colombia, the Agricultural Research Corporation, AGROSAVIA. Colombia is in the intermediate levels of ranking of innovation as the world economic forum [1], however the lack of agricultural innovation is much deeper. This AIS promotion is implemented under the assumption that the innovation systems, IS, correspond to an adequate pathway to increase the productivity, agricultural innovation [2] and social inclusion.

Agricultural innovation requires effective interaction between AIS actors, including scientist [3], [4]. Understanding features of interaction within the collaboration networks and their implications for agricultural innovation related policy outcomes, helps as guidance for intervention into operational needs of practitioners [5], [6] and policymakers. In that sense, Colombian government and Ministry of Agriculture and Social Development promulgated the Law 1876 of 2017, for the promotion of interaction and articulation [7] between actors from three main IS domains: extension, education and research and development, R&D, within the context of the economic and social reinsertion of actors in the armed conflict, following the peace process that ended in 2016.

The research interest in agricultural innovation systems has been positioned as a strategy for the study from a sectoral perspective of phenomena such as collaboration in innovation and its impact on problems related to climate change. While patent networks are used as tool for innovation systems representation [8] [9] and the empirical evidence suggests that patents provide a fairly good, although not perfect, measure of industry and firm production of knowledge at national [10], regional [11] and institutional [12] level of analysis, increasingly, researchers have embarked on efforts to demonstrate the utility of scientific research and bibliometric data for mapping collaborations network and evaluate the innovation process performance.

Some efforts for measure innovative activity in innovation systems, were based on interviews or surveys at the firm level, but a considerable number of inquiries used bibliometric tools [13] to explore the organization's network structure and thereby, explaining differences in performance. This approach allows include a wider spectrum of actors involved in knowledge production including universities and research centres [14] and measure firms knowledge base. In addition, it improves a weakness of patent analysis which may reflect industry or firm-based activity but not amend the variety of innovation activity within an innovation system.

At the national level, [15] implements a collaborative analysis based on scientific articles. At regional level [16] uses joint scientific publications as outcome for measure matching of regional innovation systems and this same measure is used to discuss on strengthening the innovation system after Germany reunification [17]. For sectoral systems, collaborative network analysis as a practical way to analyse the tourism industry [18]. This evidence reveals the importance of measuring collaboration as it reflects the existence of links between different actors such as companies and universities, because the most effective actions are collective, and it is useful understand the structures and identify actors based on bibliometric information.

The utility of scientific research mapping and collaboration analyses is implemented for evaluation of innovative performance at the regional level because poor innovative performance may be the result of a lack of communication and cooperation between national or regional innovation system institutions [19]. This lack of communication affects collaboration performance leading to an insufficient flow of knowledge and technology between actors of innovation systems.

Accordingly at the national level, [10] measure innovative performance by using total and joint science and technology papers indicators together with joint patents. This joint production reflects effective interaction and trust as key factor of innovation system performance.

The adoption of this analytical approach is particularly useful and interesting for innovation policymakers and practitioners, especially in countries with emerging economies such as Colombia, where innovative activity in sectors such as agriculture cannot be seen through patent analysis and where programs and projects that promote innovation have horizons of between two and four years. The use of bibliometric information and the social network analysis contributes to the sense of making the actors visible but also the structural flaws of the system associated with the links.

Thus, while the patent networks are used as innovation systems representation, we propose in this paper a model of agricultural innovation systems as agronomy scientific publications networks.

Although an agricultural innovation system is not only how many papers are published in a certain field and the number of publications it is only a branch of the whole innovation system, we analyze this side of the Colombian AIS.

Because the model of science measured by bibliometric information has been consolidated thanks to the availability of free and subscription-based access to data, it is argued that modeling and analysis of the innovative performance of innovation systems constitutes a conceptual and methodological alternative to trap the great variety of innovative activity that cannot be captured by the most popular approaches such as the use of patents and sampling within companies. This is an academic contribution, by the need to identify and investigate key actors and structure features for solving systemic failures in innovation systems at the regional and national level.

Our primary aim in this study, is investigate the features of collaboration patterns within co-authorship networks, power and interaction effectiveness, using bibliometric data as input. This article addresses the question of "what are the features of scientific collaboration social-networks in the Colombian AIS?". As strategy to characterize scientific collaboration among actors in Colombia's agricultural innovation system, a social network analysis based on scientific articles published in WOS Clarivate was performed. This article consists of four components: introduction, theoretical framework, methodology, results, discussion and conclusions.

