Analysis of the structure of the global avocado (*Persea americana* Mill) trade network

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ABSTRACT
Objective: To analyze the structure of the global avocado trade network and to understand the dynamics of commercial interaction between the leading countries in the market, using the social network analysis approach.
Design/Methodology/Approach: One-hundred thirty-three countries that established 989 commercial exchange relationships were analyzed. This exchange accounted for 99% of the volume of the global avocado market for the year 2021.
Results: The significant diversification in the import sources and export destinations of countries such as Netherlands and Spain suggests a robust and diversified trade strategy. Network indicators give a valuable insight into the centrality and importance of countries in the global avocado trade network. Mexico plays an important role in the network that goes beyond the quantity produced.
Study Limitations/Implications: The most current analyzed data available to date belong to the year 2021.
Findings/Conclusions: The analysis reveals the complex dynamics of interaction between the leaders of the global avocado trade.

Keywords: global trade network, avocado export, eigenvector, Social Network Analysis, agricultural markets.

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INTRODUCTION

Mexico is the main avocado producer and exporter. The current value of the "green gold" global market exceeds $18 billion dollars, distributed between the Americas (59%), Europe (22%), and Asia (11%) (Rabobank, 2023). Considered a superfood, avocado is recognized for its contribution of vitamins, minerals, and monounsaturated fats (Bhuyan *et al.*, 2019). International avocado trade mainly takes place between the United States and Mexico in the context of the United States-Mexico-Canada Agreement (USMCA). In this scenario, Mexico has an outstanding capacity to produce avocado throughout the year, as a consequence of the 226,534 hectares planted in the state of Michoacán. The decrease in production during June and July is complemented by Peru. The preference for Mexican avocado over other US suppliers plays a relevant role in this dynamic (Williams and Hanselka, 2022).

This intense commercial activity and the relationships between avocado-producing and -consuming countries can be analyzed through a Social Network Analysis (SNA).

SNA has emerged as a fundamental tool for deciphering social and structural phenomena in various disciplines. This approach provides a unique perspective to understand the structure and interactions of the global avocado trade network, identifying key actors, trade flows, and patterns of influence (Wasserman and Faust, 1994). In the context of agricultural markets, international trade networks take shape as manifestations of a complex combination of diverse underlying factors, both natural and social (Shutters and Muneepeerakul, 2012). The SNA has helped to unravel this complexity in various contexts, addressing everything from the corn trade (Aguirre-López *et al.*, 2021; Wu and Guclu, 2012, 2013) to the impact of aflatoxins in the pistachio trade (Bui-Klimke *et al.*, 2014), raw materials networks (Nobi *et al.*, 2020), textile value chains (Shepherd, 2017), and global electricity network (Ji *et al.*, 2016), among other fields of study.

Considering the worldwide importance of avocado, this study aims to analyze the structure of the global avocado trade network through the SNA approach, to understand the dynamics of commercial interaction between the leading countries in the market.

MATERIALS AND METHODS

The predominant avocado exporters and importers during the year 2021 were selected. The countries were identified through the ISO3 code (https://www.fao.org/faostat/es/#definitions), composed of three alphanumeric characters (for example, Mexico's ISO3 code is MEX). Countries with less than one ton (t) in exchanges were not considered. The information used comes from the FAOSTAT avocado trade database (2023). One-hundred thirty-three countries that established 989 commercial exchange relationships were analyzed; those nations accounted for 99% of the volume of the global avocado market for the year 2021.

The data collected was organized and structured in Microsoft® Excel. An asymmetric matrix was developed to establish relationships between importing and exporting countries based on their exchange volumes. Subsequently, Gephi software version 0.10.1 was used to develop a graphic representation of the structure of the global avocado trade network and to calculate its indicators. Color attributes were assigned to countries on the same continent to visualize interactions between continents. Similarly, the size of the nodes (countries) in the network and the thickness of their links (trade relations) were characterized through the exchange volume (tons).

