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Article

Export Diversification and Competitiveness in Global Maize Trade: Empirical Evidence in an Era of Global Economic Shifts

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Abstract

The study aimed to analyze the diversification and competitiveness of maize exports from the United States, Brazil, Argentina and Ukraine over the period 2020–2024. A quantitative, descriptive design was adopted, using secondary data from Trade Map. Export market concentration was measured with the Herfindahl–Hirschman Index, while international competitiveness was assessed through the normalized revealed comparative advantage, computed by country, year and main destination. The results indicated clearly differentiated patterns. The United States exhibited an increasingly concentrated structure centred on Mexico, with strong advantages only in Japan and Colombia, which heightened structural vulnerability. Brazil preserved low concentration levels and displayed robust, widely distributed advantages in Middle Eastern and Asian markets. Argentina combined mostly favourable diversification with stable advantages in Asia, Africa and South America, although a mild upward trend in concentration emerged toward 2024. Ukraine showed acceptable diversification but moderate and volatile competitiveness, constrained by logistical and geopolitical disruptions, particularly in trade with Türkiye. The study concluded that export sustainability depended on the joint dynamics of competitive specialisation and destination diversification, with Brazil and Argentina achieving the most balanced profiles. It was recommended that each country implement differentiated strategies in market risk management, logistical upgrading, macroeconomic and regulatory stabilisation, and penetration of emerging markets in order to reduce structural vulnerabilities in the global maize trade.

Keywords: maize exports; trade diversification; international competitiveness; Herfindahl–Hirschman Index; normalized revealed comparative advantage

1. Introduction

Corn is one of the most important crops worldwide due to its production volume, food use, and role as an industrial input (for instance, in the production of ethanol and animal feed). Along with

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wheat and rice, corn accounts for approximately 91% of global cereal production [1]. In 2023, global cereal production increased slightly, driven by higher corn harvests, underscoring the strategic weight of this grain. A historic record was registered at an estimated 2.836 billion tons, representing a growth of about 1.2% compared to 2022 [2]. Furthermore, corn constitutes a key source of economic livelihood for many exporting countries and is essential for the food security of importing nations [3]. Therefore, analyzing the diversification and competitiveness of corn exports holds both theoretical and practical significance.

Before 2022, the United States, Brazil, Argentina, and Ukraine accounted for nearly three-quarters of the world's corn exports [4]. Due to this high concentration, there may be worldwide effects on grain availability and prices if any of these suppliers' production or logistics are disrupted [5]. One recent example is the war-related partial halt to Ukrainian exports, which sparked global worries about the availability of cereals [6,7]. Similarly, unfavorable weather conditions (like droughts or floods) in major producers like the United States can have a big impact on the global corn trade [8]. Therefore, predicting vulnerabilities and opportunities in the global market requires an understanding of the degree of market and product diversification in these countries' corn ex-ports, as well as their revealed comparative advantage or international competitiveness.

In conclusion, it is critical to examine the competitiveness and diversity of corn exports from the United States, Brazil, Argentina, and Ukraine because these nations control the majority of the world's corn trade and any changes to their export performance have an impact on the entire world. Simultaneously, from a scientific standpoint, the application of the HHI and RCA provides evidence for international trade theories applied to the agri-food industry and enhances our understanding of the relationship between export concentration and comparative advantage in a major agricultural market.

At the regional level, the structure of corn trade exhibits marked contrasts between exporting zones (the Americas and Eastern Europe) and primarily importing regions (Asia, North Africa, among others). This distribution generates a problematic reality centered on the geographical dependence of corn flows and the risks associated with supplier concentration.

Asia is the largest net importer of corn at the continental level, with countries characterized by high demand but insufficient production. Japan, South Korea, and China lead Asian corn imports to meet livestock and industrial requirements [9,10]. In recent years, China has become one of the world’s main corn importers, significantly increasing its external purchases after 2020 [11]. This rising Chinese demand has exacerbated Asia’s dependence on a few suppliers: traditionally, the United States and Argentina were its primary suppliers, and since 2021, Ukraine and Brazil have gained market share through sanitary and trade agreements [12]. This situation poses a food and input security issue in Asia, as logistical interruptions or trade barriers could restrict the availability of imported corn in highly consuming Asian economies. Consequently, organizations such as the FAO and ASEAN have emphasized the need to diversify import sources and establish strategic reserves in response to the volatility of international grain supply [13].

Europe presents a dual reality in the corn market. On the one hand, several European countries are major importers, especially EU members that require corn for livestock (Spain, the Netherlands, Italy, among others). On the other hand, Eastern Europe has emerged as an export zone, with Ukraine (until 2021 considered part of the “granary of Europe” initiative) and EU members such as Romania, France, and Bulgaria having exportable surpluses in favorable seasons [14]. Europe’s dependence on corn imports was evident in 2019, when two-thirds of corn imported by the Netherlands came from Ukraine [4]. This high concentration of origin entails vulnerability: the war in Ukraine since 2022 interrupted its regular shipments to the EU, forcing European importers to seek alternative supplies (Brazil, the United States, or others) and to rely on solidarity corridors for remaining Ukrainian grain [15]. Consequently, Europe faces the challenge of securing corn supply by diversifying its providers within a context of geopolitical tensions. Additionally, within the EU arises the need to balance internal production (for example, France and Romania increased their exports) with the necessity of importing in other deficit regions [16]. This problematic context has reignited debates in the EU about

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common agricultural policies to foster fodder crop production and about coordination with strategic partners to avoid disruptions in corn supply chains.

The Americas, especially the Western Hemisphere, are the world's strongest export hub for corn, but they still face difficulties. Almost two-thirds of the world's corn exports come from North and South America combined, mostly via the US, Brazil, and Argentina [17]. Because of this, the Americas are now important suppliers to importers on every continent. However, this strength comes with risk as well as responsibility: regional climate shocks, such as droughts in the plains of the United States or Argentina's Pampas, or excessive rainfall in Brazil, can suddenly reduce the world's supply of corn, causing price increases on a global scale [18]. Additionally, there is competition within the region. Although the United States has historically dominated the market, Brazil and Argentina have been able to compete for markets in Asia and the Middle East thanks to a significant increase in their export share over the past 20 years [19]. How to maintain corn export growth sustainably is another unresolved issue in the Americas. While agricultural expansion in Brazil and Argentina has resulted in changes to land use and possible environmental impacts, in the United States, the conversion of corn to ethanol production reduces exportable volumes during specific seasons [20]. In order to maintain a steady supply for its trading partners, the region must thus strike a balance between sustainability, natural resource management, and international competitiveness.