2. Theoretical framework

The main approaches for improving agricultural innovation, includes pathways as technology supply push, farmer-driven innovation, participatory development, induced innovation and innovation systems [20]. Innovation systems approach, rests on the premise that understanding the linkages among the actors involved in innovation process, is a key factor for innovation performance [21]. A substantial amount of theory, have been developed to addresses innovation systems approach application at country [22]–[24], region [25]–[27] and sectorial level [28]–[30], including agricultural.

2.1. Agricultural Innovation Systems AIS

Innovation systems are networks of agents interacting in complex and dynamics context [31] based on social relations. The preference of an innovation systems approach for enhancing articulation and collaboration, is based on its inclusiveness and the interaction of actors to co-influence each other to innovate and to bring social and economic benefits [32]. Agricultural innovation is the outcome of complex linkages between agents by mean of collaboration activities and projects [33] through brokering [34], networking [32], [35], and mediation [36]. Adapting social context of country and regional level to the knowledge based on agricultural innovation systems, is fundamental for its effective implementation.

Agricultural innovation systems models, includes multiple stakeholders [37] and domains [38], [39] such as financial, technical, environmental, and research and development. The research and development domain is determinant for AIS performance [40], productivity [41], building a participatory approach to development[42], the evolution of farm systems [43] and co-creation of knowledge [44] by mean of stakeholders interactions.

2.2. Social Network Analysis SNA

A different theory approach for IS performance analysis, includes frameworks as resource based view [45] transaction costs [46] social network analysis and bibliometrics [4]. The IS changes emerge from process-oriented investment in interaction and shared learning between stakeholders. The social network analysis, SNA, interprets the influence of social links and interactions. Nowadays, social network researchers are increasingly interested in analyzing large networks using primary and secondary data gathered from scientific databases [47].

Interaction of stakeholders within the AIS domains such as R&D and industry [48] and R&D and extension [49] at the system level, are key factors for the evolution of the system [50]. The social capital is a valuable asset based on interpersonal interactions to facilitate collaboration between AIS stakeholders [51]. The low levels of implementation of the AIS approach in emerging economy countries such as Colombia goes hand in hand with low levels of documentation of stakeholder interaction. For this reason, understanding the dynamics of scientific collaboration networks through bibliometric analysis is an adequate way to characterize the evolution and trends at the structure of the collaboration network, as well as to generate strategies to improve innovation outputs.

The co-authorship of papers between authors, institutions, or countries, reflects collaboration [52] links at individual and network level [53]. In that sense, co-authorship network maps show the collaborative social network of research fields based on the assumption that within a network, co-authorship ties are bidirectional between authors [46].

Network maps have different shapes such as clique, diffuse and core periphery, which have consequences [54] related to the generation of innovation outcomes. Clique structure foster radical innovation, diffuse structure promotes incremental innovation and core-periphery networks enhance efficient coordination and dissemination of information, e.g. best practices [55].

The measures at the whole-network level of analysis, such as the density of ties and the degree of clustering shows collaboration capacity in the network. Density is the number of ties in the network, expressed as a proportion of the number possible [56]. The number of ties and node position measures such as centrality shows patterns in collaboration links and may help to explain differences in performance of innovation. Centrality is a property of a node's position in a network [54], and there are many different ways in which a node can be important to a structure e.g. being able to control the flow of information [57] or power.

The big four measures in centrality are degree, closeness, betweenness and eigenvector. A node has high eigenvector score to the extent it is connected to many nodes who themselves have high scores [58]. The centrality is closely linked to power because power is a function of having multiple connections or potential trading partners [54]. To identify the nodes with greater centrality, power or influence in a network, helps to facilitate the articulation of actors in agricultural innovation systems in an efficient way because these nodes are usually in the shortest connection routes between groups or individuals of a system.

Brokering is one of the most important roles in AIS [34], [59], [60]. Intermediation or brokering is measured in network analysis by men of betweenness centrality. It is a measure of how often a given node falls along the shortest path between two other nodes [55]. In AIS R&D domain, is expected that universities play a critical role in brokering process for continuous improvement on agricultural innovation and economics performance [61] and therefore it is expected their central position and high betweenness in collaboration networks. The closeness is the sum of distances from node to all others and it serves as an index of efficiency because it is interpreted as time-until- arrival of knowledge flowing through network [54].

3. Methodology

A blend of whole network and personal network research design was implemented to explore the collaboration networks of authors, institutions and countries linked in co-authorship of agronomy articles published between 1998 and 2018 in WOS Clarivate. This database was selected because it implements rigorous selection filters for the publication of articles derived from research that reflect new knowledge.

The use of bibliometrics methodologies as research profiling [62] and co-authorship networks to analyse collaboration is a widespread practice within various disciplines [63]–[65].

