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Cluster Analysis of Agricultural Input Imports in Colombia: An Approach Based on International Economics and Trade Agreements

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Abstract

This study analyzes geoeconomic patterns in Colombian imports of agricultural inputs by applying the k-means algorithm to the CIF value and gross weight complemented by an analysis of trade agreements and tariffs. The results show high dependence on a few suppliers such as Russia and the US for fertilizers and China for technology, even without preferential agreements; On the other hand, the limited effectiveness of FTAs was analysed, where tariff reduction did not generate diversification of critical suppliers; opportunities for diversification with medium-sized suppliers such as Brazil in animal feed; and the relevance of the European Union in veterinary medicines, agricultural technology, fertilizers, and seeds. The methodology integrates data from DIAN (2005-2024) and five-year analyses, showing that competitiveness in prices and logistics outweighs tariff advantages, China dominates 65% of the CIF value in technology and Russia and the United States consistently accounted for over 60% of the CIF value and gross weight of fertilizers. Regulatory, trade, and innovation policies are proposed to reduce the risk of input shortages in agri-food value chains.

Keywords

Agribusiness, agricultural policy, rural development, cluster analysis, agricultural trade, import.

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Introduction

The Colombian agricultural sector is one of the most dynamic sectors of the economy because it generates more than 80% of the food consumed by the Colombian people. According to the figures of the National Administrative Department of Statistics DANE for the first semester of 2024 presented a growth of 5.5% higher than that of 2023 (DANE, 2024). This sector is composed of primary production activities in agriculture, livestock, forestry, fishing and aquaculture (Ministerio de Educación Nacional, 2016). Several factors interact in the production of the agricultural sector, which are the essential elements necessary to produce goods. These factors include land, labor, capital, technology, organization and inputs. Agricultural inputs comprise all the products and resources needed to carry out agricultural and livestock activities, such as fertilizers, pesticides and phytosanitary products, seeds, animal feed, veterinary drugs, equipment and tools, construction materials, biological products, technology and software, and genetic material. These inputs have a direct impact on productivity and competitiveness due to their incidence on production costs, entailing risks that affect the efficiency and profitability of agricultural activity and, therefore, the producer's income (FAO, 2022).

Due to the importance of the agricultural sector and the need to ensure food security, the national government has given importance to agricultural inputs by creating law 2183 of January 6, 2022, which establishes the national system of agricultural inputs, establishes the national policy of agricultural inputs, and creates the fund for access to agricultural inputs. On the other hand, according to the Ministry of Agriculture and Rural Development (MADR), fertilizers represent 55% of the sales of inputs demanded by the agricultural sector, pesticides 27%, veterinary drugs 13% and biological products 5%.

In recent decades, Colombia has promoted its integration into the global economic

and trade landscape. These include free trade zones and common markets. It develops these free trade zones through Free Trade Agreements (FTAs). However, empirical evidence shows that this openness has had mixed impacts. Apparently, openness and trade issues through multilateralism and free trade agreements (FTAs) have provided many positive opportunities to boost the country's economic development. For example, Colombia has maintained good trade relations with the European Union, the Andean Community, Mercosur, and others.

The problems associated with the costs of agricultural inputs can be categorized into three groups: i) the influence of the international market, ii) domestic marketing, and iii) use and application (Ministerio de Agricultura y Desarrollo Rural, 2018). Since this research focuses on the analysis of imports, the influence of the international market will be analyzed in depth, which has a direct impact on the formation of national prices of the main inputs, given that Colombia does not produce the so-called simple fertilizers: Urea, source of Nitrogen, Diammonium Phosphate (DAP) source of Phosphorus and Potassium Chloride (KCL) source of Potassium. In the case of pesticides, active ingredients are the main raw material for their manufacture, and 98% are imported. In Colombia, the local industry primarily relies on imports of active ingredients for the manufacture of pesticides for the domestic market and for export. Veterinary drugs and biological products are industries that also have a significant imported component in their cost structures, since research and development activities are centralized in multinational companies, directly at the level of their parent companies.

Recent research demonstrates that machine learning (ML) methods offer a powerful alternative to conventional techniques for analyzing global trade patterns (Batarseh and Yang, 2017; Batarseh et al., 2019, 2021; Gopinath et al., 2021). These approaches enable the identification of complex patterns in import dynamics that can directly inform public policy formulation.

Studies on Colombia's imports have primarily employed econometric, statistical, and descriptive approaches. Gómez-Sánchez and Salazar-Villano (2014) developed an import demand model using cointegration analysis, while Rangel Vargas et al. (2019) identified Gross Domestic Product and the Real Exchange Rate as key determinants of import behavior. Research on trade agreements has yielded mixed findings: Trochez González et al. (2018) found limited effects of the U.S. FTA on corn prices, whereas Vargas-Chaves (2023) documented significant impacts on seed certification systems that affected crop diversity. These studies collectively highlight internal challenges in logistics infrastructure and technological capacity that constrain Colombia's trade performance (Cruz Negrete, 2018; Piedrahita et al., 2022)

The strategic importance of agricultural inputs is underscored by recent global disruptions.(Quitzow, Balmaceda and Goldthau, 2025) documented how the Ukraine conflict triggered fertilizer price volatility, revealing the vulnerability of import-dependent regions like Latin America. Meanwhile, international standards from Codex Alimentarius, IPPC, and WOAH establish critical frameworks governing inputs from seeds to veterinary products (FAO, 2024; IPPC, 2024).

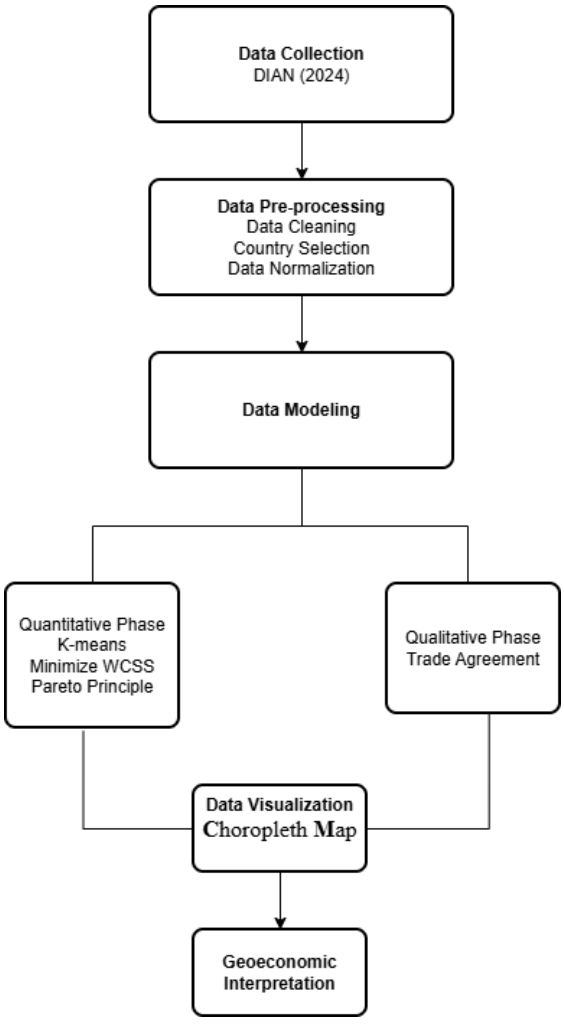
ML techniques have been widely applied across agricultural domains, including yield prediction, disease detection, and resource management (Storm, Baylis and Heckelei, 2020; Benos et al., 2021). In trade analysis specifically, researchers have employed diverse approaches: Batarseh et al. (Batarseh et al., 2019, 2021) used k-means clustering and boosting algorithms for commodity trade forecasting, while Zhang et al. (2025) applied unsupervised learning to analyze China's agricultural import channels. Advanced methods such as LSTM networks (Qin, Wu and Chen, 2025) and ensemble models (Arora, Sarkar and Ponmagal, 2025) have demonstrated superior performance in predicting trade flows and supporting decision-making.

This study aims to analyze geoeconomic patterns in Colombian agricultural input imports through an integrated approach that combines machine learning clustering with trade policy analysis. Specifically, the research seeks to: 1) What are the geoeconomic patterns in Colombian imports of agricultural inputs, considering both value (CIF) and volume (gross weight)?; 2) What factors explain the composition and evolution of these clusters, and how effective are they? ; and 3) How can these patterns inform public policies to reduce strategic vulnerability and promote supplier diversification?

By applying k-means clustering to CIF value and gross weight data from 2005-2024, this research provides a novel methodology for identifying trading partners and patterns that can inform strategic decision-making in agricultural trade policy.

Materials and methods

The present research employs a mixed methodology. The subsequent quantitative phase employs the K-means algorithm to cluster countries according to their import profiles. The results are presented on a choropleth map, a geographical representation of population density. In the subsequent phase, these patterns are interpreted in the context of trade agreements, thereby facilitating the attainment of a comprehensive geoeconomic understanding (see Figure 1).



Source: Prepared by authors

Figure 1: Proposed methodology.