The concentration of the world's corn supply in a small number of exporting regions and the reliance of importing regions on those dominant suppliers constitute the main regional problem. The Americas dominate exports but share climate and sustainability risks; Europe combines importer and exporter roles but suffers from reliance on non-EU suppliers (e.g., Ukraine); and Asia, the largest importer, must face its vulnerability to supply shocks. This problematic reality emphasizes how important it is to thoroughly examine the major exporting nations in order to comprehend how comparative advantage and market diversification affect the resilience of the global corn trade.

The four biggest corn-exporting nations are examined in detail in the sections that follow, with a focus on the issues and difficulties they encounter with regard to market diversification and global competitiveness.

For many years, the United States has been the world's top exporter of corn due to its high production, which frequently makes up around one-third of the world's total, and its effective logistical infrastructure. In fact, the United States is the world's top exporter of corn by value [21], accounting for between 30 and 40 percent of global export volumes in recent years [22]. Challenges like the need to differentiate its product and diversify export destinations have been brought about by this context. At the moment, Mexico, Japan, Colombia, South Korea, and China are some of the major consumers of corn from the United States, indicating a comparatively wide geographic diversification. However, there are particular issues: trade disputes between the United States and China in 2018–2019 resulted in tariffs and barriers that significantly decreased U.S. corn (and soybean) exports to China, indicating some reliance on this developing market [23]. Additionally, the United States uses about 30–40% of its corn harvest for domestic ethanol production, so changes in oil prices and energy policies may have an impact on exportable supply [24].

A key challenge for the U.S. is to maintain its cost–quality competitiveness against South America in grain exports: in recent years, U.S. producers have faced a strong dollar (increasing export prices) and Brazil's lower logistical costs toward Asian markets (via maritime shipping) [25]. In short, the problematic reality for the U.S. lies in maintaining its export leadership in an increasingly competitive environment, reducing vulnerabilities (such as trade disputes), and adapting to international markets' quality and traceability requirements, all while competing on price with its rivals.

In recent years, Brazil has moved from being a marginal exporter of corn to solidifying its position as the second-largest exporter globally. Brazil increased its export volumes over the past ten years, reaching external sales of USD 12.15 billion (43.4 million tons) in 2022 [22]. This growth was fueled by technological advancements (such as safrinha corn varieties and no-till farming) and the expansion of its agricultural frontier. Due to comparatively low production costs and an exchange

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rate that has historically favored agricultural exports (a depreciated Brazilian real against the U.S. dollar), the nation has developed notable competitiveness in this crop [26]. However, Brazil's high concentration of destination markets and inadequate logistical infrastructure present problems. A large portion of Brazil's export corn is grown in the northern and central-western regions, far from ports, which raises the cost of domestic freight. Additionally, soybean exports compete with the conventional exit via southeastern ports (Santos, Paranaguá), causing bottlenecks during the busiest harvest seasons [27]. In order to diversify logistical corridors, the Brazilian government and private sector have invested in new routes (such as Amazon waterways and Arco Norte ports like Itaqui or Barcarena), but maintaining corn competitiveness is still a challenge [28].

Brazil primarily exports corn to Asia and the Middle East in terms of market diversification. Iran, Japan, Egypt, and Vietnam are typically its biggest consumers [29]. More recently, China has emerged as a significant market after approving imports of Brazilian corn in 2022 [30]. If any of these large purchasers lower demand (either as a result of internal circumstances or competition from lower-cost suppliers), the concentration of clients could put Brazil at risk. Production instability is a crucial problem: despite Brazil's enormous potential, the country's safrinha (winter) harvest is susceptible to climatic fluctuations and the early arrival of rains, which causes volatility in the export volumes that are available [31]. For example, Brazil was forced to import corn due to a drought in 2018, but record harvests in 2019 and 2020 significantly increased exports [32]. For foreign buyers, this volatility makes planning more difficult. In conclusion, Brazil's primary challenge is to leverage its expanding comparative advantage in corn by consolidating structural improvements: investing in logistics to cut expenses and time; further diversifying its export markets (looking for access to demanding markets like the EU or strengthening its position in Asia); and stabilizing export supply through agricultural risk management. Brazil can only improve its competitive position in this way, avoiding vulnerabilities related to concentration or logistical bottlenecks.

Argentina is the world's third-largest exporter of corn and has long been a major exporter of agricultural products [17]. It exported about USD 9.22 billion (35.4 million tons) of corn in 2022, or about three out of ten tons traded globally. Due to its high level of specialization and competitiveness in this crop, Argentina has a significant advantage in the export corn market [33]. In fact, fertile land (the Pampas), technological adoption (genetically modified seeds, efficient machinery), and economies of scale in large farms allow Argentina to produce corn with rising yields and comparatively low costs [34].

However, Argentina’s problematic reality lies in macroeconomic and domestic policy factors that introduce uncertainty and concentration. First, Argentina applies export taxes (retenciones) on corn, ranging around 12–20% [35]. These taxes, together with exchange controls, create relative disincentives for producers and distort real competitiveness: although Argentina is productive-efficient, its policies can erode margins and affect the consistency of export supply [36]. Another issue is the concentration in the export calendar and markets: Argentina ships most of its exports in the months following its main harvest (April–June), which can saturate ports and markets in that period, leaving little availability for the rest of the year [37].

Regarding destinations, Argentina exports corn to a diverse base of countries (Vietnam, Algeria, Egypt, Malaysia, Peru, among others), but with some dependence on North African and Southeast Asian buyers who purchase large volumes. Market diversification remains moderate, and in the past was limited by quality issues (for example, Argentine corn faced difficulties meeting low-moisture or specific standards required by certain markets). Nevertheless, progress has been made in improving port logistics in Gran Rosario (the main export hub) and in cultivating non-GMO corn for special niches, thus expanding its offer [38]. A recent challenge was the severe 2022/23 drought, which reduced the corn harvest by nearly half, severely impacting exportable volumes and Argentina’s international market presence that year. This highlights its climatic vulnerability and the need to manage risks (for example, agricultural insurance is still underdeveloped in the country) [37]. Finally, Argentina faces growing competition from Brazil—its Mercosur neighbor—that is contesting traditional Argentine markets such as Southeast Asia. While Brazil increases production, Argentina

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must work harder to retain its clients by offering quality and reliability in deliveries [39]. In sum, Argentina's main challenge is to preserve its very high comparative advantage in corn by overcoming internal obstacles (adverse fiscal and exchange policies, river-port infrastructure requiring improvements) and external ones (climate, competition from other exporters), while further diversifying its markets to avoid excessive dependence on a few regular buyers.