To extract the collaborative networks features, various algorithms are used such as minimum expansion trees [66], Louvain and Kamada Kawai [67]. Several tools are available to visualize and extract and analyze bibliometric networks and to analyze innovation systems such as Cite Space [68] and VOS viewer [69].

Paying special attention to the graphical representation of co-authorship bibliometric maps, VOS Viewer was used [70] a complemented with social network analysis due to its complementarity. The social network analysis draws on graph theory and mathematical modeling to understand the social structures between stakeholders. SNA aids mapping the innovation system and capturing interaction patterns and overall interactions network structure for understanding implications of relational conditions. Several critical assumptions were made in order to assess collaboration networks using SNA approach with the bibliometric data: 1) relations that affect collaboration performance can be studied by mean of bibliometric techniques, 2) relational conditions and ties between actors adequately capture interaction patterns, 3) network structure adequately capture the patterns of relationships and 4) the articles published in WOS indexed journals in the area of agronomy, reflect the scientific production of Colombia in this area.

The methodology consists of three phases: i) data extraction and debugging, ii) graphic and analytical processing and iii) content analysis and synthesis. The data extraction includes a census of all articles whose geographical link is Colombia, the advanced search option of database was used, based on the expression: CU=Colombia.

A total of 57,360 documents was identified. To obtain the first sample, articles published in indexed journals from WOS database, were selected by Agronomy subject, and this led to a sample of 662 articles. Exclusion criterion of "number greater or equal to four citations of an article", was applied resulting a final sample of 499 articles. Raw metadata full record is extracted from WOS database, for bibliometric mapping and social network analysis.

The raw metadata were processed by means of the VOS VIEWER software to obtain the graphs of the co-authorship networks based on three units of analysis: authors, institutions and countries. For each of the co-authoring analysis types, the respective data set was downloaded in order to purify duplicate records. The final maps were generated in VOS viewer by combining a thesaurus (Eck & Waltman, 2013) for each dataset (author, institutions and countries) and its original metadata set. With the refined data, the processing of the network graphs of authors, institutions and countries is generated (graphs 1, 2 and 3).

The set of nodes within each chart reflects the use of the inclusion criterion of: "nodes with a number greater than or equal to three citations". The visualization overlay of VOS VIEWER was used to observe times evolution of the patterns of collaboration in the networks.

In order to operate the analysis of social networks, the final data sets are exported in Pajek format, to be analyzed with UCINET 6. For each set of data in Pajek format, an adjacency matrix was generated in order to characterize the network structure and the interactions based on the selected measurements of degree, eigenvector, betweenness and closeness.

The three adjacency matrices obtained through the option of importing text data from UCINET, make up the set of input data used for the calculation of the scores shown in Tables 1, 2 and 3. By means of content analysis the synthesis and description of the trends of collaboration in co-authorship within the sample of articles of the study is carried out.

The contrast of these results is complemented with the description of connection with scores of links and citations. Central and influence actors was identified using the degree centrality. As a measure of collaboration, the network density was estimated. Due to its relationship with the power of a node within a network, the frequency of the number of direct links of the nodes is mapped in order to contrast the relationship between the numbers of linkages of the actors with the power measured by the degree of centrality.

4. Results

The overall pattern in number of co-authorship articles in the sample is growing with a hole in 2014 (31 articles) and the most productivity in 2017 (122 articles). The predominant language among the articles in the sample are English (65%) and Spanish (32%). A SNA was performed to understand the interactions and how the various actors co-influenced each other (Table1,2,3) and to identify the 'critical' actors or single node.

The following keys of interpretation are applied in the visualization of the co-authorship network (Figures 1 and 2).

The first one is that the size of the nodes or bubbles within the networks reflects the frequency or number of documents from an author, organization, or country. The second key is that the lines or arcs between nodes represent the existence and intensity of the co-authorial links. The third is that the position of a node (central or peripheral) reflects the power or influence of an author, organization, or country within the network. The fourth key refers to the colours of the nodes.

The Vos viewer clustering algorithm assigns the colours of the nodes based on the estimation of a measure of similarity between them. Therefore, it is possible to conclude that nodes of the same color are strongly related. In that sense, another similarity measure that complements color is the closeness between nodes. The shorter the distance between two nodes, the closer the relationship between them can be inferred.

In the case of overlay visualization (Figure 3), the interpretation is different. In overlay maps, the color of the nodes expresses an attribute of the node, in this case, it reflects the average date of publication. In that sense, the nodes in purple color express countries with tradition in the permanence within the scientific network. The yellow color represents countries that are emerging within the panorama of scientific collaboration.