Data collection

The data set under consideration encompasses import data from 2001 to 2024, as provided by the National Directorate of Taxes and Customs (DIAN). DIAN supplies information in accordance with the Harmonized Commodity System, version 2022. Data preparation involves the process of data loading, processing and cleaning. The Pareto principle was used to identify the countries that concentrated on the highest value of imports, thus allowing the analysis to focus on the most relevant actors. Given that this study focuses on agricultural inputs, 4-digit HS tariff headings were considered at the tariff heading level and are shown in Table A1. To generate an analysis in common terms, the tariff headings were grouped into input categories, according to information from technical and specialized documents. The table 1 below relates each category to the tariff items considered in this study.

Tariff item	Category
3101,3102,3103,3104,3105,	Fertilizers
1201,1202,1204,1205,1206,1207,1209	Seeds
2309,1214	Animal feed
3004,3002,2937,8414	Veterinary medicines
8701,8432,8433,8201,8424	Equipment & Tools
8806, 9015,9025, 9026, 8523,4911,9032,8543	Technology and software
3101,3808	Biological products
1209	Genetic material
9406, 7308, 7314	Construction Material

Source: Prepared by authors

Table 1: Tariff item of each category.

For the preparation of data for the descriptive analysis, variables selected are shown in Table 2.

Denotation	Description and Measurement
Tariff item	is a code in the customs tariff schedule that identifies a specific product and determines the duties, taxes, and regulations that apply to it in international trade.
CIF	Agricultural inputs import value of products exchanged between nations. It is expressed in monetary terms, miles US Dollars
Gross Weight	The weight of the goods including packaging, in tons
Origin country	country of origin of the goods, i.e. where they are produced, grown, manufactured, extracted, or processed.
Tariff	Tariff duty according to the customs tariff.
Trade agreement	An agreement code so that the importer receives preferential treatment.

Source: Prepared by authors

Table 2: Variables.

Data pre-processing

Subsequently, data preparation involved a three-stage preprocessing pipeline:

1. Data cleaning: Records with missing or inconsistent values in critical fields e.g., CIF value, gross weight, or country of origin were removed to ensure data integrity.

2. Country selection: To focus the analysis on the most economically significant trading partners, the Pareto principle (80/20 rule) was applied. Countries accounting for the top 80% of the cumulative CIF value of imports for each agricultural input category were selected for the cluster analysis. This step reduces computational complexity while ensuring the analysis captures the dominant patterns that are most relevant for policy formulation.

3. Data normalization: Prior to clustering, the selected variables: CIF value ins USD and Gross Weight in tons were standardized using z-score normalization. This ensures that both variables contribute equally to the distance calculations in the k-means algorithm, preventing the model from being biased by the different scales of the features. The formula for z-score normalization is as follows:

$$\boldsymbol{Z = \frac{X - \mu}{\sigma}} \quad (1)$$

Where X denotes the original value of the feature, Z signifies the standardized value, μ represents the mean of the feature across the dataset, and σ indicates the standard deviation of the feature across the dataset.

Data modeling

The term "Machine Learning" originated from A.L. Samuel in his paper "Some Studies in Machine Learning Using the Game of Checkers" (Samuel, 1959). Machine Learning is defined as deriving patterns learned from data via interpreting the data through unknown inputs. Machine learning is part of artificial intelligence and statistics, and machine learning algorithm processes a sizeable amount of information which for the human brain is a natural occurrence (Samuel, 1959; Simon et al., 2022). ML techniques often encompass four paradigms-descriptive, diagnostic, predictive, and prescriptive and the focus of this study is in the descriptive and predictive domain. Two techniques are used in the descriptive domain: data visualization and data analysis. Data visualization produces graphical images of data or concepts, which helps decision making. Data analytics consists of common statistical techniques, including mean, media, standard deviation, range, stem, and histogram and advanced data mining techniques used to describe hidden patterns in the data (Liu et al., 2023).

To classify countries of origin according to their import characteristics, we applied a non-hierarchical exploratory clustering technique, specifically the K-means algorithm. The classification was based on a two-dimensional feature space comprising the total CIF value (in thousands of USD) and the total gross weight (in tons) for each country. Prior to clustering, a preliminary correlation analysis was performed, revealing that CIF value and Gross Weight are only weakly correlated. This low correlation indicates that each variable contributes distinct information to the clustering process and avoids redundancy in the formation of groups. Therefore, both variables were retained to capture meaningful variation in import patterns. This unsupervised statistical method is effective for segmenting the data into homogeneous groups, allowing the identification of intrinsic patterns and similarities in agricultural input trade flows that are not immediately apparent through descriptive analysis alone. (Batarseh et al., 2021; Zhang et al., 2025). The analysis was conducted in Python.

It is important to clarify that K-means always relies on two complementary steps: (1) assigning each observation to the nearest cluster center using Euclidean distance, and (2) updating each centroid as the mean of all observations assigned to it. Thus, the centroid expression shown in Equation 2 and the Euclidean distance expression in Equation 3 represent two essential components of the same algorithmic process, not separate methodologies.

To determine the optimal number of clusters, we employ the elbow method, which evaluates the relationship between the Within-Cluster Sum of Squares (WCSS) and the number of clusters. As the number of clusters increases, the WCSS decreases; however, beyond a certain point, the rate of improvement becomes marginal. This inflection point or "elbow" is considered the optimal number of clusters. The WCSS is computed as:

$$\boldsymbol{WCSS\,(k) = \sum_{i=1}^{k} \sum_{x \in C_i} |x - \mu_i|^2} \quad (2)$$

Here, k represents the number of clusters, C_i denotes the set of points in cluster, x stands for a data point and μ_i signifies the centroid of cluster i. This centroid formula reflects the updating step of the K-means algorithm.

To formalize the clustering process, let a set of observations $x_1, x_2, \ldots, x_n$, denote Colombia's agricultural import records from different countries. The K-means algorithm partitions

the n observations into k clusters by minimizing the WCSS. Each iteration consists of two steps: (i) assigning each observation to the nearest centroid using Euclidean distance, and (ii) recalculating each centroid as the mean of the points assigned to it.

The assignment step of the K-means algorithm relies on Euclidean distance. For each data point x_p, we compute its Euclidean distance to all centroids and assign it to the nearest one:

$$\boldsymbol{Distance}\left(\boldsymbol{x_i}, \boldsymbol{\mu_j}\right) = \left|\boldsymbol{x_i} - \boldsymbol{\mu_j}\right| = \sqrt{\sum_{\boldsymbol{d=1}}^{\boldsymbol{D}} \left(\boldsymbol{X_{id}} - \boldsymbol{\mu_{jd}}\right)^{\boldsymbol{2}}} \quad (3)$$

Where D is the dimensionality of the data point. This step ensures that each observation is grouped with the most similar centroid in terms of Euclidean proximity.

Data visualization

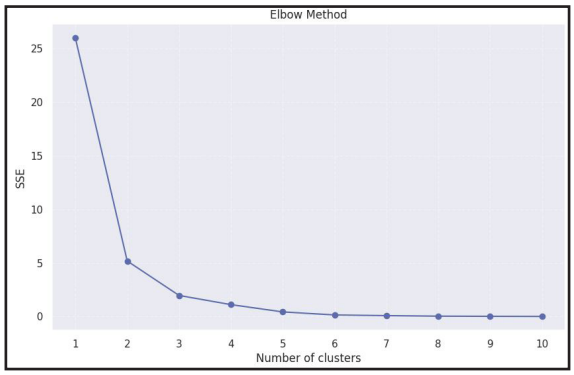
In data visualization, choropleth map used to show the temporal evolution of clusters with their respective tariff labels and trade agreements and CIF dispersion vs. Weight .

Geoconomic interpretation

Cluster analysis is a more advanced statistical technique than traditional descriptive statistics. It involves the grouping of countries according to their strategic import patterns (i.e. high, medium, or low), thus allowing for the identification of critical dependencies and opportunities for diversification. The core value of the model is the integration of quantitative results with qualitative variables, such as trade agreements and tariff rates, thereby facilitating a causal interpretation of patterns. This approach has the capacity to transform trade data into an actionable diagnosis for public policy, revealing not only the identity of the suppliers but also the reasons for their predominance and the means of mitigating strategic risks.

Results and discussion

The application of the k-means algorithm with k = 3, validated using the elbow method (see the Figure 1), reveals a consistent structure in most input categories. The cluster centroids for the fertiliser category in the 2020-2024 period (see the Figure 2) demonstrate a clear separation between groups (see the Table 2).



Source: Prepared by authors

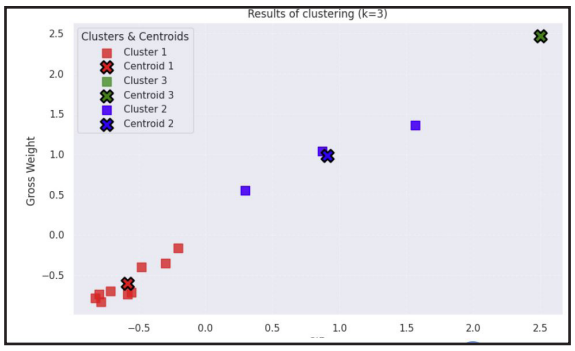
Figure 2: Elbow method result.