Different social network indicators were used to analyze the dynamics of global avocado trade. A graphic representation of the indicators was developed using the DataWrapper software. These indicators help to understand the structure and interactions in the trade network, as well as to identify the key actors and their influence on the global avocado exchange (Table 1).

RESULTS AND DISCUSSION

Avocado producers and exporters

The global avocado market during 2021 amounted to 3,202,009 t, out of which 3,200,812 t were analyzed, with a value of $8.407 billion dollars. The leading producers

Table 1. SNA indicators employed.

Indicator	Definition	Interpretation in avocado trade
Network size	Total nodes.	Total number of countries that participate in the commercialization of avocado.
Number of links	Relationship between network nodes.	Trade relations established between countries.
Degree	Links of a node.	Commercial relations that a country has, there is no difference between export or import.
Out Degree	Outbound links from a node.	Countries to which a country exports avocado. Breadth of commercial relationships.
In Degree	Inbound links of a node.	Countries from which a country imports avocado. Supply dependency.
Eigenvector centrality (Nodes)	Relative importance of a node in the network.	Influence of a country considering both its direct connections and the position of the countries with which it is related.
PageRank Distribution (Network)	Importance of a node based on its position and connections.	Relevance of a country considering both the quantity and quality of its network connections.

are Mexico (MEX), Colombia (COL), Peru (PER), Dominican Republic (DOM) and Chile (CHL). Most of these countries are also major exporters. Mexico is the largest producer and exporter of avocado, with 2,442,945 t produced on 226,534 hectares, with an average yield of 10.8 $t \bullet ha^{-1}$.

Some producing countries do not appear as exporters, since they allocate their production to domestic consumption. These countries include Indonesia (IDN) with 669,260 t, Brazil (BRA) with 300,894 t, and Haiti (HTI) with 248,135 t.

Figure 1 highlights the exporting countries based on their exportation volumes. Mexico exported 1,405,117 t to 44 countries, which represents 44% of the global market. The USA imported 77% of Mexico's production —1,085,353 t of the said volume (with a value greater than $2.858 billion dollars)—, followed by Canada (CAN) and Japan (JPN) with 103,449 t (7.4%) and 64,473 t (4.6%), respectively.

The second exporter (PER), with 18% of the world supply, exported 569,458 t to 45 countries, mainly to the Netherlands (NLD), ESP, USA, CHL, and the United Kingdom (GBR). The third exporter (NLD) supplied 11% of the world demand, exporting 337,156 t to 41 destinations; for this purpose, it imported 457,136 t from 33 nations. This situation makes this European nation the most important country in the structure of the global avocado trade network, given the commercial size of its interaction, combined with the number of countries with which it exchanges avocado (*i.e.*, its interconnectivity in the grid). The fourth place (ESP) covered 4% of the global market (50 countries); for this purpose, it exported 133,377 t to 28 nations. It imported 213,908 t to which it added its own production (116,770 t), which positioned it as the main European producer.