4.1. Authors Co-authorship network

Figure 1 shows a network of co-authors made up of the 116 most cited authors in the sample. Network typology in Figure 1, corresponds to diffuse type and the proportion of Colombian authors on the network is 40%. The Figure shows Teran (orange cluster) in a central position of the network, despite their low number of connections with respect to other authors such as Beebe (red cluster) or Blair (green cluster). In the upper part of the network of authors we can observe the most influential group of Colombian authors of the network (blue cluster), with a peripheral position within the network for this group of nodes. These characteristics of the positioning indicate in addition like pattern within the scientific network of the area of agronomy, a high interdependence between investigators of Colombia and foreign investigators.

Table1. Top 10 Degree centrality, eigenvector, closeness and betweenness by author

Author	Degree-centrality	Number of links	Eigenvector	Closeness-Centrality	Betweeneess
Beebe	0.060	32	0.051	0.502	18.611
Blair	0.051	30	0.042	0.502	22.278
Ceballos	0.040	18	0.499	0.406	7.061
Rao	0.039	27	0.466	0.493	22.807
Morante	0.031	15	0.033	0.361	1.722
Calle	0.030	14	0.458	0.551	1.314
Tohme	0.029	28	0.044	0.527	30.566
Perez	0.025	11	0.409	0.347	0.735
Fregene	0.023	19	0.085	0.411	8.260
Teran	0.020	7	0.011	0.391	1.479

Table2. Institutions Degree Centrality, Eigenvector, Closeness, Betweeneess

# of links	Institution	Degree Centrality	Eigenvector	Closeness	Betweeneess
63	CIAT	0.150	0.650	0.846	57.946
30	UNAL	0.040	0.305	0.611	17.444
33	ARS	0.039	0.323	0.627	9.464
27	Cornell University	0.030	0.303	0.597	5.490
21	CIMMYT	0.017	0.145	0.566	4.833
8	University Idaho	0.015	0.174	0.517	0.049
13	Chinese acad agr sci	0.012	0.063	0.513	2.633
12	Int crops res inst semi ar	0.011	0.131	0.507	0.523
7	Cirad	0.010	0.148	0.478	0.156
10	AGROSAVIA	0.006	0.047	0.507	0.478

Table3. Countries frequency and degree centrality

Frequence	Country	Degree	Eigenvector	Closeness centrality	Betweeneess
652	Colombia	0.119	0.646	1.000	18.708
321	Estados Unidos	0.058	0.539	0.907	8.783
123	Francia	0.022	0.192	0.765	3.040
109	México	0.02	0.209	0.750	2.339
103	Australia	0.019	0.143	0.765	1.927
104	Alemania	0.019	0.154	0.709	0.471
100	Brazil	0.018	0.187	0.736	1.108
99	Inglaterra	0.018	0.133	0.796	4.446
96	China	0.017	0.136	0.696	0.443

The network density—thus the nodes tied as a proportion of all possible ties in a network (Reed & Hickey, 2016), was 0.131, meaning that only 13% of the possible direct linkages were present. This implies that the interaction of actors is less than quarter of what is expected, indicating a low level of collaborative capacity (Yang, Li, & Shyu, 2009) in the network, since a greater density or number of links would reflect a greater level of collaboration. The power among the actors measured by the degree of centrality identifies ten authors with the higher scores: Beebe (0.060), Blair (0.051), Ceballos (0.040), Rao (0.039), Morante (0.031), Calle (0.030), Tohme (0.29), Perez (0.25), Fregene (0.023) y Teran (0.020) (Tble 1). The foreigner authors had the most influence and are the most connected in the network. These positions of the authors of Table1, indicates authors ability to retain power over information in the network.