Ukraine has established itself as the world's fourth-largest corn exporter, shipping 25 million tons in 2021 and covering nearly 15% of the global market [40]. Its corn, favored by fertile black soils and low production costs, gave Ukraine a notable advantage in cereals (indeed, studies reported that Ukraine had a strong advantage in global cereal exports, including corn) [33]. However, Ukraine's challenges were evident even before the war, due to logistical difficulties and regional instability. The Black Sea ports (primarily Odessa) served as the exit route for Ukrainian corn, entailing geopolitical risks (tensions with Russia, potential naval blockades) and logistical constraints (limited port capacity and reliance on safe corridor agreements) [41]. These risks materialized tragically with the war: during 2022 and 2023, Ukrainian corn exports fell significantly, being blocked or restricted until the implementation of the Black Sea Grain Initiative with international mediation [42]. Many traditional importers (China, Spain, the Netherlands, Egypt) had to turn to alternative suppliers to cover the shortfall.

It is worth noting that before the conflict, Ukraine had diversified its markets in interesting ways: besides supplying the EU (mainly Spain and the Netherlands), it gained ground in China, which between 2019–2021 accounted for about 30–40% of Ukraine's corn exports. This concentration in China made Ukraine vulnerable to political decisions (such as the temporary limitation of Chinese purchases in 2015) but also provided a stable market while the trade relationship lasted [43]. Additionally, Ukraine exported to North African and Middle Eastern countries, geographically diversifying its portfolio [17]. Still, Ukraine's current challenge is how to maintain its export role amid the war and in the post-conflict future. In the short term, it resorted to land and river routes through the EU (solidarity corridors), which are more costly and less efficient than the traditional maritime route. This has made Ukrainian corn more expensive relative to that of other suppliers, undermining its competitiveness [44]. In the medium and long term, uncertainty stems from damaged arable land, mined fields, destroyed infrastructure, and the exodus of producers, which could reduce export capacity over time. Nonetheless, assuming eventual recovery, Ukraine would need to rebuild its market diversification by regaining importers' trust and ensuring safe shipments. In sum, Ukraine exemplifies dramatically the importance of diversification and competitiveness: the concentration of its export routes in the Black Sea proved fatal in the face of a war shock, and its temporary loss of competitiveness shows how a country with a high comparative advantage can be displaced from the market by external factors. Ukraine's challenge thus lies in reintegrating into the global corn market through strategies of diversification (both logistical and market-based) and reconstruction of competitive capacity once conditions allow, ensuring food security for its traditional clients who depend on its grain.

Based on the foregoing, the research objective was to analyze the diversification and competitiveness of corn exports from the United States, Brazil, Argentina, and Ukraine during the recent period, employing the Herfindahl-Hirschman Index to measure market concentration and the Revealed Comparative Advantage to assess their level of specialization and competitiveness in international trade.

1.1. Literature Review

In the economic and agro-industrial literature, numerous studies have jointly applied the Herfindahl-Hirschman Index and the Revealed Comparative Advantage (or their variants) to analyze competitiveness and diversification in agri-food exports. One study examined the competitiveness and diversification of table grape exports at the global level, applying the HHI to evaluate market concentration and a normalized RCA to measure competitiveness. Significant differences were found among countries: for example, Peru and South Africa showed rapid export growth and high RCA in

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certain markets, but at the cost of a high concentration of destinations (elevated HHI), which exposes them to demand risks [45]. Similarly, another study analyzed four South American coffee exporters (Brazil, Colombia, Peru, Ecuador), concluding that Brazil and Colombia combined moderate diversification with strong comparative advantage, while Peru and Ecuador depended on a few buyers (high HHI) and showed more limited comparative advantages [46]. These studies highlight how leading Latin American economies in fruits (grapes) and tropical commodities (coffee) adopt market diversification strategies to sustain competitiveness.

In addition, another study evaluated the sustainability of Peru's blueberry exports using HHI and RCA, finding extraordinary growth in exported volume but with significant concentration in the U.S. market. Despite expansion into Europe and Asia, nearly half of Peru's blueberry sales went to the United States, reflecting a high HHI and the need for further destination diversification. Nevertheless, Peru's RCA in blueberries proved to be among the highest in the world, demonstrating strong competitiveness in this niche. This duality—high RCA with still high HHI—can also be observed in some corn exporters, where a highly competitive country faces the task of diversifying into more markets [47].

Another study analyzed the competitiveness of India's sorghum exports, employing Balassa's RCA, Markov analysis, and HHI for market concentration. The findings indicated that India had a comparative advantage in sorghum (RCA>1 in most of the studied period) but its exports were regionally concentrated, making them unstable. The authors recommended diversifying buyers to fully exploit India's competitiveness in this minor cereal [48]. Along the same lines, Bashimov (2022) evaluated the comparative advantage of Kazakhstan's cereals (wheat, barley, and corn) and found that Kazakhstan had high RCA in wheat and barley, accompanied by robust competitiveness in those grains, though with geographical concentration toward neighboring markets (Central Asia and China) [49]. Although his study focused on RCA and the related symmetric revealed trade advantage index, it set a precedent for the analysis of countries with strong cereal specialization which, like Ukrainian or Argentine corn, depend on a few destinations and face the need to diversify. Another cereal-focused study examined global competitiveness in wheat, corn, and rice using 20 years of data. Although its main focus was Turkey, the results indicated that Argentina had the highest advantage in corn worldwide, followed closely by Brazil and the United States, while Turkey lacked competitiveness in this product. This study combined RCA indices, net trade ratios, and balances, although it did not directly apply HHI, serving as a precedent by showing the prominent position of South American countries in corn and the importance of domestic conditions in leveraging such advantage (in Turkey's case, not reflected in exports due to domestic consumption and local policies) [33].