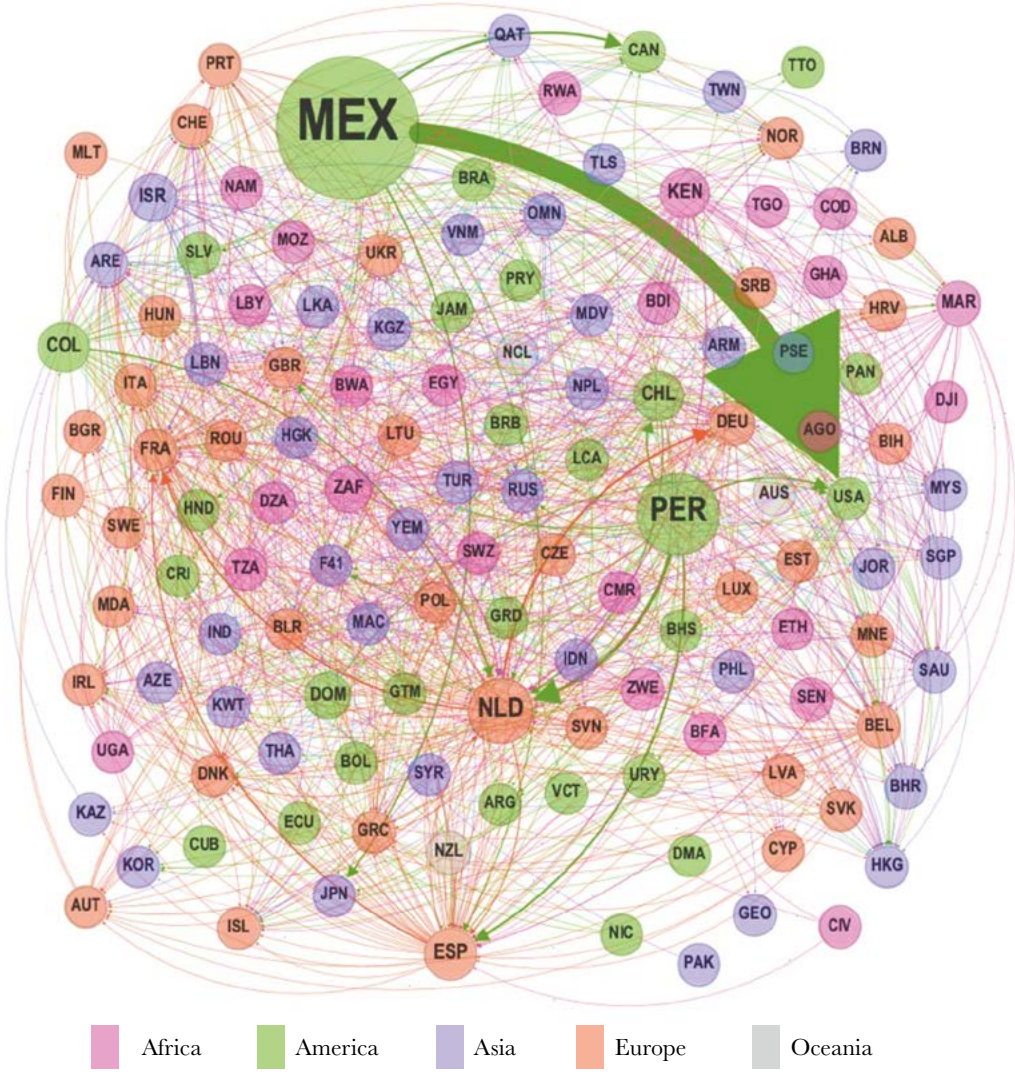

Figure 1. Global Network of Avocado Exporters (2021).
Note: The size of the node and its relationships is a function of the exported t.

Avocado import destinations

The main buyer of avocado is the USA with 1,213,412 t, which represents 38% of the world production ($3.13 billion dollars). It imports avocado from 5 countries and exports this produce to 23 countries, among them the Republic of Korea (KOR), JPN, and Singapore (SGP), with 2,017, 1,242, and 809 t, respectively.

The European Union —made up of 27 countries with great commercial connectivity— is the second destination for avocado exports in the world. The EU members include NLD and ESP, the second and third importers, respectively. France holds the fourth position, with 181,288 t purchased from 32 countries; however, it exports 19,293 t to 30 international destinations (Figure 2).