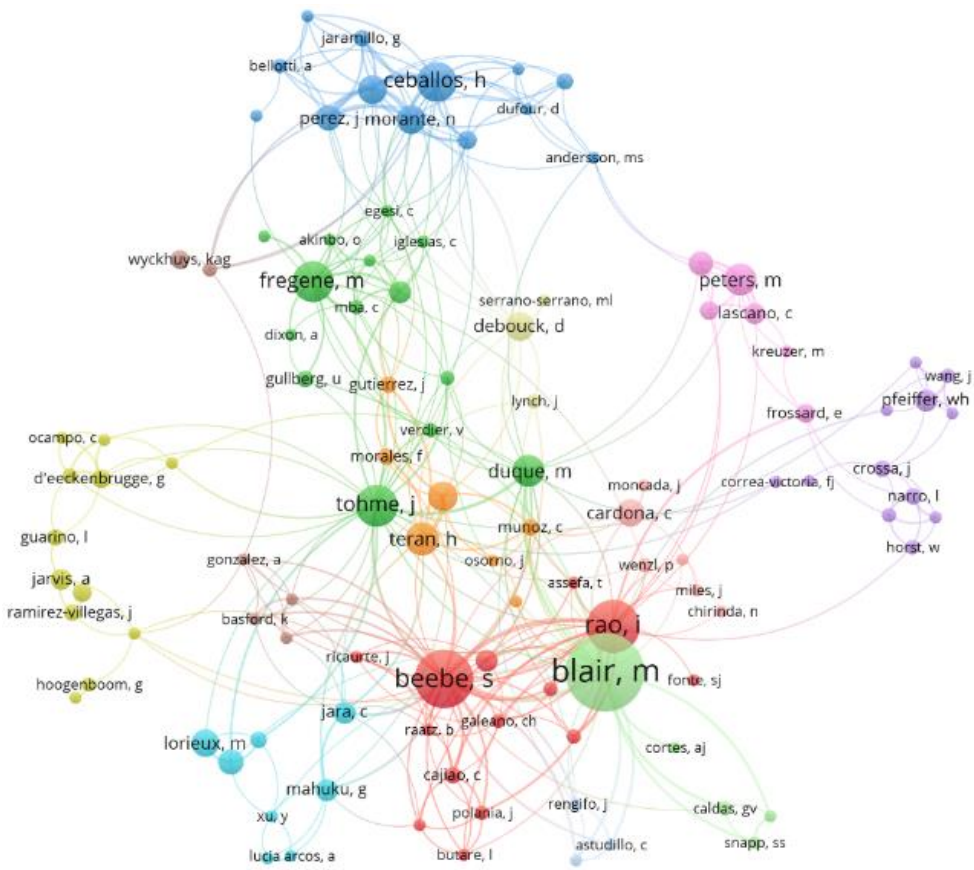

Figure 1. Co-authorship network between authors of Agronomy articles in Colombia.

Beebe is the most influential author in the network, based on the scores of degree of centrality (0.06) and eigenvector (0.051), Eigenvector is often interpreted as status or power, for the amount of ties and the well-connected state of the others nodes which have ties. In that sense, Ceballos (0.499), Rao (0.466), Calle (0.458) y Perez (0.409) are the core, or the dominant coalition in the network.

Based on the closeness scores, Tohme (0.527) and Calle (0.551) and betweenness, Tohme (30.556) are the most important authors. The high value of betweenness centrality for Tohme, indicates a favored position for information acquisition and sharing and coincides with its central position in Figure 1. Betweenness centrality reflects the amount of brokerage each node has between all other nodes in the network [56]. The low scores of peripheral authors indicate lower ability or the difficulty with which they can create links with network actors. Whereas the current peripheral position of main Table1.

Colombian authors in the network, makes them more vulnerable for knowledge sharing and diffusion by more powerful actors in the network. The lower number of links of Colombian authors in the network, may be an indication of the need to improve individual skills to generate bonds of friendship and trust as well as to maintain these links in collaborative networks.

4.2. Institutions Co-authorship network

A total of 80 institutions are included in the co-authorship map of institutions in Figure 2. Figure 2 shows the scientific collaboration network of institutions within the sample articles. Network typology in Figure 2, corresponds to diffuse type and the proportion of Colombian institutions on the network was 19%. Sixty-one percent of the institutions in the network are universities.

The proportion of Colombian universities within this group is 32%, while 68% of universities are foreign. This proportion of university institutions coincides with the universities central role postulated in several related researches, (Agogué et al., 2017; Coenen, 2007; Laurens Klerkx, Schut, et al., 2012) for the mediation of knowledge and technology in agricultural innovation systems.