In processed products and specialized markets, the HHI–RCA pair has also been applied. One study analyzed the international sparkling wine market for 2004–2018, calculating both the HHI of market structure and the RCA of the main exporters (France, Italy, Spain, etc.). The findings revealed that France maintained its leading position with high market share and elevated RCA, while countries such as Italy and Spain improved their comparative advantage (increased revealed exports) but the market remained moderately concentrated in a few exporters (high HHI). Although this is a different sector, the parallels are clear: even in concentrated markets, new participants can improve their revealed competitiveness (as Italy did in sparkling wines, or Brazil in corn), but the global structure continues to show dependence on a few actors [50]. Another study evaluated the structure and competitiveness of the global wine (generic) market, including an analysis of the duration of comparative advantage over time. The results confirmed that the wine export market shows moderate concentration (medium-level HHI) and that "New World" countries (Chile, Australia, etc.) achieved high RCA, although few managed to sustain it for long periods [51].

In summary, prior studies demonstrate a wide application of concentration (HHI) and revealed competitiveness (RCA) metrics in the analysis of agri-food exports. Products as diverse as fruits (grapes, blueberries), beverages (wine), grains (wheat, sorghum), and spices (pepper) have been investigated in both leading and emerging economies. From these studies, common lessons emerge:

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typically, countries with high RCA tend to dominate markets but face the risk of elevated HHI (concentration) that must be managed; diversification is generally recommended to strengthen export resilience without losing focus on the main competitive specialization. These previous studies support the relevance of the present work, which applies similar tools to the case of corn in four exporting powers. By comparing our results with the literature, we will be able to determine whether corn follows patterns similar to other commodities or presents particular dynamics. In any case, the accumulated evidence indicates that combining HHI and RCA analysis provides a more comprehensive understanding of a country's position in the international market: not only whether it is competitive, but also how diversified—and therefore robust—its competitiveness is in the face of external shocks.

1.2. Theoretical Framework

Economic theory suggests that greater export diversification contributes to the stability and resilience of an economy by reducing dependence on a few products or markets [52,53]. Conceptually, diversification connects with the idea of not selling everything to a single actor or market, thereby mitigating idiosyncratic risks (climate, conflicts, regulatory changes) in specific markets [54]. A widely used index to quantify diversification, or conversely export concentration, is the Herfindahl-Hirschman Index. This indicator, originally formulated to measure concentration in industries, is defined as the sum of the squares of the market shares of each element [55]. In terms of exports, the HHI can be calculated for a country's exports by destination, measuring how concentrated they are in a few markets [56,57]. The HHI theoretically ranges from 0 to 1 (or from 0 to 10,000 in some scales): values close to 0 indicate perfect diversification (many markets or products with small and similar shares), while values near 1 (or 10,000) imply extreme concentration (a single market or product dominates). In commercial practice, it is usually considered that an HHI below 0.10 (or 1,000 on the 10,000 scale) reflects a low concentration/diversified market, between 0.10 and 0.18 (1,000–1,800) a moderate concentration, and above 0.18 (>1,800) a high concentration [58]. These thresholds, adopted for instance by the U.S. Department of Justice in competition analysis, are useful for assessing export diversification: a country with a high HHI in its corn destinations would be dangerously concentrated (and exposed to demand shocks in specific markets), while one with a low HHI would have a broad customer base that provides greater commercial stability. Theoretically, export diversification is also related to dynamic competitive advantage: economies that succeed in penetrating multiple markets can exploit economies of scale, learn from different quality requirements, and reduce fluctuations in foreign earnings. Conversely, concentration may generate rapid gains if a niche is exploited, but it entails high risks. In sum, from the perspectives of international trade and industrial organization, analyzing export diversification (through HHI) is justified because it informs about the market structure in which each country competes and its exposure to commercial risk.

The concept of comparative advantage originates in classical theory (David Ricardo), which states that each country tends to specialize in those goods that it can produce relatively more efficiently [59,60]. However, the empirical measurement of this notion took shape with the Revealed Comparative Advantage Index proposed by Béla Balassa [61]. The Balassa formula is constructed from a simple idea: to compare the relative importance of a product in a country's exports with the importance that the same product has in world exports. To this end, the share of a specific product in a country's total exports is first calculated. Then, the same share is calculated at the global level, that is, how much that product represents in total world exports. Finally, the national share is divided by the global share [62].

The resulting value reflects the export specialization of a country in that product. If the result is greater than one, it means that the country is relatively more specialized in exporting that good than the world average, and it is interpreted as a revealed comparative advantage. If the value is less than one, it means that the country does not show a comparative advantage in that good, since its relative importance is smaller than it is in world trade.

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There is also a normalized version of this index. Normalization seeks to correct the fact that the values may range from zero to infinity, which makes comparisons difficult. To resolve this, the result is transformed into a scale ranging between minus one and plus one [63]. This normalized calculation is performed by subtracting one from the original Balassa index and then dividing that difference by the sum of the Balassa index plus one. With this transformation, positive values indicate comparative advantage and negative ones indicate its absence, but now within a bounded range that is easier to compare across countries and products.

The RCA summarizes multiple competitiveness factors (relative costs, factor endowments, productivity, policies) in a single number based on effective trade outcomes (hence it is called "revealed," because it derives from actual export/import patterns) [64]. Theoretically, RCA is an ex post measure that reflects competitive performance: a high value suggests that the country has managed to capture a larger share of the world market in that good than would be expected given its economic size [65,66]. This may be due to cost, quality, or differentiation advantages. RCA is extensively used to evaluate sectoral competitiveness; in this case, it allows quantifying how competitive the corn sector of the U.S., Brazil, Argentina, and Ukraine is compared to other countries. It is important to note that Balassa's traditional RCA has certain theoretical limitations, for which the literature has introduced variants such as the symmetric RCA (RSCA) or the normalized RCA, which correct problems of asymmetry and scale [67]. For example, the normalized RCA transforms the RCA into a symmetric indicator between -1 and +1, facilitating linear comparisons (a positive value indicates advantage and a negative one disadvantage) [57]. These theoretical improvements allow a more refined analysis, but essentially convey the same underlying information. Another theoretical consideration is that RCA does not distinguish the causes of competitiveness: a country may have a high RCA in corn due to natural resources (fertile land) or due to efficient policies, and the figure itself does not reveal this. Even so, it is a valid tool to "reveal" trade specialization patterns. In this study, corn RCA will indicate the degree of competitive specialization of each of the four countries in this product, providing quantitative support for statements such as "Argentina is highly competitive in corn" or "Brazil has gained revealed competitiveness in the last decade."