Finally, Chile is the country whose imports have the highest growth rate, increasing from 1,000 t in 2012 to 59,000 t in 2022 (Rabobank, 2023). Together with the USA, Chile

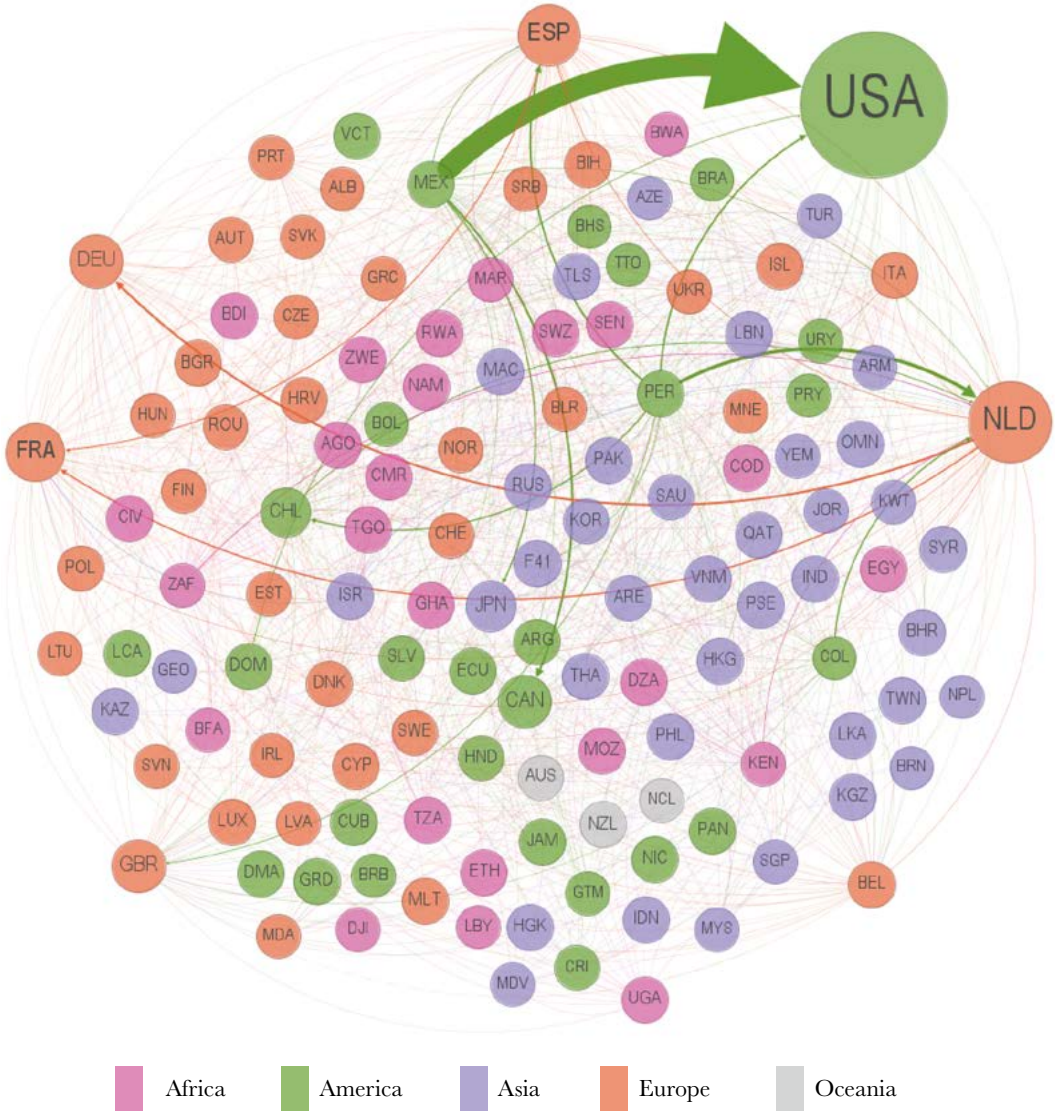

Figure 2. Global network of avocado importers (2021).
Note: The size of the node is a function of the imported t: likewise, the thickness of its relations is proportional to the quantity (t) exported and imported between two nodes.

is the only American country whose exports do not only consists of its own production. CHL imports from 5 countries and exports 104,347 t to 33 destinations.