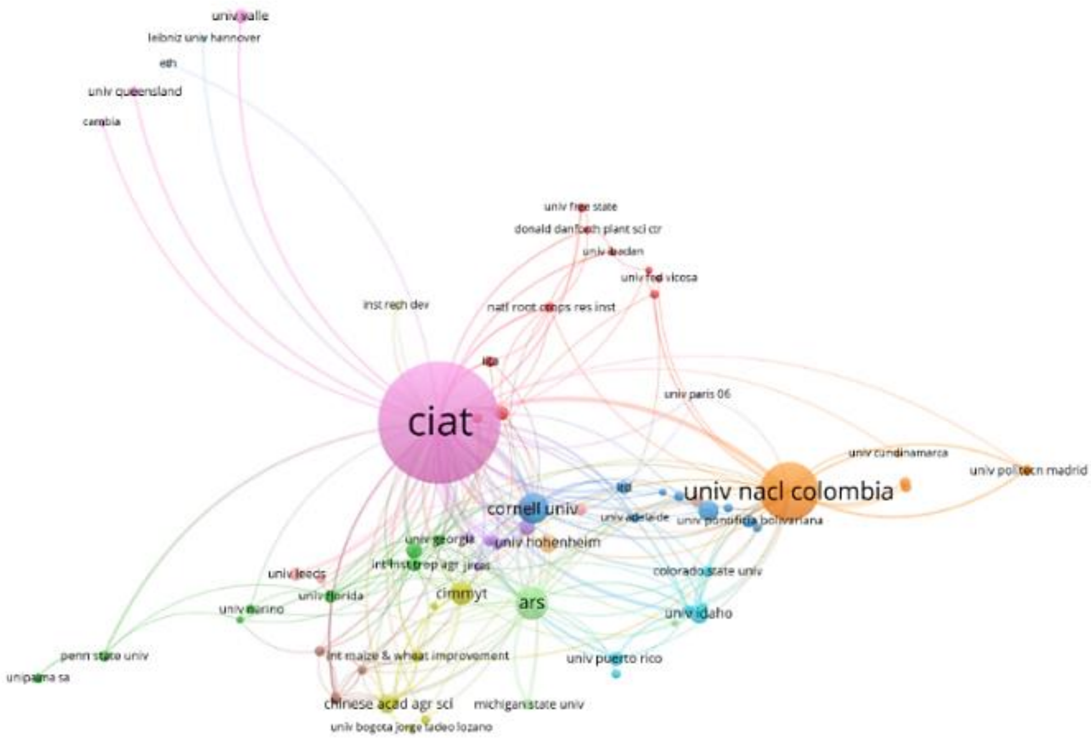

Figure 2. Co-authorship network between institutions of Agronomy articles in Colombia.

The Figure 2 shows CIAT (pink cluster) in a central position of the network, and high number of links (63) with respect to other institutions such as Universidad Nacional de Colombia (30 links) (orange cluster) or Cornell University (27 links) (blue cluster). In the right part of the network of institutions, we can observe the most influential group of Colombian institutions, mainly universities from the regions with the highest regional GDP: Bogota and Antioquia of the network (blue cluster), with a peripheral position within the network for this group of nodes.

The Universidad Nacional de Colombia, UNAL, is the best-connected university with a total of 30 links, followed by the Universidad de Antioquia with 7 links. Even though the Universidad del Valle is in the same region as the author with the most influential institution in the network, CIAT, it has lower levels of links and influence in the network. The lower number of links of Colombian institutions in the network, may be originated by inadequate levels of organizational capacity of universities and agricultural research centers associated with the availability of funds and human talent with high level training that are linked to global knowledge networks.

CIAT had the highest degree of centrality (0.150), eigenvector (0.650), closeness (0.846) and betweenness (57.946) because of its centered role in organizing multi-stakeholder (government partners, national research organizations and universities, non-governmental organizations, civil society, and the many farmers) links with global partners as CGIAR, HarvestPlus, FLAR, CCAFS for maximize health and nutrition benefits in AIS, move smallholder agriculture from subsistence to profit and helps countries strengthen resilience and adaptive capacity to the impacts of climate change.

The eigenvector score of CIAT highlights not only to the extent it is connected to many nodes, but also the other nodes who themselves have high scores too. That high centrality scores reflects a strong influence within this area of agronomy research in Colombia, or better measure of exposure to knowledge flows.

UNAL, the main public university in Colombia, had the second highest degree of centrality and collaboration due to its link with universities (26) and international research centers (4). This high proportion of links to universities shows a high level of homophily within their network.

Previous studies highlight the importance of the interaction of universities as representatives of the scientific domain with extension agents (L Klerkx, Hall, & Leeuwis, 2009; S Morriss et al., 2006) and industry (Fukugawa, 2017; L Klerkx & Aarts, 2013) in agricultural innovation systems. However, the findings show a secondary role of extension agents from

Colombia, such as AGROSAVIA and the absence of links with industry agents. The absence of links with the industry is an indicator that reflects restrictions for the advancement of AIS such as the low heterogeneity of scientific collaboration networks and the low institutional capacity to establish strong bonds of trust with actors of disparate interests within the networks.

4.3. Countries Co-authorship network

An increasing share of scientific papers is co-authored by scientists from two or more nations (Leydesdorff & Wagner, 2008). The Figure 3, shows the 40 most important countries in the collaboration network. The distribution of the geographical origin of the network countries Europe (33%), America (28%), Africa (20%), and Asia (15%). The proportion of non-English speaking countries (more than 68%) within the sample articles, confirms the effect of collaborative networks in increasing co-authorship of scientific articles, on topics such as agronomy.

