Evolution of global grain trade network and supply risk assessment based on complex network

Gang Wang*, Rosidah Binti Musa*, Baihua Li**, Xiaoxue Liu***

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Abstract

The global distribution of grain resources is uneven, and this paper analyzes the evolution of the global trade network of wheat, corn and rice from 2012 to 2021, based on the complex network. At the same time, a global grain trade supply risk assessment index system was established to assess the supply risk of the main import trade countries of wheat, corn and rice in 2021, and the following conclusions were obtained. The trade relationship of corn was the most dense, and the trade connectivity between countries was the highest, while the trade group differentiation of rice was the highest, and the trade group characteristics were more prominent. Canada, America, Australia, Russia, Argentina, Ukraine, Brazil, India and China were the major grain export countries. Italy, America, France, Germany, the Netherlands and South Africa occupied the important positions in the global grain trade network. The supply risk of wheat trade gradually increased with the import volume from high to low. The supply risk of rice was higher than that of wheat and corn as a whole, and the high risk was mainly concentrated in countries with high import trade.

Keywords: *Global grain trade, Trade network, Network evolution, Supply risk.*

1. Introduction

Grain is the material basis for ensuring people's basic life and the stable development of economic and social. However, with the gradual increase of the current world ecological environment risk and the continuous growth of the international population, the pressure on world grain demand is gradually increasing (Lotze-Campen *et al.*, 2014). According to the data of the Food and Agriculture Organization of the United Nations (FAO), as many as 828 million people in the world would face hunger in 2021, mainly in Africa, Asia, Latin America and the Caribbean. In 2022, about 205 million people in 45 countries and regions were in the "crisis" or more serious level of grain insecurity, with a significant increase over the previous year (Jongwanich and Park, 2011; Lahiff, 2014). As important grain exporters, Russia and Ukraine, with the outbreak of the Russian-Ukrainian war, international grain prices began to rise, and the global

* City University Malaysia, Department of Accounting and Business, Petaling Jaya, Malaysia.
** Hebei International Joint Research Center for Remote Sensing of Agricultural Drought Monitoring, Hebei GEO University, China; Science and Technology Department, Shijiazhuang, China.
*** Hebei GEO University, Science and Technology Department, Shijiazhuang, China.
Corresponding author: libaihua09@163.com

grain trade pattern became more volatile, further exacerbating the global grain supply risk (Myers *et al.*, 2017). In addition, many factors, such as the imbalance of world grain distribution, regional differences in grain resources, the spread of international epidemic, and trade policies, had aggravated the risks of international grain trade, and grain security had gradually become an important issue in the economic and social development of countries (Cassman, 2007).

Due to the differences in food resources in different regions of the world and the gradual deepening of economic globalization, international trade has become an important way to meet a country's food needs (Wu and Gudu, 2013). The trade activities carried out by countries to meet their own grain needs had formed more complex trade relationships, which had made the global grain trade more closely linked (Schnebele *et al.*, 2019). Different countries play different roles or positions in global grain trade, and the trade dependence formed by grain import and export trade is an important factor affecting the supply security of a country's grain trade. When a country's grain demand needs to be met through import to a large extent, and import countries are relatively concentrated, it will have greater dependence on the grain import market. Furthermore, when there are fluctuations or interruptions in the food supply or trade of the supplying country, there will be a direct risk of food supply to the importing country. Insufficient food supply will also have a potential impact on the stability of the domestic economy and society. Therefore, researching the global grain trade and understanding the characteristics of grain trade in different countries have important reference significance for ensuring national food supply security.

In the existing research on global grain trade, some scholars had analyzed the import and export trade policies and trade competitiveness of the world or regions (Bellamy and Basole, 2013). Complex network is an important method to evaluate the complex links between economy and society. Many scholars had used complex network to study the international trade of global commodities, such as energy, mineral resources, agricultural products, etc (Wen *et al.*, 2021). In terms of global grain trade, some scholars have carried out complex network analysis of global trade on single food products such as wheat and corn, and put forward corresponding suggestions on food trade security (Fair *et al.*, 2017). However, there are few studies on the changes in the development pattern of global grain trade. At the same time, in the studies of the risk of grain import trade, most of them were based on the trade status or impact factors and put forward trade risk response suggestions, lacking the assessment of supply risk (Erdmann and Graedel, 2011).