The structures of the global avocado export and import networks prove the dominance of MEX as the main exporter and the USA as the main importer. However, these structures minimize the role of the European Union as an importer, as its destinations are spread among the 27 countries that make up this unique economic bloc.

Avocado intermediary countries

Setting aside the traded volumes, Figure 3 emphasizes which countries have greater international connectivity, measured by their degree as an SNA variable that adds the

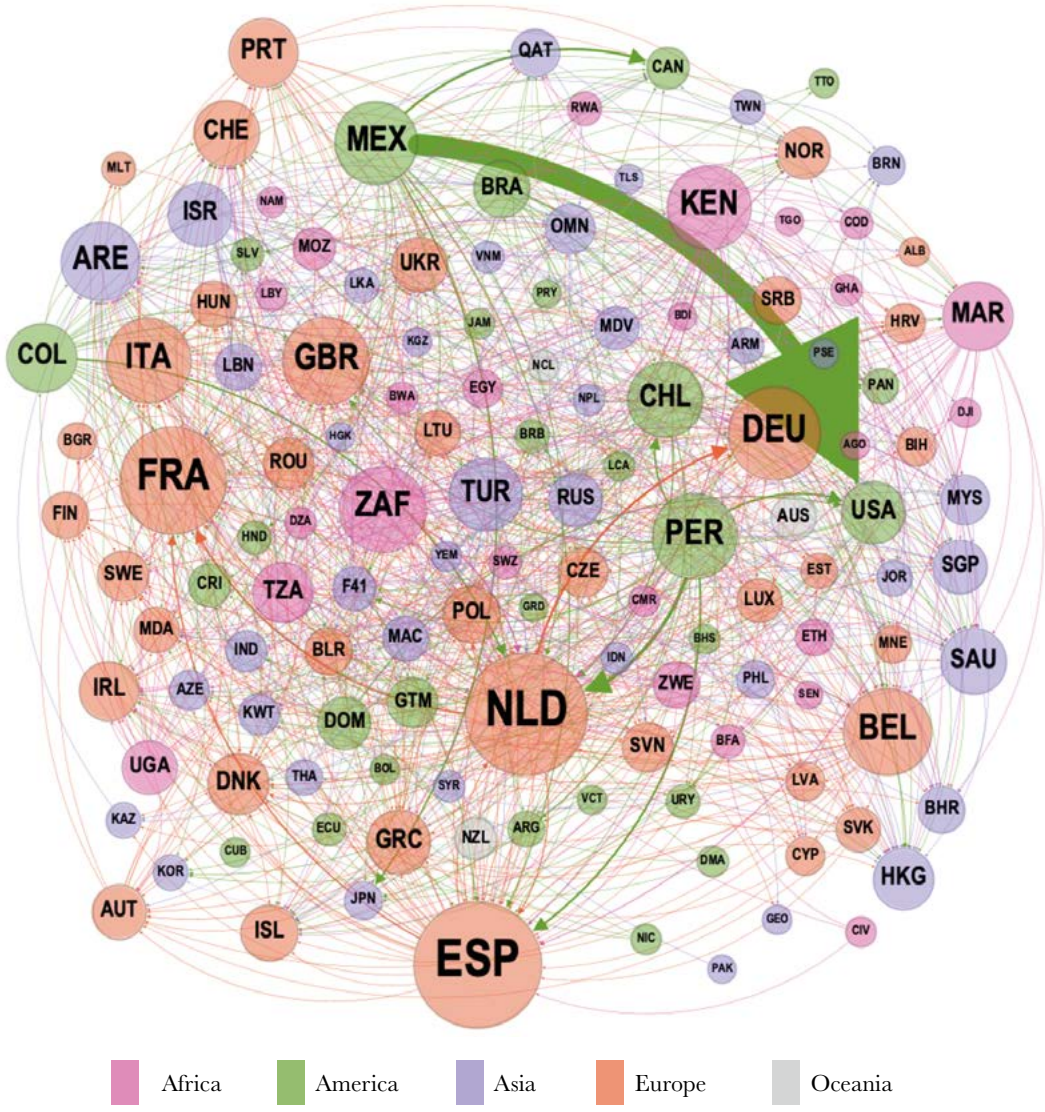

Figure 3. Avocado Global Connectivity Network (2021).
Note: The size of the node is a function of its degree (*i.e.*, the sum of the number of imports and exports).