Colombia had the highest degree of centrality (0.119), eigenvector (0.646), closeness (1.000) and betweeness (18.708) because of its central role in the scope of the study. The overlay visualization of VOS VIEWER shows traditional links with Costa Rica (2006), Switzerland (2007), USA and France (2008) and emerging collaboration links with Chile (2013), Japan (2014), New Zealand and Denmark (2015). As the agricultural innovation system expands, useful innovation can increasingly occur somewhere else; identifying innovations and making them locally available will be a major challenge for policymakers [71] (Leydesdorff & Wagner, 2008).

5. Discussion

We have conceptualized the coauthorship connections as collaborative ties between institutions, authors, and countries as through which knowledge flows are effectuated. We have extracted the datasets from WoS Clarivate, using exclusion criteria by category of agronomic knowledge and by country of origin of the investigations Colombia. This strategy might lead us to exclude important knowledge or influential organizations within the broader AIS.

While the use of other data sources such as the Scopus database, and this may have provided a broad perspective due to the greater volume of publications, there is a limitation that Scopus does not differentiate between agronomy, dairy, or veterinary knowledge categories. Scopus groups all data into one large area of agricultural science.

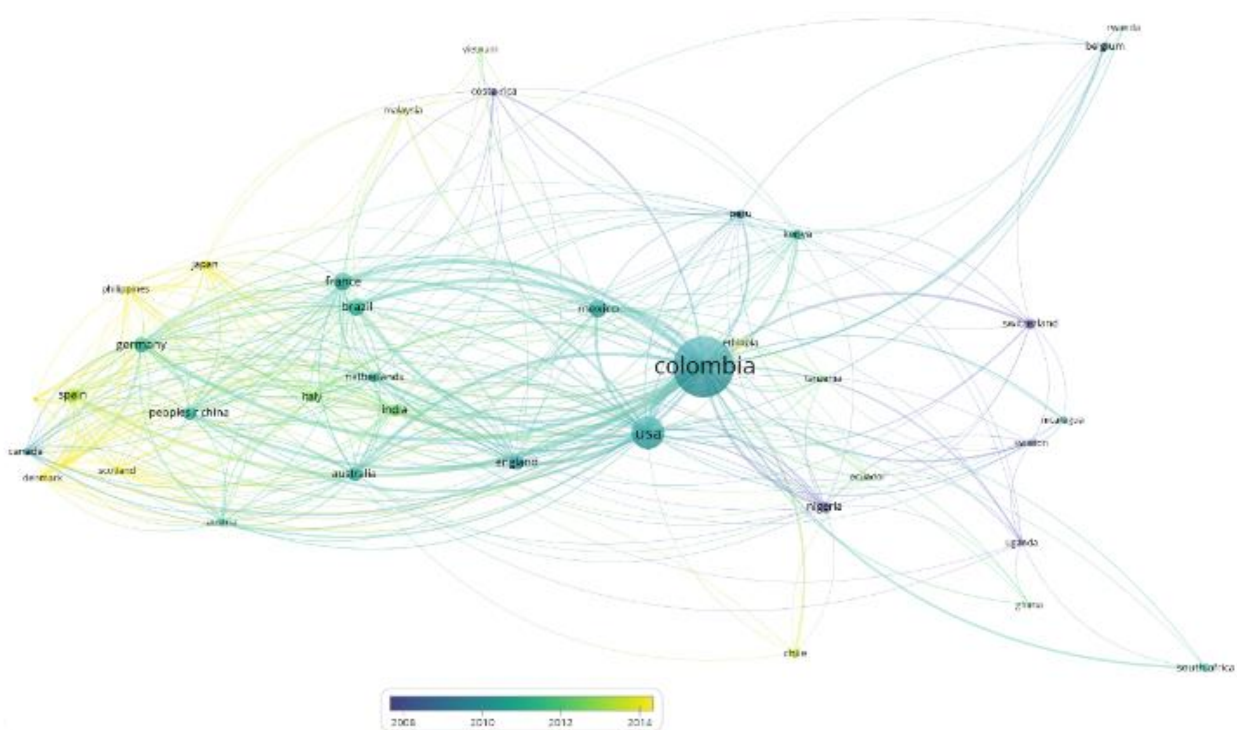

Figure 3. Overlay visualization of co-authorship network between countries of Agronomy articles in Colombia.

Other possible sources of data are open access platforms (google scholar, dimensions) for retrieving bibliometric information metadata. Although these sources offer a significantly higher volume of information, their use often leads to multiple errors associated with gaps within the datasets resulting from the lack of rigorous review processes and the lack of clarity regarding the criteria for indexing documents.