	CIF (miles US dollars)	Gross Weight (tons)
High Import	1067590.18	2236684.32
Middle import	588619.52	1296045.47
Low import	139108.06	291556.63

Source: Prepared by authors

Table 3: Cluster centroids.

Figure 3 presents the distribution of countries across the three clusters generated by the K-means algorithm, based on standardized CIF value and Gross Weight. A clear separation between the clusters is observed, particularly between Cluster 1 and Cluster 3, indicating substantial differences in the import characteristics of these country groups. Cluster 1 is composed of countries with relatively low CIF values and low gross weight, forming a compact group near the origin. Cluster 2 contains countries with moderate values in both dimensions, while Cluster 3 represents the country with the highest CIF value and gross weight in the dataset. It is important to note that Cluster 3 consists of a single country Russia. This explains why, in Figure 3, the cluster is represented by a single point whose location coincides with its centroid. The centroids displayed in Figure 3 reflect the average position of each cluster in the standardized feature space, and their separation visually confirms the heterogeneity between the groups. Furthermore, the three clusters capture 92.4% of the variance in the two-variable data structure, indicating that the clustering solution provides a robust representation of the underlying import patterns.



Source: Prepared by authors

Figure 3: Visualization of fertilizer clusters (2020-2024).

This section presents the core findings of the cluster analysis, organized by input category. Table 4 provides a synthesized overview of the main trends and economic insights for all categories between 2005 and 2024. For readers interested in the detailed year-by-year cluster composition, including country-specific percentages for CIF value and gross weight, Main Trade Agreement, Average tariff the complete results are available in Appendix Tables A2 through A9.

To complement the analysis, a comparative performance analysis was carried out by trade block for agricultural inputs imported into Colombia for all the periods analyzed. Table 5 shows those belonging to cluster 1, i.e., those with a high level of imports. For more information on the percentage of countries belonging to each block or country participating in the category according to the cluster analysis classification, see Table A10.

The disparity in cluster 1 participation among economic blocs could be associated with differences in their productive structures, comparative advantages, and trade strategies. Mercosur and the Andean Community show declining or marginal participation, while China and the US consolidate their presence. The Barranquilla Free Trade Zone has potential in biological products, but its irregularity suggests challenges in sustainability or competitiveness. Regarding the impact of trade agreements, the US takes advantage of its FTAs to diversify exports. In contrast, blocks such as CARICOM or the Pacific Alliance do not register activity, possibly because they prioritize other sectors. Brazil and Mexico, with equipment and tools, could strengthen their integration into regional value chains, especially in agricultural technology.

Category	Main Trend (2005-2024)	Key Pattern & Periods	Economic Insight
Fertilizers	Concentration	RUS/USA dominance (>60% CIF) all periods. Peak RUS (59%) in 2020-24 despite sanctions.	Price/logistics > tariff advantages. High strategic vulnerability.
Seeds	Concentration & Reset	USA dominance, interrupted by BOL/ARG (2005-14), then USA regained >80% share.	Structural competitiveness outweighs FTAs—limited long-term diversification.
Animal feed	Stability	USA stable leader (55-58% CIF). BRA grew in Cluster 2 (24%→34%) despite high tariffs.	FTA consolidates leader; competitive advantages (proximity/quality) enable challengers.
Veterinary medicines	Diversification & Value Shift	Shift from multi-country (ARG, BRA, MEX) to USA/CHN focus. CIF stable, but weight fell from 73% to 24%	Transition to high-value products from key partners, with Mexico dominating bulk imports.
Equipment & Tools	Regional Diversification	MEX/BRA dominance (2005-14: ~80% CIF) → CHN/BRA/USA shared leadership (2020-24: ~41% each).	Regional agreements initially dominated, but Asian competition fragmented the market.
Technology and software	Full Transition	USA leader (2005-2019) → CHN leader (2020-2024: 65% CIF).	Cost competitiveness and scale displace traditional partners, regardless of FTAs.
Biological products	Asian Consolidation	CHN increased dominance (52%→65% CIF). ZFBa/USA presence declined (36%→26%).	Absolute price competitiveness overcomes lack of trade agreements.
Genetic material	Absolute Concentration	Only RUS/USA suppliers throughout all periods. No cluster analysis possible.	Maximum dependency risk. Critical vulnerability for food security.
Construction Material	Asian Dominance	CHN increased share (52%→59% CIF) despite high tariffs (7.98%). EU/USA secondary role.	Bulk commodity imports where price competitiveness dominates all other factors.

Source: Prepared by authors

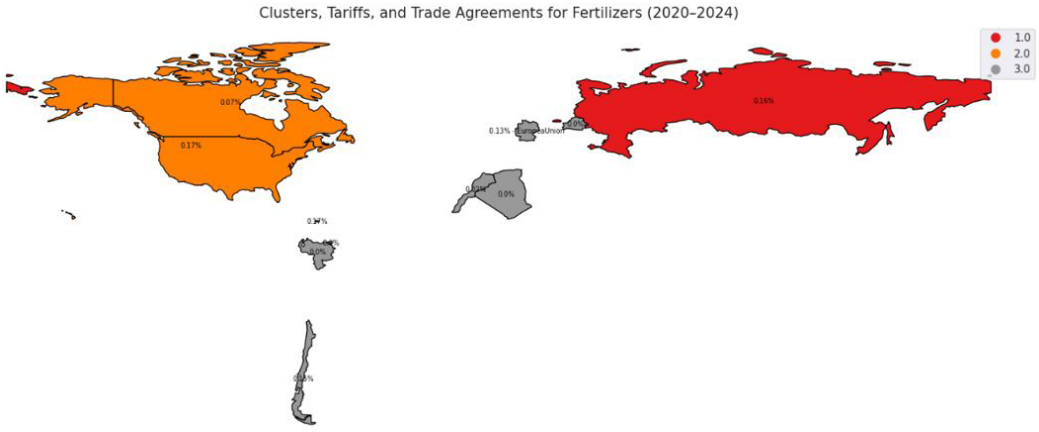
Table 4: Trends of agricultural input imports.

Trade Bloc	Agreement in force	Category in Cluster 1			
		2005-2009	2010-2014	2015-2019	2020-2024
European Union	EU AC (2013)	NA	-	-	
Andean Community	Agreement (1969)	Construction material (VEN) -20%	-	-	-
Mercosur	Agreement (1991)	Veterinary medicines (ARG, BRA) -50%	Equipment and tools (BRA) -25%	-	-
Pacific Alliance	Agreement (2016)	-	-	-	-
CARICOM	Cartagena Agreement (1992)	-	-	-	-
China	No FTA (Negotiation in Progress)	Technology and software, Biological products	Biological products, Construction material	Biological products, Construction material	Biological products, Construction material, Equipment and tools
Russia	No FTA	Fertilizers	Fertilizers	Fertilizers	-
México	ECA (1993)	Equipment and tools	-	Equipment and tools	-
Brazil	ECA 72 G (2017)	-	-	Equipment and tools	-
United States	FTA con EE.UU. (Effective from 2012)	Fertilizers, Seed Technology and software	Fertilizers, Seeds Technology and Software, Animal feed	Fertilizers, Seeds Technology and software, Animal feed, Euipment and tools	Seeds, Animal feed
Canada	FTA with Canada (20119	-	-	-	-
India	No FTA	-	Construction material	-	-
Barranquilla Free Trade Zone	Free Zone Regime	Technology and software, Biological products	-	Biological products	-

Note: Although Mexico, the US, and Canada have a treaty between Mexico, the United States, and Canada that replaced the North American Free Trade Agreement (NAFTA) as of July 1, 2020, there is no direct trade agreement between the USMCA as a bloc. However, Colombia has bilateral agreements with each of the three members of the USMCA, which is why each country is shown separately. The situation is similar with Brazil, given that it belongs to Mercosur and ALADI, depending on the input, it falls under one or the other. In cases where no bloc or agreement had been created, it was designated as NA, not applicable. Acronyms: ECA-Economic Complementation Agreement, FTA-Free Trade Agreement.
Source: Prepared by authors