entries (imports) and exits (exports) of a given country, highlighting the international intermediaries, which import not only for consumption, but also for exportation purposes.

Figure 3 show that European countries play a major role as international commercial intermediaries that increase the reach of avocado destinations in the world, as is the case of ESP, NLD, FRA, DEU, and BEL, which exchange avocado with 78, 74, 62, 51 and 47 countries, respectively. GBR is a lesser commercial intermediary which imports from 36 countries and exports to 11, despite not producing avocados.

Although they are not large producers, they have an intense commercial activity in the global avocado market. They are key suppliers for the same European countries, importing mainly from American and African countries. This reflects their economic and logistical capacity to supply the European Union.

Figure 4 shows the role of ESP as one of the main distributors in Europe, resulting from its intense commercial activity as an intermediary. It imports from 28 countries (entry level) distributed in the 5 continents, including PER, MEX, NLD, Morocco (MAR), COL, Kenya (KEN), and CHL. It exports to 50 countries (exit level), particularly to NLD, with which it has an intense commercial interaction, since they supply avocados to each other. In Figure 4, the countries located to the left of ESP are its 28 suppliers, while those located to its right are its 50 destinations.

It seems to be a pattern that most exporters are low-income countries and that exports represent an important share of their GDP, while importing countries (especially commercial intermediaries) have a better economic development, as confirmed by their GDP.

Indicators of the global avocado network

Figure 5 shows a detailed view of the position and importance of different countries in the global avocado trade network. Network indicators provide valuable information about the structure and dynamics of this network, which helps to understand trade interactions between countries in the avocado market.

Therefore, although ESP has a higher exit level and is the main supplier of the European Union, the role of NLD as a major supplier stands out, as a result of its commercial relations with other countries that also play an important role in the avocado trade.

The PageRank indicator evaluates the importance of a country based on the quantity and quality of links it receives from other countries. On the one hand, NLD has the highest PageRank value (0.08) —*i.e.*, it receives a high number of links from other countries with high centrality in the network—, as a result of its role as an important distribution center