Based on the data of international grain trade from 2012 to 2021, this paper constructed a global grain trade network with complex network method to analyze the overall characteristics and differences of the network among the major grain varieties in the world, so as to obtained the key countries in the global grain trade network and the pattern evolution, and finally put forward policy recommendations to maintain the stability and supply security of the world grain trade.

2. Data and method

2.1. *Data source*

Global grain trade research mainly uses information on major grain import and export trade in various countries as research data. Select wheat, corn, and rice as the research objects of global grain trade, and summarize the global trade information of wheat, corn, and rice from 2012 to 2021.The trade statistics in the United Nations Trade Database (UN Comtrade) cover the trade flows and data of wheat, corn, and rice in various countries from 2012 to 2021; Retrieve the HS codes of wheat, corn, and rice to obtain the names of trade import and export countries and trade volumes. We further selected the information of grain import of each country as the analysis data, because the import information was usually more accurate (Shi *et al.*, 2020). In order to achieve the comparability of data between trading countries, the total amount of trade (in USD) was selected as the weight analysis of trade relations (Shi *et al.*, 2020). We cleaned and pretreated the original data to obtain the number of global trading countries, trade relations and

trade volume of wheat, corn and rice from 2012 to 2021, respectively, for the construction and analysis of the global grain trade network.

2.2. *Method*

In the analysis of the relationship and pattern of global grain trade, we mainly used the complex network method to construct the global grain trade network, with trading countries as nodes and trade import relations as edges. We analyzed the position and differences of trading countries in the global grain trade pattern through the topological structure and characteristics of the grain trade network.The global trade networks of wheat, corn and rice, $WGTN_e$, $CGTN_f$ and $RGTN_m$, are respectively constructed by using complex networks. The trade network is composed of C=(P, G) sets, where the node P=(p_i: i=1, 2, 3… n) represents the trading country. We express the trade relationship between p_i and p_j as a_{ij}. If national p_i carries out grain trade with national p_j, it would draw a link from p_i to p_j, a_{ij}=1, otherwise, a_{ij}=0, it would not draw any link. The weight of the node edge in the network is expressed as G, G={gij}, which is the total amount of grain trade between the two countries (unit: USD), and the direction of commodity trade flow is the direction of the edge (Zhang *et al.*, 2014).

The network density, average clustering coefficient and modular degree were selected as the analysis indicators of the overall topological structure of the trade network. Among them, network density was used to measure the degree of close connection between two countries in the trade network. The higher the network density, the closer the connection between countries in the network. The average clustering coefficient was a reflection of the connectivity between trading countries, indicating the possibility of the formation of trade relations. The higher the average clustering coefficient was, the better the trade connectivity between countries was. The degree of modularity indicated the degree of group differentiation in the network. The greater the degree of modularity, the more obvious the network differentiation and the stronger the group.

Figure 1 - Network of international wheat trade relations in 2021.