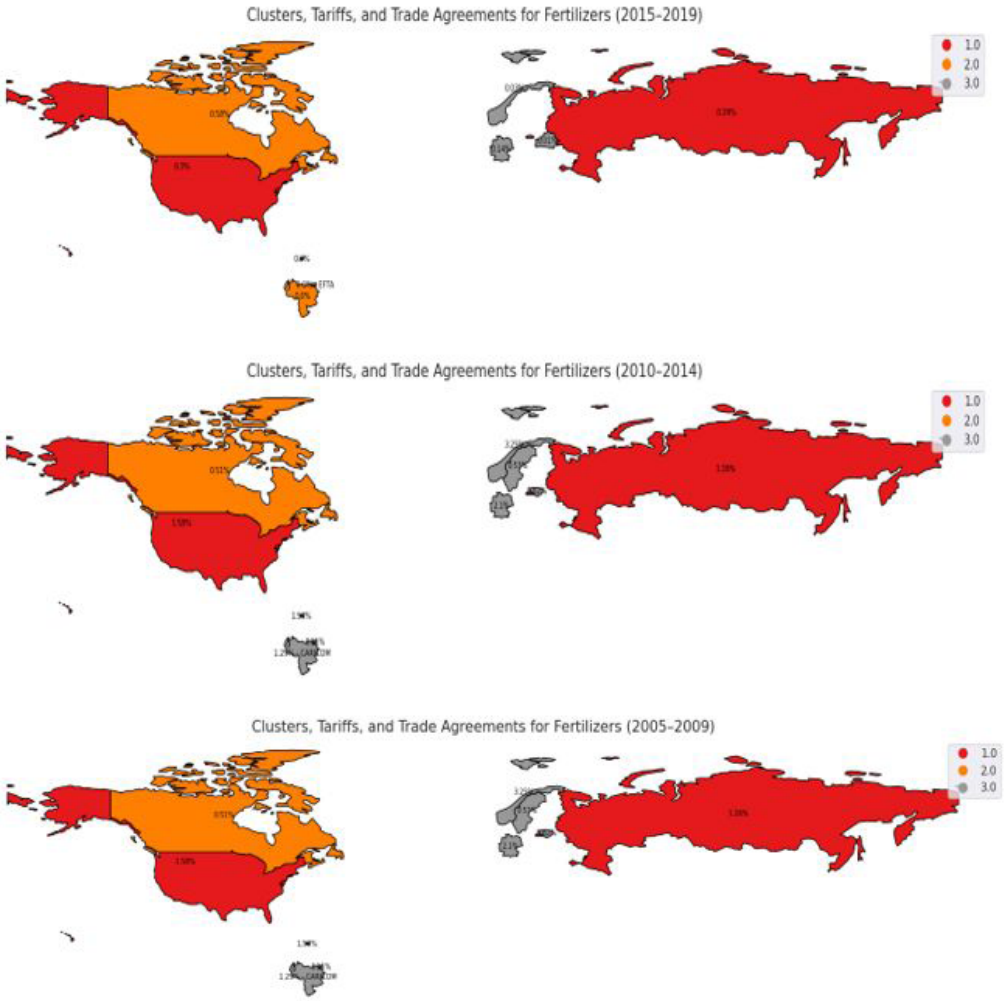
Table 5: Product categories by trade bloc and period (2006–2024), for Cluster 1.

Figure 4 show clusters, tariffs, and trade agreements for fertilizers for the periods 2005–2009, 2010–2014, 2015–2019, and 2020–2024. The figure is highly relevant because it reveals the underlying structure of the global fertilizer market.



Source: Prepared by authors

Figure 4: Choropleth map showing clusters, tariffs, and trade agreements for fertilizers for the periods 2005–2009, 2010–2014, 2015–2019, and 2020–2024. (To be continued).



Note: It was developed based on the results of the cluster and the complementary analysis of the average tariff of each country in each cluster. See A2, A3, A4, and A5
Source: Prepared by authors

Figure 4: Choropleth map showing clusters, tariffs, and trade agreements for fertilizers for the periods 2005–2009, 2010–2014, 2015–2019, and 2020–2024. (Continuation).

The main objective of this study is to analyse the clusters applied to Colombian agricultural imports between 2005 and 2024. To this end, an exhaustive review of the relevant scientific and trade policy literature was carried out, allowing five main patterns to be identified. These patterns are presented and discussed below in the context of economic and trade policy literature.

The first finding reveals a high level of dependence on a small number of suppliers for essential resources. Russia and the United States consistently accounted for over 60% of the CIF value and gross weight of fertilizers (Cluster 1), despite not having a bilateral free trade agreement (FTA). This suggests that economies of scale and logistics costs outweigh tariff advantages, which corroborates the findings of Quitzow et al. (2025) Latin American countries suffer from high levels of import dependency, which exposes them to external supply shocks, a vulnerability that has been exacerbated by the increase in fertilizer prices following the war in Ukraine. Similarly, the United States regained its leadership in seeds (80% of CIF) after 2015, despite competing with Andean Community and Mercosur countries that had tariff preferences. This suggests that the structural advantages of competitiveness, which Baier and Regmi (2023) identified as a key factor in successful FTAs, can sometimes operate independently of them.

A second pattern is the reconfiguration of supply chains, with China's rise being particularly notable. Despite not having an FTA, this country

has achieved a dominant position in technology and software (65% CIF, 78% weight) and biological products. Its overall competitiveness, encompassing both value and volume, challenges traditional gravitational models that favour proximity and trade agreements (Zhang et al., 2025). At the same time, the veterinary medicine sector is transitioning towards higher-value products. The divergence between stable CIF and a sharp drop in gross weight suggests an upgrading process in the import basket. This is consistent with the hypothesis that trade integration can encourage specialisation in higher-value segments (Storm, Baylis and Heckelei, 2020).

The third pattern reveals contrasting sectoral dynamics. While the FTA with the US consolidated its stable leadership in the animal feed sector (Cluster 1, 55-58% CIF), regional agreements lost relevance in the equipment and tools sector due to growing market fragmentation. This reflects the theory of sectoral heterogeneity, whereby the effectiveness of trade policies is influenced by the inherent characteristics of products and markets (Batarseh et al., 2021).

A fourth pattern that was identified was the consistent underutilisation of trading partners with which existing agreements were in place. Despite having low preferential tariffs (e.g. 0.13% for the EU), countries in Cluster 3, which include members of the European Union and CARICOM, maintained marginal shares (e.g. 8% for fertilisers from the EU). The extant evidence suggests that the formal existence of an FTA is a necessary but not sufficient condition for boosting trade flows, thus supporting the theory that non-tariff barriers and transaction costs may persist even after tariff liberalization (Piñeiro et al., 2023).

Finally, the fifth pattern demonstrates the remarkable resilience of suppliers without trade agreements. In the context of trade negotiations, China has exhibited a capacity to preserve or augment its market share in various sectors, a feat further compounded by its ability to do so despite facing substantially higher tariffs than competitors with free trade agreements (FTAs). A similar resilience has been demonstrated by Brazil in the domain of animal feed, underscoring the country's capacity to maintain or increase its market share in the face of competitive tariff environments. This finding suggests that significant competitive advantages, such as geographic proximity, productive complementarity, or differentiated quality, have the capacity to offset and even surpass the disadvantages associated with tariffs. This expands the conventional understanding of the determinants of international trade.

Public policy implications for the agricultural sector in Colombia

Cluster analysis reveals distinct strategic patterns in Colombia's agricultural input imports that demand targeted policy responses. These empirical findings provide a critical evidence base for the National Agricultural Innovation System (SNIA), established in (2017) as Colombia's multi-level governance framework for coordinating science, technology, and innovation in agriculture. The SNIA's structure comprising subsystems for Research and Technological Development, Agricultural Extension, and Education and Training offers the institutional "how" to transform these diagnostic insights into concrete state action. Since agricultural innovation is inextricably linked to input supply chain efficiency, the following recommendations are designed to leverage the SNIA's architecture to reduce vulnerability, capitalize on diversification opportunities, and strengthen sectoral resilience.

The analysis identifies extreme import concentration in genetically sensitive materials (exclusive dependence on Russia and the United States) and a persistently limited supplier base for fertilizers (Cluster 1 > 60% of CIF value and gross weight). This high dependency creates significant vulnerability to geopolitical and market disruptions. To address this strategic risk, a dual approach leveraging the SNIA is essential, combining immediate commercial diversification with a long-term strategy for national input development. The Ministry of Commerce, Industry, and Tourism, in coordination with the SNIA's technical bodies, should implement a targeted diversification program. This program must actively promote new commercial partnerships with competitively proven suppliers from Cluster 2, such as Canada and China for fertilizers. These countries have demonstrated reliable supply capacity without preferential trade agreements, offering a viable pathway to immediately mitigate supply chain risk. Concurrently, the Subsystem of Research and Technological Development of the SNIA must be strengthened to orchestrate a long-term solution. This involves: Directing the research agendas of Agrosavia and partner universities towards the development and domestic production of alternative fertilizers and bio-inputs

and securing public investment and international cooperation funding specifically for the research, registration, and scaling of these nationally produced inputs, reducing the legal and financial barriers to their adoption. To ensure the efficacy of both strategies, the Subsystem of Agricultural Extension must be activated. The Departmental Agricultural Extension Plans (PDEA) should incorporate training programs on the efficient use of both newly diversified imports and domestic alternatives. This includes promoting regenerative agriculture practices that reduce the overall dependency on synthetic fertilizers, thereby building systemic resilience at the farm level.