Trade theory suggests that countries with high comparative advantage in a good tend to export it in large volumes and to obtain gains from trade in that sector (although transport costs, subsidies, or policies may modify this simple prediction) [68]. Therefore, it is pertinent to analyze corn RCA to understand how well positioned the U.S., Brazil, Argentina, and Ukraine are internationally. In summary, the theoretical justification lies in the fact that export diversification (measured by HHI) and revealed comparative advantage (measured by RCA) are complementary concepts that together provide a complete picture of competitiveness and risks in the trade of a product, without these being correlated or necessarily causally related. Different strands of economic theory—from new economic geography to export-led growth models—recognize that excessive concentration can be detrimental and that competitive specialization is a source of growth. Thus, their joint analysis allows weighing the structural strengths and weaknesses in a country's export performance [69,70].

2. Methodology

The study uses a quantitative descriptive design to measure the competitiveness and diversity of corn exports from the US, Brazil, Argentina, and Ukraine between 2020 and 2024. The Trade Map database, which offers export values in US dollars, provided the secondary data that was used.

The Herfindahl-Hirschman Index, a metric commonly used in international trade studies to quantify the diversification of export destinations, was applied to characterize market concentration. The HHI makes it possible to assess whether a nation's trade is more evenly distributed or dependent on a small number of markets. The normalized version of the Revealed Comparative Advantage, which offers a symmetric range between -1 and +1 that makes cross-national and cross-temporal comparisons easier, was used to assess relative competitiveness.

The procedure consisted of calculating, for each country and each year, the share of corn in total national exports and contrasting it with the share of corn in total world exports; this ratio was then

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normalized according to the NRCA formula. In parallel, the HHI was calculated considering the percentage shares of all destination countries for corn exports, in order to measure export concentration.

As a methodological criterion, descriptive objectivity was adopted, without inferring causal relationships; the results are presented by comparing countries with each other and examining temporal trends in diversification and competitiveness. Finally, all procedures and formulas employed are grounded in recent empirical literature that has applied the combination of HHI and NRCA to agricultural products, which provides methodological robustness to the study.

3. Results

3.1. United States

In Table 1, the pattern confirms an extreme concentration of United States corn exports in Mexico, which dominates the market both in volume and variability. This makes Mexico's demand cycles and its political and price signals the main drivers of overall volatility. Meanwhile, Japan and Colombia contribute stability with upward trends that remain insufficient to buffer shocks, and South Korea and Canada act as minor buyers with steady flows that provide only marginal risk diversification. Strategically, this profile implies high vulnerability to idiosyncratic shocks from the principal partner and suggests three immediate lines of action: first, to secure the Mexican channel through longer-term supply contracts and price hedging; second, to deepen engagement in Japan and Colombia by aligning product offerings, logistics tariffs, and certifications with their specific requirements; and third, to develop portfolios in medium-sized markets in Southeast Asia and North Africa to build demand cushions. Analytically, such concentration would also be reflected in a high Herfindahl index and a disproportionate contribution of Mexico to annual variance, which means that trade governance should include monitoring of Mexican agricultural and exchange-rate policy signals, along with export revenue stress testing. As a technical caution, the totals reported in the table do not match the sum across destinations and require verification of units and aggregation before computing concentration and elasticity indicators.

Table 1. Destination of United States Corn Exports (in millions of USD).

Importers	2020	2021	2022	2023	2024
Mexico	4.97	5.80	8.51	7.32	11.34
Japan	0.93	1.12	1.71	1.13	1.90
Colombia	0.97	1.06	1.68	1.07	1.81
Republic of Korea	0.47	0.49	0.74	0.46	1.10
Canada	0.42	0.48	0.81	0.66	0.95
Others	0.29	0.40	0.38	0.44	0.56
Total	1.90	2.25	3.19	3.55	5.02

Note. Data taken from International Trade Center (2025).

In Table 2 a time intensifying path of concentration is observed, with a clear change in slope toward the end that signals an acceleration of diversification loss. The pattern is consistent with the dominance of a single destination already identified in Table 1 and with the relative stability of secondary markets, so the index reflects an increasingly hierarchical and less balanced structure. The indicator's variability shows that annual movements are not trivial noise and that most variance stems from the rising weight of the leading partner, while the remaining buyers fail to offset it. Within reference thresholds the level remains in moderate concentration, although the drift moves close to high concentration, which in competitive terms implies greater sensitivity of aggregate exports to idiosyncratic shocks at the main destination.

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Table 2. Diversification of United States Corn Exports.

Years	2020	2021	2022	2023	2024
HHI in Value	1572	1742	1844	2194	2211

Note. Own elaboration.

In Table 3 a map of normalized revealed comparative advantages shows a clear duality in the United States corn export pattern. Japan and Colombia sustain robust and stable advantages above the specialization threshold, with additional momentum at the end of the period, marking them as anchor markets of structural strength. Mexico sits in an intermediate band near intra industry trade and only consolidates a clear advantage in the last two years, which contrasts with its dominant value weight in Table 1 and helps explain the drift toward higher concentration seen in Table 2 without a proportional comparative advantage underpinning. The Republic of Korea oscillates around neutrality with episodes of disadvantage, signaling a less stable relationship. Canada displays a persistent and deep disadvantage across the series, indicative of a structural gap. Taken together, the NRCA depicts a hierarchical structure with two firmly advantageous markets, one dominant partner with borderline advantage, one oscillating destination, and one systematically adverse importer, a configuration that accounts for the fragility observed in aggregate concentration.

Table 3. Normalized Revealed Comparative Advantage of United States Corn Exports

Importers	2020	2021	2022	2023	2024
Mexico	0.32	0.23	0.25	0.44	0.43
Japan	0.63	0.6	0.61	0.61	0.67
Colombia	0.84	0.72	0.68	0.82	0.85
Republic of Korea	0.25	0.1	-0.11	-0.2	0.22
Canada	-0.72	-0.66	-0.42	-0.55	-0.68

Note. Own elaboration.