The use of co-authorship information as a representation of collaboration is a widespread and accepted method in different areas of study [72], [73]. However, several authors argue that due to multiple factors such as power relations, friendship ties or coherence to be included as an author in scientific works, co-authorship does not represent the existence of collaboration [74]. Despite these divergences, the use of this type of analysis allows the verification of indicators to map the flows of knowledge and the performance of the three main functions of innovation systems.

The use of co-authoring information as a representation of collaboration is a widespread and accepted method in different areas of study. However, several authors argue that due to multiple factors such as power relations, friendship ties or coherence to be included as an author in scientific works, co-authorship does not represent the existence of collaboration. Despite these divergences, the use of this type of analysis allows the verification of indicators to map the flows of knowledge and the performance of the three main functions of innovation systems.

The "Betweenness centrality" indicator made it possible to identify actors with high potential to play the role of intermediaries of scientific knowledge in agronomy. The authors and institutions with high scores in this indicator can be categorized as "rock stars" within the agricultural innovation system. These organizations and researchers have additional attributes such as high closeness and connections with highly central nodes and connectivity within the network.

The analysis of the "Eigenfactor" indicator allowed us to establish which nodes are better connected based on the criteria of which have better "friends". Based on these analysis results, a potential for improvement in the management of linkages was identified, especially within the state and sectorial agricultural research centers in Colombia. The estimated scores favor organizations and authors linked to institutions belonging to global research networks; however, the most important state center in agricultural research in Colombia, Agrosavia, reflects scores that put it on a par with the best-connected organizations within the network. This result highlights why the volume of knowledge production and the number of links of this research and transfer center, present levels below the average of the top organizations within the network.

Although within the Colombian economic scheme agricultural production has been losing relevance within the gross domestic product, the existence of state agricultural research organizations and the promotion of sectoral research centers such as coffee, oil palm, sugar cane, and cocoa, would presage the existence of strengths in local scientific research communities. However, the results of the SNA calculations (especially for the influential organizations) do not suggest this.

On the contrary, we conclude that more influential organizations base their strength on their external links and networks. Although the Colombian agricultural innovation system has initially gained visibility thanks to the presence and strength of supranational agricultural research organizations, this has not been enough to ensure that these collaborative links radiate to local and regional organizations. Only national organizations such as the National University of Colombia have strengthened their presence as a key actor in the system

6. Conclusions

In this paper, we have drawn on bibliometric data relating to 449 journal articles listed in the WoS Clarivate and the co-authorship methods of the VOSviewer bibliometric software to examine the network features of Colombian Agronomy research. The co-authorship network visualization and social network analysis enabled us to explore the structure of the science system of agronomy research in Colombia. Moreover, this allowed us to verify the existence, intensity, and characteristics of the centrality of the most influential authors and organizations within the networks of scientific co-authorship.

The articles in the selected sample, were written by authors from 73 countries. The authors from Colombia were dominant in the literature. In the recent period, both the USA and Colombia had leading positions, although France increased its position significantly. New Zealand, Denmark and Finland were absent in the early until 2012 but had noticeable presence in the recent period. A propensity is identified to collaborate with countries of America, USA, Brazil and Mexico over Europe and Asia

Author co-authorship analysis finally allowed the identification of invisible colleges, the Figures that connected one sub-network, and one phase of the agricultural innovation system with another. Surprisingly it picked out the scholars with institutional affiliations in global research centers located in Colombia (Beebe, Blair, Rao) and to a lesser extent, provide researchers with links to national research centers and universities (Ceballos, Perez). No presence of regional actors is observed. The analysis also highlighted the dominance of Anglo-American scholars.

The number and kinds of actors in the collaboration network, represents diversity of interests mainly centered on research and development and extension domains of the AIS. The apparent lack of connection between authors and institutions in the network, represented in the low network density levels, potentially inhibited the collaboration for playing essential innovation system roles such as innovation intermediation or brokerage. Identified as a potential area of growth for scientific collaboration in Colombia, the building of individual skills for authors and the development of organizational capacities focused on the roles and functions of collaborative networks.

National and international research centers play a central role within the Colombian AIS collaborative network. The universities are more recipients of technologies and services rather than determinants. The specialization of public or private universities in agricultural issues can be a driving force for universities to play a leading role in the development of agricultural knowledge in Colombia. The study finally is restricted under the choice of publications and data sets extracted from WoS Clarivate and for the delimitation to an area of knowledge, agronomy. Although this allowed to identify in more detail individual and structural characteristics of a part of the agricultural innovation system of Colombia, it is suggested for future research the adoption of a regional approach, for example of administrative regions (in Colombia, departments) for the delimitation of the system, analysis, and extraction of the data sets.

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