Veterinary medicines show a marked transition towards high-value products (stable CIF value but gross weight plummeting from 73% to 24%), indicating a market shift from bulk commodities to specialized ingredients and finished products. This divergence between value and volume metrics reveals a segmented market requiring distinct policy approach. SNIA provides the ideal framework to navigate this dual market structure. A segmented strategy should be implemented through its respective subsystems to simultaneously build technological sovereignty and guarantee the supply of essential medicines. For High-Value products, Cluster 1-USA/China, The Subsystem of Research and Technological Development, led by Agrosavia and Colciencias, must prioritize veterinary pharmacology and biotechnology. This involves: Fostering public-private partnerships and technology transfer alliances for the local development and production of Active Pharmaceutical Ingredients (APIs) and creating specialized research groups and grant lines focused on advanced veterinary therapies, vaccines, and diagnostics to capture value in this high-margin segment and reduce import dependency. For Bulk Essential Medicines, Cluster 2-Mexico, The Subsystem of Agricultural Extension and trade authorities should work in concert to ensure supply chain security for cost-effective, essential veterinary products. Strengthen trade facilitation measures and logistical corridors with key Cluster 2 suppliers like Mexico. Integrate into the Departmental Agricultural Extension Plans (PDEA) training programs on the rational use of these bulk imported medicines, ensuring their effective and accessible application by livestock producers

China has achieved dominant positions in technology and biological products, with 65% CIF and 78% gross weight respectively, without free trade agreements, demonstrating unprecedented price competitiveness. Considering this reality and the urgent need to adapt agri-food systems to climate change, it is recommended that existing technical cooperation platforms are utilised. Import policies should be coordinated with initiatives such as AgriLAC Resiliente CGIAR, It operates in Colombia and seeks to increase the resilience and sustainability of agri-food systems. The strategy must be segmented. For technologically complex inputs, where China has structural advantages, technical cooperation agreements should be prioritized, making use of CGIAR initiatives in genetic improvement, plant health and agronomy instead of traditional, tariff-focused negotiations. For biological products, implement quality assurance protocols that ensure price competitiveness does not compromise national biosecurity or climate adaptation, in line with CGIAR's Germplasm Bank initiatives and phytosanitary standards. This approach would enable Chinese imports to enhance the immediate competitiveness and long-term resilience of the Colombian agricultural sector simultaneously. It is recommended that the SNIA strengthens its measures relating to science, technology and innovation by creating specialised committees on disruptive technologies, such as precision agriculture and biotechnology, to identify opportunities for South-South collaboration with China and other leaders beyond free trade agreements (FTAs). The SNIA should also guide the user registration and classification process in a coordinated manner to identify level 3 and 4 producers who are ready to adopt advanced technologies, connecting them with Chinese suppliers or equivalent national developments.

The United States maintains stable leadership in animal feed imports (Cluster 1, 55-58% CIF), effectively utilizing preferences under the bilateral free trade agreement. However, the concurrent competitiveness of non-FTA partners despite tariff disadvantages points to untapped opportunities for complementary sourcing strategies. Maximize tariff-rate quotas and preferential access under the US-Colombia FTA for compound feed ingredients. Concurrently, develop specialized logistics corridors to facilitate imports from Brazil (Cluster 2), which has maintained competitive supply despite facing tariffs of 13-18%, suggesting strong inherent advantages in product quality or geographic proximity. A pragmatic innovation policy within the SNIA should move beyond a singular focus on FTAs by pursuing a dual strategy of strategic R&D alliances and producer

association. This involves: Promoting strategic R&D partnerships with resilient suppliers, such as Colombia-Brazil technical cooperation in animal nutrition or Colombia-China collaboration in digital agriculture, to leverage complementary strengths and build technological capacity. Strengthening producer associativity as a key social capability, where the Departmental Agricultural Extension Plans (PDEAs) prioritize the development of cooperatives and associations. This enables Colombian producers to achieve the economies of scale necessary to compete with major suppliers, improve their bargaining power, and access quality inputs at competitive prices, thereby enhancing overall sector resilience

Cluster 3 suppliers remain consistently marginalized across multiple input categories despite favorable trade agreements. For instance, the European Union maintains only 8% market share in fertilizer imports despite the EU-Colombia Trade Agreement, while CARICOM members show minimal participation despite the Cartagena Agreement. This persistent underutilization despite generally low tariff barriers (e.g., 0.13% average tariff for EU fertilizers) suggests that addressing this gap requires moving beyond tariff reduction to actively bridge existing market disconnections. Cluster 3 suppliers remain consistently marginalized across multiple input categories despite favorable trade agreements. For instance, the European Union maintains only 8% market share in fertilizer imports despite the EU-Colombia Trade Agreement, while CARICOM members show minimal participation despite the Cartagena Agreement. This persistent underutilization despite generally low tariff barriers (e.g., 0.13% average tariff for EU fertilizers) suggests that addressing this gap requires moving beyond tariff reduction to actively bridge existing market disconnections

Finally, a Pragmatic Innovation Policy within the SNIA implies not focusing exclusively on FTAs, but promoting strategic R&D alliances with resilient suppliers, such as the Colombia-Brazil technical cooperation in animal feed or the Colombia-China technical cooperation in digital agriculture; and, complementarily, it is necessary to foster associativity as a key social capacity, so that the PDEAs prioritize the strengthening of cooperatives and associations that allow Colombian producers to achieve the necessary scale to compete with countries like Brazil, negotiate better, and access quality inputs at competitive prices.

Conclusion

This study demonstrates that cluster analysis provides a powerful tool for diagnosing strategic patterns in Colombia's agricultural input imports, revealing significant disparities in country participation across the three identified clusters. These variations are associated with differences in productive structures, comparative advantages, and commercial strategies, while the persistent dominance of certain suppliers even in the absence of trade agreements highlights how price and logistical competitiveness can outweigh tariff advantages.

However, several limitations must be acknowledged. The analysis relied on data aggregated at the 4-digit HS code level, which may mask product-specific dynamics within broader categories. Furthermore, the study did not account for non-tariff measures which constitute significant barriers in agricultural trade. The k-means methodology itself, while effective for identifying patterns, does not establish causal relationships.

Notwithstanding these limitations, the findings offer actionable insights. The Barranquilla Free Trade Zone emerges as a strategic platform to enhance competitiveness through economic and technological incentives. Future research should incorporate disaggregated data and analyze non-tariff barriers, particularly for clusters with high supplier concentration. Additional studies could also quantitatively assess the impact of the Barranquilla Free Trade Zone on specific value chains and examine the role of FTAs in export diversification through detailed case studies

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Appendix

Tariff item	Description
3101	Animal or vegetable fertilisers, whether or not mixed together or chemically treated; fertilisers produced by the mixing or chemical treatment of animal or vegetable products.
3102	Mineral or chemical fertilisers, nitrogenous.
3103	Mineral or chemical fertilisers, phosphatic.
3104	Mineral or chemical fertilisers, potassic.
3105	Mineral or chemical fertilisers containing two or three of the fertilising elements nitrogen, phosphorus and potassium; other fertilisers; goods of this Chapter in tablets or similar forms or in packages of a gross weight not exceeding 10 kg.
3808	Insecticides, rodenticides, fungicides, herbicides, anti-sprouting products and plant-growth regulators, disinfectants and similar products, put up in forms or packings for retail sale or as preparations or articles (for example, sulphur-treated bands, wicks and candles, and fly-papers).
1201	Soya beans, whether or not broken.
1202	Ground-nuts, not roasted or otherwise cooked, whether or not shelled or broken.
1204	Linseed, whether or not broken.
1205	Rape or colza seeds, whether or not broken.
1206	Sunflower seeds, whether or not broken.
1207	Other oil seeds and oleaginous fruits, whether or not broken.
1209	Seeds, fruit and spores, of a kind used for sowing.
2309	Preparations of a kind used in animal feeding.
1214	Swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets.
3004	Medicaments (excluding goods of heading 30.02, 30.05 or 30.06) consisting of mixed or unmixed products for therapeutic or prophylactic uses, put up in measured doses (including those in the form of transdermal administration systems) or in forms or packings for retail sale.
3002	Human blood; animal blood prepared for therapeutic, prophylactic or diagnostic uses; antisera, other blood fractions and immunological products, whether or not modified or obtained by means of biotechnological processes; vaccines, toxins, cultures of micro-organisms (excluding yeasts) and similar products; cell cultures, whether or not modified.
2937	Hormones, prostaglandins, thromboxanes and leukotrienes, natural or reproduced by synthesis; derivatives and structural analogues thereof, including chain modified polypeptides, used primarily as hormones.
8414	Air or vacuum pumps, air or other gas compressors and fans; ventilating or recycling hoods incorporating a fan, whether or not fitted with filters; gas-tight biological safety cabinets, whether or not fitted with filters.
8701	Tractors (other than tractors of heading 87.09).
8432	Agricultural, horticultural or forestry machinery for soil preparation or cultivation; lawn or sports-ground rollers.
8433	Harvesting or threshing machinery, including straw or fodder balers; grass or hay mowers; machines for cleaning, sorting or grading eggs, fruit or other agricultural produce, other than machinery of heading 84.37.
8201	Hand tools, the following : spades, shovels, mattocks, picks, hoes, forks and rakes; axes, bill hooks and similar hewing tools; secateurs and pruners of any kind; scythes, sickles, hay knives, hedge shears, timber wedges and other tools of a kind used in agriculture, horticulture or forestry.
8424	Mechanical appliances (whether or not hand-operated) for projecting, dispersing or spraying liquids or powders; fire extinguishers, whether or not charged; spray guns and similar appliances; steam or sand blasting machines and similar jet projecting machines.
9406	Furniture; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings; luminaires and lighting fittings, not elsewhere specified or included; illuminated signs, illuminated name-plates and the like; prefabricated buildings
7314	Cloth (including endless bands), grill, netting and fencing, of iron or steel wire; expanded metal of iron or steel.
7308	Structures (excluding prefabricated buildings of heading 94.06) and parts of structures (for example, bridges and bridge-sections, lock-gates, towers, lattice masts, roofs, roofing frame-works, doors and windows and their frames and thresholds for doors, shutters, balustrades, pillars and columns), of iron or steel; plates, rods, angles, shapes, sections, tubes and the like, prepared for use in structures, of iron or steel.
8806	Structures (excluding prefabricated buildings of heading 94.06) and parts of structures (for example, bridges and bridge-sections, lock-gates, towers, lattice masts, roofs, roofing frame-works, doors and windows and their frames and thresholds for doors, shutters, balustrades, pillars and columns), of iron or steel; plates, rods, angles, shapes, sections, tubes and the like, prepared for use in structures, of iron or steel.
9026	Instruments and apparatus for measuring or checking the flow, level, pressure or other variables of liquids or gases (for example, flow meters, level gauges, manometers, heat meters), excluding instruments and apparatus of heading 90.14, 90.15, 90.28 or 90.32.
9025	Hydrometers and similar floating instruments, thermometers, pyrometers, barometers, hygrometers and psychrometers, recording or not, and any combination of these instruments.
9015	Surveying (including photogrammetrical surveying), hydrographic, oceanographic, hydrological, meteorological or geophysical instruments and appliances, excluding compasses; rangefinders.
8523	Discs, tapes, solid-state non-volatile storage devices, «smart cards» and other media for the recording of sound or of other phenomena, whether or not recorded, including matrices and masters for the production of discs, but excluding products of Chapter 37.
4911	Other printed matter, including printed pictures and photographs.
9032	Other printed matter, including printed pictures and photographs.
8543	Electrical machines and apparatus, having individual functions, not specified or included elsewhere in this Chapter.