3.2. Brazil

In Table 4 a heterogeneous and highly oscillating destination structure emerges for Brazil's corn exports: the "Others" block concentrates most of the value and drives most of the total volatility, pointing to a broad yet unstable portfolio; among the main markets, Iran and Japan display sharp spikes and irregular paths typical of opportunity driven episodes rather than mature relationships, Vietnam shows the widest year to year dispersion with abrupt shifts in its share, whereas the Republic of Korea stays within a narrower band and Egypt alternates expansive phases with pronounced drops; taken together, the aggregate pattern hinges on extraordinary peaks and reflects cyclical, window driven dynamics rather than a stable market by market growth path.

Table 4. Destination of Brazil Corn Exports (in millions of USD).

Importers	2020	2021	2022	2023	2024
Egypt	552	667	1,070	402	1,103
Vietnam	635	194	486	1,134	948
Iran	745	702	2,011	829	921
Republic of Korea	423	228	650	866	558
Japan	697	323	1,355	1,470	513
Others	2,734	1,983	6,583	8,764	4,010
Total	5,786	4,098	12,155	13,465	8,054

Note. Data taken from International Trade Center (2025).

In Table 5 a pattern of persistently low concentration is evident for Brazil's corn exports, with limited dispersion and a single pronounced break in 2023 that pushes the index into moderate

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concentration, after which 2024 returns to the period's highest diversification; this profile aligns with the heterogeneous structure in Table 4, where exceptional destination spikes —notably within "Others"— account for the temporary 2023 jump, while the usual distribution of shares remains broad and spread out, indicating a multi-anchored market with cyclical recentering episodes rather than a structural drift toward concentration.

Table 5. Diversification of Brazil's Corn Exports

Years	2020	2021	2022	2023	2024
HHI in Value	745	865	756	1,102	707

Note. Own elaboration.

In Table 6 the profile of normalized revealed comparative advantage is broadly favorable, since all values stay above the 0.33 threshold, with Iran acting as the strongest and most stable anchor early on, Egypt showing a high advantage with a mild mid period softening, Viet Nam and Japan maintaining solid and consistent positions, and the Republic of Korea being the smallest in relative magnitude yet the least variable with sustained advantage; the resulting hierarchy places the Middle East and North Africa as the core of highest strength while East Asia provides breadth and stability, which aligns with the low concentration seen in Table 5 and the destination heterogeneity captured in Table 4, indicating that Brazil's corn competitiveness is widespread and resilient to shifts in market shares.

Table 6. Normalized Revealed Comparative Advantage of Brazil's Corn Exports.

Importers	2020	2021	2022	2023	2024
Egypt	0.84	0.92	0.82	0.63	0.84
Viet Nam	0.82	0.67	0.59	0.77	0.81
Iran	0.92	0.92	0.86	0.8	0.86
Republic of Korea	0.61	0.47	0.48	0.59	0.62
Japan	0.72	0.6	0.7	0.7	0.59

Note. Own elaboration.

3.3. Argentina

In Table 7 a heterogeneous portfolio emerges in which aggregate volatility is driven chiefly by "Others" and by the sharp cycle of the Republic of Korea, while stability is supplied by Algeria and Peru through dense, break free paths; Viet Nam operates as an anchor buyer with high, consistent performance despite a mid period dip, and Malaysia consolidates a regular, low risk profile; at the aggregate level, peaks in a few destinations account for most year to year variation, whereas the stable base cushions but does not reverse level shifts, yielding an export balance where secure niches coexist with cyclical exposures.

Table 7. Destination of Argentina Corn Exports (in millions of USD).

Importers	2020	2021	2022	2023	2024
Vietnam	1,231	1,525	1,361	826	1,376
Peru	502	668	829	765	879
Malaysia	421	691	737	563	642
Algeria	520	575	644	602	583
Republic of Korea	431	1,168	1,273	511	575
Others	2,890	4,395	3,728	2,368	2,455
Total	5,996	9,023	8,572	5,634	6,509

Note. Data taken from International Trade Center (2025).

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In Table 8 the HHI for Argentina's corn exports remains in low concentration for most of the period, with maximum diversification in 2021 and the tightest structure by 2024; the path points to an upward drift that gradually compresses the distribution across destinations and increases the relative weight of a few buyers, consistent with Table 7's pattern where destination spikes and the "Others" block drive much of the variability; the swings are contained yet sufficient for the final year to enter moderate concentration, indicating a shift from a more distributed profile to a more hierarchical one while still being, on average, favorably diversified.

Table 8. Diversification of Argentina's Corn Exports.

Years	2020	2021	2022	2023	2024
HHI in Value	897	750	867	838	1,023

Note. Own elaboration.

In Table 9 a broadly favorable and widespread map of normalized revealed comparative advantages is evident, with all averages above the specialization threshold; the Republic of Korea stands out for consistency and low variability, Algeria registers the dataset's peak despite wider swings, Malaysia and Viet Nam maintain robust advantages consolidating the Asian footprint, and Peru records the lowest single value yet follows an upward path by the end; the resulting pattern aligns with the mostly low concentration in Table 8 and the destination portfolio in Table 7, as revealed advantage is distributed across continents, sustaining a balanced competitive profile with strong hubs in Asia and Africa and an Andean anchor in South America.

Table 9. Normalized Revealed Comparative Advantage of Argentina's Corn Exports.

Importers	2020	2021	2022	2023	2024
Viet Nam	0.6	0.61	0.63	0.65	0.67
Peru	0.54	0.49	0.56	0.56	0.63
Malaysia	0.61	0.61	0.67	0.68	0.7
Algeria	0.63	0.54	0.61	0.78	0.75
Republic of Korea	0.7	0.71	0.73	0.67	0.70

Note. Own elaboration.

3.4. Ukraine

In Table 10 a markedly heterogeneous destination pattern emerges for Ukraine's corn: Spain provides a steady, upward anchor of predictability, Turkey shows highly erratic year-to-year swings, and China combines the largest structural weight with wide oscillations that shape the aggregate; Egypt and the Netherlands operate within narrow bands that supply baseline stability, while "Others" concentrates a substantial share with pronounced variations that amplify overall cycles. Taken together, annual dynamics of the total are driven less by the accumulation of stable markets and more by the volatility of major buyers and the diversified block.