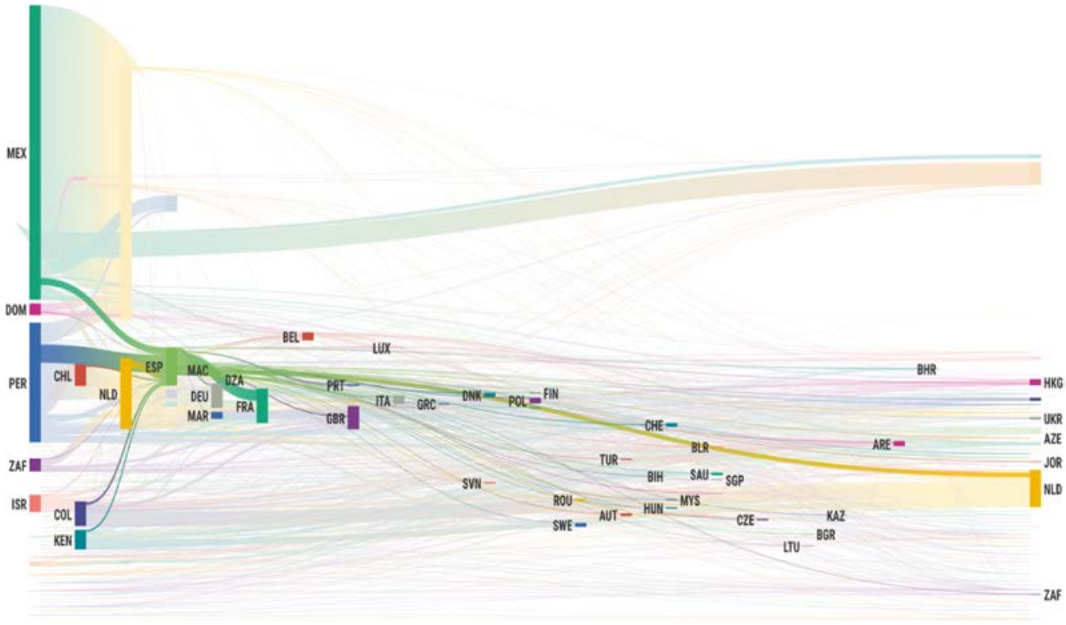

Figure 4. Spain as the main international intermediary in the avocado trade. Note: For more information, please consult the interactive graph: https://tinyurl.com/Sanky-Aguacate.

Country	Production (t)	Exports (t)	Imports (t)	Out-Degree	In-Degree	PageRank	Eigenvector
NLD	0	337,156	457,136	41	33	0.08	1.00
FRA	1,100	19,293	181,288	30	32	0.06	0.96
ESP	116,770	133,377	213,908	50	28	0.04	0.93
GBR	0	523	114,272	11	36	0.03	0.89
DEU	0	37,577	121,647	26	25	0.04	0.86
ITA	0	2,542	41,654	24	21	0.03	0.73
BEL	0	15,980	39,277	23	24	0.02	0.59
ARE	0	2,814	23,667	9	31	0.02	0.42
USA	136,750	8,817	1,213,412	23	5	0.01	0.01
COL	979,618	116,796	395	32	1	0.00	0.00
KEN	416,803	94,016	143	43	1	0.00	0.00
DOM	634,368	55,735	0	20	0	0.00	0.00
IDN	669,260	210	0	3	0	0.00	0.00
PER	777,096	569,458	0	45	0	0.00	0.00
MEX	2,442,945	1,405,117	0	44	0	0.00	0.00

Figure 5. Top 5 leading countries in avocado production, exports, imports, and network indicators (2021).

in Europe. On the other hand, MEX, the largest producer and exporter of avocado, nevertheless has a low PageRank value, which suggests that its position in the network is not based solely on the volume of its avocado production and exportation. This situation is explained by the proximity of MEX to the USA, to which it exports 77% of its production.

The Eigenvector indicator evaluates the importance of a country, taking into consideration the importance of the countries with which it is connected. NLD (1.0) is the most important country in the Global Avocado Network, followed by FRA (0.96) and ESP (0.93). These values indicate their connections to important countries on the network, which are related to their role as important avocado exporters. MEX, despite its high production, has a relatively low Eigenvector value, which suggests that its importance in the network may be influenced by other factors beyond its avocado production, such as its export concentration focused on the USA.

CONCLUSIONS

The analysis of the structure of the global avocado trade network has provided a detailed understanding of the dynamics of commercial interaction between the leading countries in this market. Network indicators (*e.g.*, exit level, entry level, PageRank, and Eigenvector) have revealed crucial aspects about the centrality and importance of countries in this network. Countries like NLD and ESP stand out for the diversification of both their import sources and export destinations, suggesting a robust trade strategy.

MEX and the USA are the most important countries in the global avocado trade network, in relation to their exchanged volumes. However, based on their connectivity, the most important countries are found in Europe: NLD, FRA, and ESP.

Meanwhile, the importance of Mexico in the network, despite being the largest producer and exporter of avocado, goes beyond the quantity it produces.

This study lays the foundation for future research about seasonal supply, productivity, and price fluctuations in different destinations, as well as for the identification of the attractive growth rate of its imports.

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