Source: SA-version 2022

Table A1: Tariff items for agricultural input..

Category	Cluster	Details	2005-2009	2010-2014	2015-2019	2020-2024
Fertilizers	1	Countries	RUS, USA	USA, RUS	RUS, USA	RUS
		% CIF	64%	64%	62%	59%
		% Gross Weight	59%	61%	60%	58%
		Main Trade Agreement	-	-	-	-
		Average tariff	3.35%	1.43%	0.29%	-
	2	Countries	CAN, VEN	CAN	VEN, CHN, CAN	CAN, CHN, USA
		% CIF	27%	11%	26%	33%
		% Gross Weight	29%	11%	27%	34%
		Main Trade Agreement	Comunidad Andina	-	-	-
		Average tariff	2.27%	0.51%	0.48%	-
	3	Countries	CHN, DEUMAR, NLD, TTO, NOR, LTU, SWE, VGB	VEN, TTO, SWE, NLD, NOR, LTU, CHN, DEU	TTO, NOR BLR, DEU	DEU, DZA, BLR, CHL, FIN, MAR, NLD, TTO, VEN
		% CIF	10%	10%	12%	8%
		% Gross Weight	11%	10%	13%	8%
		Main Trade Agreement	Agreement Caricom	Agreement Caricom	ALC. cn Noruega	AC. con UE
		Average tariff	3.23%	1.18%	0.04%	0.1282
Seeds	1	Countries	USA	USA	-	-
		% CIF	73%	40%	-	-
		% Gross Weight	73%	47%	-	-
		Main Trade Agreement	-	FTA. con EEUU	-	-
		Average tariff	6.67%	3.15%	-	-
	2	Countries	BOL	BOL	-	-
		% CIF	19%	40%	-	-
		% Gross Weight	19%	23%	-	-
		Main Trade Agreement	Comunidad Andina	Comunidad Andina	-	-
		Average tariff	0.28%	0.40%	-	-
	3	Countries	ARG	ARG	-	-
		% CIF	8%	20%	-	-
		% Gross Weight	8%	30%	-	-
		Main Trade Agreement	Mercosur	Mercosur	-	-
		Average tariff	5.19%	2.58%	-	-

Source: Prepared by authors

Table A2: Fertilizers and seeds.

Category	Cluster	Details	2005-2009	2010-2014	2015-2019	2020-2024
Fertilizers	1	Countries	-	USA	USA	USA
		% CIF	-	55%	56%	58%
		% Gross Weight	-	57%	57%	62%
		Main Trade Agreement	-	FTA. con EEUU	-	FTA. con EEUU
		Average tariff	-	6.20 %	0.72%	0.44
	2	Countries	-	CHN, PER	BRA	BRA
		% CIF	-	29%	24%	34%
		% Gross Weight	-	32%	18%	30%
		Main Trade Agreement	-	Comunidad Andina	-	ECA 72 G Brasil Mercosur
		Average tariff	-	4.83%	18.22%	13.19%
	3	Countries	-	BRA, ARG	PER, CHN	PER, CHN, ECU, MEX
		% CIF	-	16%	13%	7%
		% Gross Weight	-	11%	16%	8%
		Main Trade Agreement	-	Mercosur	-	Agreement de Cartagena Alianza Pacífico
		Average tariff	-	5.23%	6.37	1.19%
Seeds	1	Countries	ARG, BRA, USA, MEX	DEU, USA	DEU, USA	USA, CHN
		% CIF	49%	71%	70%	64%
		% Gross Weight	73%	24%	23%	24%
		Main Trade Agreement	Mercosur Ac -Mexico	-	AC. con UE	FTA. con EEUU
		Average tariff	4.76 %	3.85	1.66	2.39
	2	Countries	DEU	MEX, CHN	MEX, CHN	MEX
		% CIF	41%	17%	17%	23%
		% Gross Weight	11%	59%	60%	69%
		Main Trade Agreement	-	Ac -Mexico Comunidad Andina	Ac -Mexico	Ac -Mexico
		Average tariff	7.16 %	3.29	2.20	0.84
	3	Countries	CAN, NLD	ARG, BRA, CAN, ESP, IND	BRA	BRA, NLD, ESP
		% CIF	10%	12%	14%	13%
		% Gross Weight	15%	17%	16%	7%
		Main Trade Agreement	-	Mercosur	214 ECA 72 G Brasil	214 ECA 72 G Brasil AC. con UE
		Average tariff	6.74%	3.44	0.94	0.99

Source: Prepared by authors

Table A3: Animal feed and veterinary medicines.

Category	Cluster	Details	2005-2009	2010-2014	2015-2019	2020-2024
Equipment and Tools	1	Countries	MEX	BRA	MEX, USA, BRA	CHN
		% CIF	77%	79%	48%	41%
		% Gross Weight	75%	80%	26%	64%
		Main Trade Agreement	-	Mercosur	Ac -Mexico, FTA. con EEUU 214 ECA 72 G Brasil	-
		Average tariff	4.97 %	1.94%	2.21	4.52
	2	Countries	USA	USA	CHN	BRA, MEX
		% CIF	13%	13%	39%	41%
		% Gross Weight	11%	11%	65%	24%
		Main Trade Agreement	-	-	-	-
		Average tariff	9.75%	5.57%	3.30%	2.62%
	3	Countries	BRA	MEX	JPN	USA
		% CIF	10%	8%	13%	18%
		% Gross Weight	13%	9%	9%	12%
		Main Trade Agreement	Mercosur	Ac -Mexico	-	Ac -Mexico
		Average tariff	6.70	1.94	2.50	3.36
Technology and software	1	Countries	USA	USA	USA	CHN
		% CIF	76%	62%	60%	65%
		% Gross Weight	38%	24%	73%	78%
		Main Trade Agreement	-	-	FTA. con EEUU	-
		Average tariff	8.18 %	5.34 %	0.72%	2.28%
	2	Countries	CHN, PER	CHN	CHN	USA
		% CIF	12%	28%	31%	26%
		% Gross Weight	47%	51%	19%	14%
		Main Trade Agreement	-	-	-	FTA. con EEUU
		Average tariff	7.60%	4.88%	18.22%	1.95%
	3	Countries	MEX, CN-TW, BRA, DEU	PER, MEX, CN-TW	PER, MEX, CN-TW, DEU	PER, MEX, CN-TW, BRA
		% CIF	12%	10%	9%	8%
		% Gross Weight	15%	26%	8%	8%
		Main Trade Agreement	Comunidad Andina	Comunidad Andina	AC. con UE	-
		Average tariff	8.22%	4.04%	6.37%	2.03%

Source: Prepared by authors

Table A4: Equipment and tools and technology and software.