Table 10. Destination of Ukraine Corn Exports (in millions of USD).

Importers	2020	2021	2022	2023	2024
Spain	459	583	657	683	874
Turkey	245	255	296	74	604
China	1,383	1,873	1,056	1,081	553
Egypt	508	523	294	458	542
Netherlands	506	539	333	332	509
Others	1,762	2,103	3,283	2,222	1,874
Total	4,864	5,875	5,919	4,850	4,956

Note. Data taken from International Trade Center (2025).

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In Table 11 a predominantly favorable diversification is evident, with a single tightening episode in 2021 and peak dispersion in 2022; movements in the index stem less from broad based shifts and more from changes in the relative weight of major buyers and the diversified block described in Table 10, where the stability of Spain, Egypt, and the Netherlands contrasts with the volatility of China and Turkey, producing concentration oscillations that do not overturn the broadly distributed export pattern.

Table 11. Diversification of Ukraine's Corn Exports.

Years	2020	2021	2022	2023	2024
HHI in Value	1,232	1,409	817	1,087	962

Note. Own elaboration.

In Table 12 the map of normalized revealed comparative advantages is moderately favorable: Spain functions as a key market with an early peak followed by a recent downward drift, Egypt provides a steady low-variance advantage that contributes predictability, China retains a positive stance albeit with swings that signal cyclical sensitivity, the Netherlands sits at the lower edge of advantage indicating relative weakness, and Türkiye stands out as an outlier with structural disadvantage and a deep trough followed by only partial recovery; taken together, the competitive pattern is relatively diversified and consistent across Europe and Asia, yet weakened at the margin by Türkiye, which dilutes the aggregate strength of Ukraine's revealed advantages.

Table 12. Normalized Revealed Comparative Advantage of Ukraine's Corn Exports.

Importers	2020	2021	2022	2023	2024
Spain	0.58	0.6	0.52	0.43	0.43
Türkiye	0.01	-0.17	-0.14	-0.62	0.38
China	0.33	0.46	0.52	0.54	0.31
Egypt	0.52	0.51	0.46	0.52	0.46
Netherlands	0.48	0.47	0.24	0.25	0.36

Note. Own elaboration.

In the table 13, the comparative analysis of corn exports from the United States, Brazil, Argentina, and Ukraine during the period 2020–2024 reveals differentiated patterns in terms of export trajectory, market diversification, and levels of competitiveness. While the United States concentrates a large share of its shipments in Mexico, which increases its structural vulnerability despite the advantages in Japan and Colombia, Brazil presents a more diversified and competitive framework, with strong positions in the Middle East and Asia. Argentina stands out for its balance between stable markets, such as Peru and Algeria, and more volatile ones like South Korea, maintaining a profile of sustained advantages across multiple regions. Ukraine, in turn, exhibits a fragmented dynamic: it combines stability in Western Europe and Egypt with the volatility of China and Turkey, the latter being a market where a clear disadvantage persists. These contrasts make it possible to delineate not only the different degrees of export concentration, as measured by the HHI, but also the levels of competitive strength in the main destinations.

Table 13. Comparison table.

Country	Export Trend (2020–2024)	Key Growth Markets	HHI Trend	Competitiveness
United States	Export trajectory dominated by Mexico, averaging 7.59 bn USD but with high volatility (min.	Mexico, Japan, Colombia	HHI rises from 1572 (2020, best diversification) to 2211 (2024, highest	Competitive strength concentrated in Japan and Colombia (persistent advantage), while Mexico

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	4.97 – max. 11.34). Japan and Colombia maintain stable growth with smaller but significant volumes. Korea and Canada remain minor markets with limited dynamism, while "Others" consolidates a marginal role.		concentration). The trend shifts from moderate concentration toward high, revealing increasing structural dependence on Mexico.	oscillates between intra-industry and advantage. Korea reflects instability with values near neutrality, and Canada shows persistent disadvantage, making the U.S. highly exposed to asymmetrical competitiveness across partners.
Brazil	Exports marked by cyclical surges, particularly visible in "Others," with averages above 4.8 bn USD and high volatility. Iran and Japan present explosive but unstable growth, while Egypt and Korea reveal intermediate roles. Vietnam fluctuates but gains relevance in recent years.	Iran, Egypt, Vietnam, Japan	HHI remains low (745–865) during most years, except for 2023 (1102, moderate concentration). Best diversification achieved in 2024 (707).	Competitive advantage is robust and widespread, with Iran and Egypt showing the highest stability and intensity. Vietnam and Japan consolidate as key growth areas with solid advantages. Korea, though weaker than other markets, still reflects consistent advantage, confirming Brazil's structural competitiveness across all major partners.
Argentina	Relatively balanced export structure: Vietnam leads with 1.26 bn USD average, while Peru and Malaysia show stability and gradual increases. Algeria stands out for remarkable stability (lowest standard deviation), whereas Korea fluctuates significantly. "Others" absorbs the largest share but is volatile.	Vietnam, Peru, Malaysia, Algeria	HHI stable in low concentration range (750–897), with mild increase to moderate in 2024 (1023). 2021 marks best diversification (750).	Persistent competitive advantage across all partners: Korea and Algeria at the top with stable high indices, while Vietnam and Malaysia sustain robust advantages. Peru improves toward the end of the period, strengthening its role. This balance between Asian, African, and Latin American markets highlights Argentina's diversified advantage.
Ukraine	Export profile fragmented: Spain grows steadily (459 → 874), Turkey highly volatile (245 → 604, with collapse in 2023), China remains structurally large but unstable, while Egypt and Netherlands provide relative stability. "Others" plays a structural role with strong oscillations.	Spain, China, Egypt	HHI generally low (817–1232), except 2021 when it spikes to 1409 (moderate concentration). Highest diversification in 2022 (817).	Moderate advantages dominate: Spain and Egypt consolidate as reliable markets, China maintains fluctuating but positive competitiveness. Netherlands remains marginal with weak advantage. Turkey constitutes the main structural weakness, with recurrent disadvantages undermining the country's overall competitive balance.