Category	Cluster	Details	2005-2009	2010-2014	2015-2019	2020-2024
Equipment and Tools	1	Countries	CHN, ZFBa	CHN	CHN	CHN
		% CIF	52%	56%	60%	65%
		% Gross Weight	63%	71%	73%	78%
		Main Trade Agreement	-	-	-	-
		Average tariff	8.22 %	3.70 %	1.66%	2.90%
	2	Countries	DEU, BRA, USA	ZFBa, USA	ZFBa, USA	ZFBa, USA
		% CIF	36%	33%	31%	26%
		% Gross Weight	19%	20%	19%	14%
		Main Trade Agreement	Mercosur	-	FTA. con EEUU	FTA. con EEUU
		Average tariff	6.42%	3.29	0.45%	2.16%
	3	Countries	BEL, ECU, IND, VEN	MEX, IND, BRA, ARG, DEU	MEX, IND, BRA, DEU	DEU, IND, MEX
		% CIF	12%	11%	9%	8%
		% Gross Weight	18%	8%	8%	8%
		Main Trade Agreement	Comunidad Andina	Ac -Mexico Mercosur	Ac -Mexico Mercosur AC. con UE	Ac -Mexico C. con UE
		Average tariff	4.26%	2.72%	0.55%	2.15%
Technology and software	1	Countries	VEN	CHN	CHN, IND	CHN
		% CIF	52	49%	60%	59%
		% Gross Weight	72	64%	73%	66%
		Main Trade Agreement	Comunidad Andina	-	-	-
		Average tariff	4.19%	7.33%	7.31%	7.98%
	2	Countries	CHN, USA	USA, ESP	ESP	ESP, IND
		% CIF	39%	37%	43%	35%
		% Gross Weight	24%	28%	50%	29%
		Main Trade Agreement	-	-	AC. con UE	AC. con UE
		Average tariff	13.82%	7.33%	4.10 %	5.08
	3	Countries	CAN, ESP, MYS	ITA, ARE, DEU	MEX, USA, DEU	MEX, PER, ECU, BRA
		% CIF	9%	14%	44%	6%
		% Gross Weight	4%	8%	44%	6%
		Main Trade Agreement	-	-	Ac -Mexico FTA. con EEUU	Ac -Mexico Comunidad Andina Alianza Pacífico
		Average tariff	13.03%	7.43%	4.71%	2.15%

Source: Prepared by authors

Table A5: Biological products and construction material.

Tables A6, A7, A8, and A9 show the distribution of the main supplier countries of agricultural inputs, grouped by market share clusters, for the periods 2005–2009, 2010–2014, 2015–2019, and 2020–2024. The percentages corresponding to the CIF value and gross weight of imports are shown, as well as the main trade agreement in force with each country and the tariff applied.

Category	Cluster	Countries	% CIF	% Gross Weight	Trade Agreements	Tariff of each country
Fertilizers	1	RUS	20%	19%	-	3.1
		USA	27%	24%		3.6
	2	CAN	11%	12%	Agreement de Cartagena	2.35
		VEN	9%	9%		2.21
	3	CHN	3%	2%	Agreement Caricom	4.29
		DEU	5%	7%		4.59
		MAR	3%	7%		1.35
		NLD	4%	4%		4.53
		TTO	5%	5%		0.23
		NOR	4%	3%		6.65
		LTU	3%	3%		2.63
		SWE	5%	4%		1.63
		VGB	1%	1%		3.19
Seeds	1	USA	92.81%	96.34%	-	6.67
	2	BOL	6.95%	3.57%	Agreement de Cartagena	0.28
	3	ARG	0.24%	0.09%	Mercosur	5.19
Veterinary medicines	1	ARG	8%	20%	Mercosur México-Colombia	5.79
		BRA	14%	24%		3.8
		USA	40%	18%		6.45
		MEX	12%	26%		3
	2	DEU	18%	4%	-	7.16
	3	CAN	3%	6%	-	7.16
		NLD	5%	4%		6.34
Equipment and Tools	1	MEX	77%	75%	-	4.97
	2	USA	13%	11%	-	9.75
	3	BRA	10%	13%	Mercosur	6.7
Technology and software	1	USA	52%	20%	-	8.19
	2	CHN	10%	27%	-	9.5
		PER	7%	22%		5.71
	3	BRA	6%	8%	-	7.22
		CN-TW	3%	11%		9.72
		MEX	13%	5%		7.36
		DEU	10%	7%		8.6
Biological products	1	CHN	21%	28%	-	6.58
		ZFBa	19%	22%		6.48
	2	DEU	12%	4%	Mercosur	6.52
		BRA	12%	7%		6.15
		USA	18%	13%		6.61
	3	BEL	3%	4%	Agreement de Cartagena	7.34
		ECU	3%	6%		0.23
		IND	4%	6%		7.22
		VEN	8%	12%		2.28
Construction Material	1	VEN	33%	54%	Agreement de Cartagena	4.19
	2	CHN	16%	20%	-	12.65
		USA	34%	16%		15
	3	CAN	6%	2%	-	13.64
		ESP	7%	6%		12.9
		MYS	5%	2%		12.56
Animal Feed	NA	NA	NA	NA	NA	NA
Genetic material	NA	NA	NA	NA	NA	NA

Source: Prepared by authors

Table A6: Participation of countries supplying agricultural inputs is according to CIF value, gross weight and applied tariff 2005-2009.

Category	Cluster	Countries	% CIF	% Gross Weight	Trade Agreements	Tariff of each country
Fertilizers	1	USA	27%	24%	-	1.58
		RUS	24%	24%		1.28
	2	CAN	11%	11%	-	0.51
	3	VEN	7%	7%	Agreement Caricom	1.29
		TTO	5%	5%		0.11
		SWE	3%	3%		0.53
		NLD	3%	4%		2.64
		NOR	3%	4%		3.25
		LTU	6%	6%		0.82
		CHN	7%	8%		1.93
		DEU	5%	5%		2.1
Seeds	1	USA	40%	47%	FTA. con EEUU	3.15
	2	BOL	40%	23%	Agreement de Cartagena	0.41
	3	ARG	20%	30%	Mercosur	2.58
Veterinary medicines	1	DEU	24%	4%	-	4.26
		USA	36%	16%		3.44
	2	MEX	9%	29%	México con cod. Agreement 21 1 Agreement de Cartagena	1.73
		CHN	5%	18%		4.87
	3	ARG	4%	11%	Mercosur	2.75
		BRA	8%	14%		1.49
		CAN	4%	3%		4.45
		ESP	5%	2%		4.53
		IND	4%	3%		4
Equipment and Tools	1	BRA	79%	80%	Mercosur	2.24
	2	USA	13%	11%	-	5.58
	3	MEX	8%	9%	México con cod. Agreement 21	1.95
Technology and software	1	USA	52%	24%	-	5.34
	2	CHN	24%	34%	-	4.88
	3	PER	6%	23%	1 Agreement de Cartagena	2.98
		MEX	14%	5%		3.8
		CN-TW	4%	23%		5.35
Biological products	1	CHN	31%	46%	-	3.71
	2	ZFBa	18%	16%	-	3.55
		USA	19%	10%		3.04
	3	MEX	3%	4%	México con cod. Agreement 21 Mercosur	0.98
		IND	6%	9%		3.88
		BRA	10%	5%		2.13
		ARG	3%	5%		3.4
		DEU	10%	4%		3.21
Construction Material	1	CHN	30%	45%	-	7.81
	2	USA	26%	18%	-	7.49
		ESP	19%	21%		7.19
	3	ITA	11%	6%	-	7.31
		ARE	7%	6%		8.13
		DEU	7%	5%		6.87
Animal Feed	1	USA	38%	40%	FTA. con EEUU - cód Agreement 097-Grav cupos	6.2
	2	CHN	23%	18%	Agreement de Cartagena	9.5
		PER	17%	26%		0.17
	3	BRA	10%	6%	Mercosur	5.83
		ARG	12%	9%		4.64
Genetic material	NA	NA	NA	NA	NA	NA

Source: Prepared by authors

Table A7: Participation of countries supplying agricultural inputs is according to CIF value, gross weight and applied tariff 2010-2014.

Category	Cluster	Countries	% CIF	% Gross Weight	Trade Agreements	Tariff of each country
Fertilizers	1	RUS	28%	28%	-	0.29
		USA	24%	21%		0.3
	2	VEN	8%	9%	-	0
		CHN	13%	14%		0.86
		CAN	10%	11%		0.58
	3	TTO	5%	5%	ALC. cn Noruega	0
		NOR	3%	3%		0.03
		BLR	4%	4%		0.01
		DEU	5%	4%		0.14
Veterinary medicines	1	DEU	39%	20%	AC. con UE	1.78
		USA	36%	5%		1.55
	2	MEX	11%	41%	México con cod. Agreement 21	0.98
		CHN	7%	25%		3.44
	3	BRA	7%	%	214 ECA 72 G Brasil	0.94
Equipment and Tools	1	MEX	26%	17%	México con cod. Agreement 21 FTA. con EEUU 214 ECA 72 G Brasil	1.89
		USA	23%	13%		3.14
		BRA	24%	21%		1.62
	2	CHN	20%	43%	-	3.3
	3	JPN	7%	6%	-	2.51
Technology and software	1	USA	35%	9%	FTA. con EEUU	2.73
	2	CHN	32%	46%	-	2.98
	3	PER	6%	18%	AC. con UE	2.26
		MEX	14%	9%		2.2
		CN-TW	3%	15%		3.3
		DEU	10%	4%		2.65
Biological products	1	CHN	38%	51%	-	1.66
	2	USA	21%	9%	FTA. con EEUU	0.24
		ZFBa	17%	18%		0.67
	3	MEX	4%	7%	México con cod. Agreement 21 Mercosur AC. con UE	0.7
		IND	5%	7%		0.62
		BRA	5%	4%		0.6
		DEU	8%	3%		0.28
Construction Material	1	CHN	26%	38%	-	7.61
		IND	28%	30%		7.02
	2	ESP	23%	19%	AC. con UE	4.1
	3	MEX	6%	4%	México con cod. Agreement 21 FTA. con EEUU	2.07
		USA	10%	4%		4.46
		DEU	8%	4%		4.25
Animal	1	USA	56%	57%	-	0.72
Feed	2	BRA	21%	16%	-	18.22
	3	PER	8%	13%	-	0.73
		CHN	15%	14%		12.02
Seeds	NA	NA	NA	NA	NA	NA
Genetic material	NA	NA	NA	NA	NA	NA

Source: Prepared by authors

Table A8: Participation of countries supplying agricultural inputs is according to CIF value, gross weight and applied tariff 2015-2019.

Category	Cluster	Countries	% CIF	% Gross Weight	Trade Agreements	Tariff of each country
Fertilizers	1	RUS	10%	12%	-	0.16
	2	CAN	4%	3%	-	0.07
		CHN	2%	2%	-	0.45
		USA	2%	3%	-	0.17
	3	DEU	5%	5%	124 AC. con UE - cód Agreement	0.13
		DZA	2%	2%	-	0
		BLR	4%	5%	-	0
		CHL	3%	2%	-	0.15
		FIN	6%	6%	-	0
		MAR	2%	2%	-	2
		NLD	14%	15%	124 AC. con UE - cód Agreement	8
		TTO	19%	18%	-	0
		VEN	26%	26%	-	0
Animal feed	1	USA	48%	49%	FTA. con EEUU - cód Agreement 096- general	0.44
	2	BRA	28%	24%	214 ECA 72 G Brasil Brasil con Código 014 (MERCOSUR)	13.19
	3	PER	4%	7%	1 Agreement de Cartagena Alianza Pacífico - México Cód. 152	1.19%
		CHN	8%	9%		
		ECU	5%	5%		
		MEX	7%	5%		
Veterinary medicines	1	USA CHN	13%	7%	FTA. con EEUU - cód Agreement 096- general	2.39
	2	MEX	23%	69%	México con cod. Agreement 21	0.84
	3	BRA	64%	24%	214 ECA 72 G Brasil 124 AC. con UE - cód Agreement 124 -general	0.99
		NLD				
		ESP				
Equipment and Tools	1	CHN	18%	12%	-	4.52
	2	BRA	41%	24%	-	2.62
		MEX				
	3	USA	41%	64%	México con cod. Agreement 21	3.36
Technology and software	1	CHN	51%	74%	-	2.28
	2	USA	41%	13%	-	1.95
	3	BRA	4%	7%	FTA. con EEUU - cód Agreement 096-general	2.03
		CN-TW	4%	4%		
		MEX	10%	10%		
		PER	4%	21%		
Biological products	1	CHN	46%	59%	-	2.9
	2	ZFBa	15%	15%	FTA. con EEUU - cód Agreement 096-general	2.16
		USA	22%	6%		
	3	DEU	6%	5%	México con cod. Agreement 21 AC. con UE - cód Agreement 124 - general	2.15
		IND	7%	8%		
		MEX	5%	7%		
Construction Material	1	CHN	38%	45%	-	7.98
	2	ESP	25%	14%	AC. con UE - cód Agreement 124 -genera	5.08
		IND	21%	26%		
	3	MEX	6%	4%	México con cod. Agreement 21 1 Agreement de Cartagena Alianza Pacífico - México Cód. 152	2.15
		PER	4%	4%		
		ECU	3%	4%		
		BRA	4%	3%		

Source: Prepared by authors

Table A9: Participation of countries supplying agricultural inputs is according to CIF value, gross weight and applied tariff 2020-2024.

Cluster	Trade Bloc	2005-2009	2010-2014	2015-2019	2020-2024
Cluster 1	Comunidad Andina (CAN)	X Construction Material (VEN) 1/5=0.2=20%	-	-	-
	Alianza del Pacífico	-	-	-	-
	Caricom	-	-	-	-
	Mercosur	Veterinary Medicines (ARG, BRA) 50%	Equipment and Tools (BRA) 25%	-	-
	Unión Europea	-	-	-	-
	T-MEC	It did not exist	It did not exist	It did not exist	-
	USA	Fertilizers	Fertilizers	Fertilizers	-
		Seeds	Seeds	Seeds	Seeds
		Technology and software	Animal Feed Technology and software	Animal Feed Equipment and Tools Technology and software	Animal Feed
	MEX	Equipment and Tools		Equipment and Tools	
	RUS	Fertilizers	Fertilizers	Fertilizers	-
	CAN				
	VEN				
	CHN	Technology and software	Biological products	Biological products	Equipment and Tools
		Biological products	Construction Material	Construction Material	Biological products Construction Material
	BRA			Equipment and Tools	
	ZFBa	Technology and software Biological products		Biological products	
	IND		Construction Material		
Cluster 2	Comunidad Andina	-	Animal Feed (PER) 1/4=25%	-	-
	Alianza del Pacífico	-	-	-	Animal Feed (MEX)
	Caricom				
	Mercosur	Biological products (BRA) =1/5=20%	Animal Feed (BRA,ARG) =2/5=40%	-	-
	Unión	Technology and software (DEU)=1/26=3.84%	Construction Material (ESP)		Construction Material (ESP)
	Europea	Biological products (DEU)=1/26=3.84%	1/27=3.70%		1/26=3.84%
	USA	Equipment and Tools Technology and software Biological products Construction Material	Equipment and Tools Biological products Construction Material		
	MEX	-	-	-	Equipment and Tools
	RUS				
	CAN	Fertilizers	Fertilizers	Fertilizers	Fertilizers
	VEN	-	-	Fertilizers	
	CHN	Technology and software Construction Material	Animal Feed Technology and software	Fertilizers Equipment and Tools	Fertilizers
	BRA	Technology and software	-	-	Equipment and Tools
	ZFBa		Biological products		
	ESP		Construction Material		
	IND				Construction Material

Source: Prepared by authors

Table A10: Classification of products by trade level and tariff condition in selected trade blocs and countries (2005–2024) according to K-means analysis (to be continued).

Cluster	Trade Bloc	2005-2009	2010-2014	2015-2019	2020-2024
Cluster 3	Comunidad Andina	Technology and software (ECU) =1/4=25% Technology and software (PER) =1/4=25% Biological products (ECU) =1/4=25%	Technology and software (PER) =1/4=25%	Animal Feed (PER) 1/4=25%	Animal Feed (PER, ECU) 1/4=25% Construction Material (PER, ECU) 2/4=50%
	Alianza del Pacífico				Construction Material
	Caricom	TTO	TTO	TTO	TTO
	Mercosur	Equipment and Tools (BRA) =1/5=20% Technology and software (BRA) =1/5=20%	Veterinary Medicines (ARG,BRA) =2/5=40% Biological products (ARG, BRA) =2/5=40%	Biological products (BRA) ==1/5=20%	
	Unión Europea	Fertilizers (DEU, NLD, LTU, SWE) 4/26=15.38% Technology and software (BEL)=1/26=3.84% Biological products (BEL)=1/26=3.84%	Fertilizers (DEU,NLD,LTU,SWE) 4/27=14.81% Biological products (DEU)=1/27=3.70% Construction Material (DEU, ITA)=2/27=7.40% Construction Material (DEU)=1/27=3.70%	Fertilizers (DEU)=1/27=3.70% Biological products (DEU)=1/27=3.70% Construction Material (DEU)=1/27=3.70%	Fertilizers (DEU,NLD,FIN) 3/26=11.53% Biological products (DEU) 1/26=3.84%
	USA	Biological products (BEL)=1/26=3.84%	Construction Material	Construction Material	Equipment and Tools
	MEX	Technology and software	Equipment and Tools Biological products Construction Material	Construction Material	Biological products Construction Material
	RUS	-	-	-	-
	CAN	Construction Material			
	BRA	-	-	Veterinary Medicines	Veterinary Medicines Construction Material
	VEN	Biological products	Fertilizers	-	Fertilizers
	CHN	Fertilizers	Fertilizers Animal Feed	Animal Feed	Animal Feed
	MAR	Fertilizers	-	-	Fertilizers
	NOR	Fertilizers	Fertilizers	Fertilizers	Fertilizers
	VGB	Fertilizers	-	-	-
	MAR	-	-	-	Fertilizers
	CHL	-	-	-	Fertilizers
	CHN	-	-	Equipment and Tools	-
	CN-TW	Technology and software	-	-	-
	IND	Biological products	Biological products	-	Biological products
	ESP	Construction Material	-	-	-
	ARE		Construction Material	-	-

Source: Prepared by authors

Table A10: Classification of products by trade level and tariff condition in selected trade blocs and countries (2005–2024) according to K-means analysis (Continuation).