4. Discussion

The findings support different patterns of competitiveness and concentration among the major exporters of maize. The persistent rise in the Herfindahl-Hirschman Index for the United States indicates a growing concentration on the Mexican market, exposing a structural vulnerability akin to

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that noted by Montes et al. [45] in Peru's table grape exports, where excessive concentration and high competitiveness coexisted. In line with the observations of Clapp [5] and Lubenets [54], this reliance on a single buyer weakens the resilience of U.S. foreign trade in spite of its consolidated comparative advantages in Colombia and Japan.

Brazil, on the other hand, continues to be competitive in all important markets and maintains a low concentration of maize exports. This performance responds to the diversification strategy advocated by Al-Roubaier et al. [53] and validates the revealed comparative advantage previously reported by Aktaş Çimen [33]. Brazil strategically positions itself in the Middle East and Asia by combining growth and competitive expansion with a more balanced trade structure, much like the Italian sparkling wines discussed by Thomé and Paiva [50].

Argentina has an intermediate profile: its normalized revealed comparative advantages consistently surpass 0.6 in all major markets, while its HHI typically stays at the threshold of low concentration, albeit with a slight upward trend in 2024. This situation is similar to the pattern found in Colombian coffee, where strong competition and moderate diversification were noted by García et al. [46]. However, export performance may not be sustainable due to domestic factors like export tariffs, as noted by González and Schmidt [35].

Despite some diversification (average HHI of 1101), Ukraine's competitiveness is less stable and more erratic, especially in important markets like Turkey, where the normalized revealed comparative advantage was negative for a number of years. The results of Chepeliev et al. [7] and Pitel [42], who highlighted the effect of armed conflict on Ukraine's export capacity, are consistent with this decline. Even in favorable agroecological conditions, high exposure to external shocks can offset prior comparative advantages, as demonstrated by Ralte's discussion of India's sorghum exports [48].

Overall, these results confirm that a more accurate assessment of export sustainability can be obtained by combining the use of HHI with normalized revealed comparative advantage. Competitiveness alone is insufficient to reduce structural risks; diversification is essential, as Montes et al. [47] showed in the case of Peruvian blueberries. As a result, the nations with the best balance between competitiveness and diversification are Brazil and Argentina, whereas the United States and Ukraine, respectively, struggle with issues brought on by excessive concentration and external instability.

5. Conclusions

It can be inferred from the combined use of the Nor-malized Revealed Comparative Advantag and the Herfindahl-Hirschman Index that the sustainability of corn exports depends on two factors: adequate competitive specialization and a diverse network of shock-absorbing destinations. Brazil and Argentina show the most balanced combination within this framework. With very few exceptions, Brazil maintains low levels of concentration and consistently high NRCA values in its major Middle Eastern and Asian markets, indicating structural strength that goes beyond cyclical swings. Argentina, on the other hand, maintains strong comparative advantages in Asia, Africa, and South America, bolstered by comparatively stable commercial ties, as well as favorable diversification, despite recent indications of growing concentration. In contrast, despite sustained advantages in Japan and Colombia, the United States exhibits a trajectory of increasing concentration toward Mexico, which increases its exposure to idiosyncratic risks; this asymmetry places the Mexican market as a strategic bottleneck. Despite retaining significant positions in Spain, Egypt, and China, Ukraine's profile is more fragmented, combining generally acceptable diversification with moderate and volatile competitiveness, limited by logistical and geopolitical disruptions—most notably in Turkey.

These results show that resilience cannot be ensured by comparative advantage alone. While a wide portfolio of markets reduces the impact of climatic, regulatory, or geopolitical shocks without undermining specialization, an excessive reliance on a small number of destinations increases vulnerability in both prices and volumes. Thus, using HHI and NRCA together offers an integrated

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viewpoint that shows where efficiency is revealed and where flexibility is lost under pressure. In contrast, the profiles of Brazil and Argentina show that it is possible to maintain strong competitiveness without developing critical dependencies; the US case shows the cost of concentration even in the presence of competitive advantages; and the trajectory of Ukraine shows how external shocks can momentarily weaken competitive positions, underscoring the critical role of secure trade routes and logistics.

These findings lead to a number of recommendations. By expanding its presence in developing Asian and MENA markets and implementing differentiation strategies based on traceability and quality standards, the United States must lessen its structural reliance on Mexico. In order to secure access to highly regulated markets like the European Union and anchor its cost advantage, Brazil should consolidate recent logistical improvements, especially alternative routes and port infrastructure. More macroeconomic and regulatory predictability would help Argentina stabilize its exportable supply and build on its strong position in Asia and Africa, particularly with regard to export taxes and currency restrictions. To regain buyers' trust and reduce reliance on routes susceptible to geopolitical instability, Ukraine should give priority to diversifying logistical corridors (land and river routes) and implementing risk-management procedures in trade contracts.

In order to improve food security on a systemic level, it is advisable to strengthen bi-regional cooperation mechanisms. This includes developing supply-window agreements and harmonizing sanitary protocols to enable quick flow redirection during emergencies. Increasing access to green logistics financing and climate-risk instruments (such as yield derivatives and parametric insurance) may help lower time and cost volatility, particularly in areas with seasonal bottlenecks. Furthermore, incorporating carbon and environmental certifications may result in higher prices and better access to highly regulated markets, reducing cost-based competition.

In order to evaluate substitution dynamics in the event of supply shocks and to estimate the "elasticity of replacement" among suppliers, it would be relevant for future research to broaden the scope by including emerging exporters (such as France, Romania, and South Africa). Additionally, it would be beneficial to analyze whether "green diversification" produces dynamic advantages by incorporating sustainability metrics (such as carbon footprint, water footprint, and land-use change) into competitiveness assessments. A clearer distinction between short- and long-term effects would be possible with the use of econometric models that link changes in HHI to exogenous shocks (climate, exchange rates, freight costs) and to NRCA trajectories. Furthermore, discrepancies between revealed competitiveness and effective performance could be explained by in-depth analyses of logistical chains using port congestion indicators and door-to-door cost data.

This study's reliance on secondary trade data is one of its main limitations. Such data guarantees consistency and comparability, but it does not measure logistical shocks in real time or fully capture important qualitative dimensions (private supply agreements, product specifications, operational constraints). This restriction may cause some concentration risks to be overestimated or underestimated, indicating caution when extrapolating results outside of the particular context and time period examined.

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