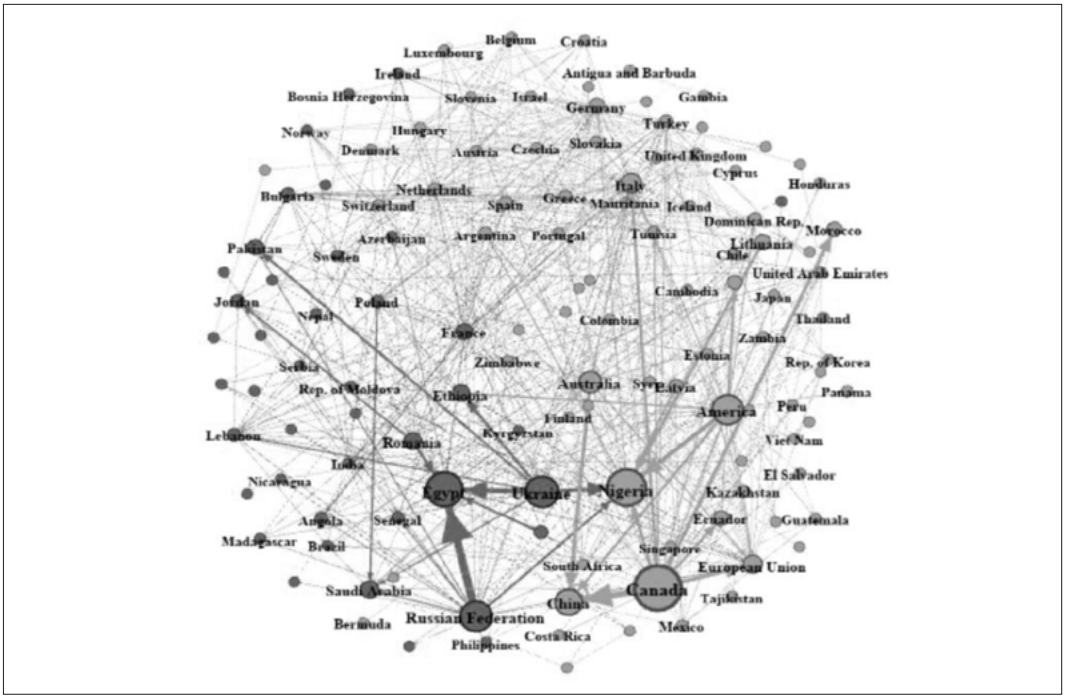


Figure 2 - Network of international corn trade relations in 2021.

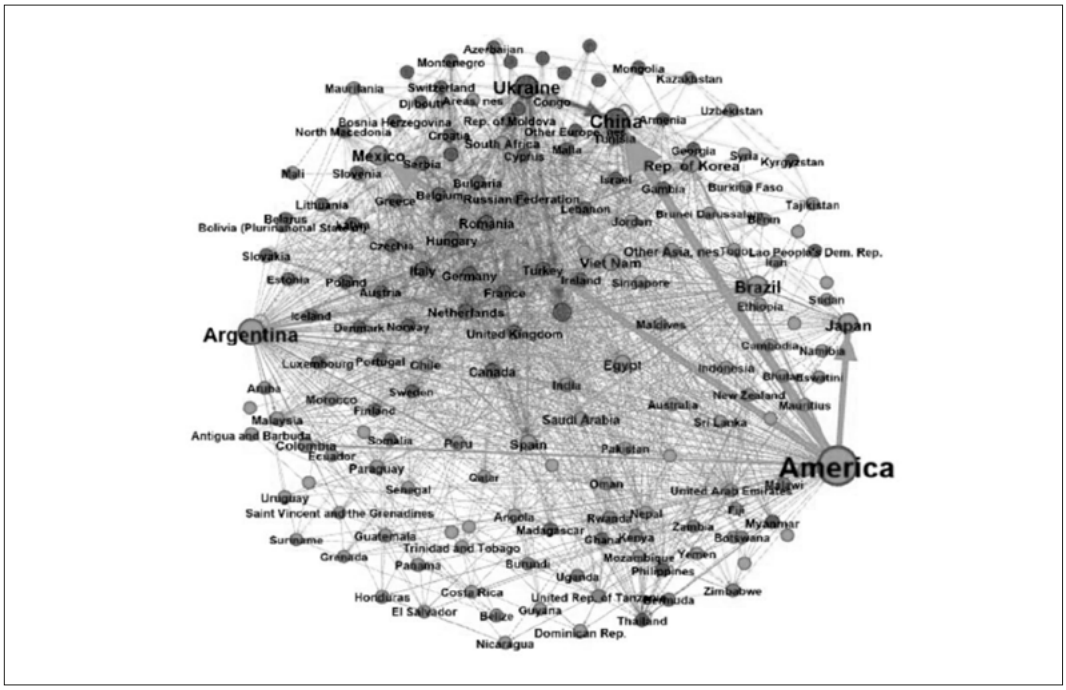
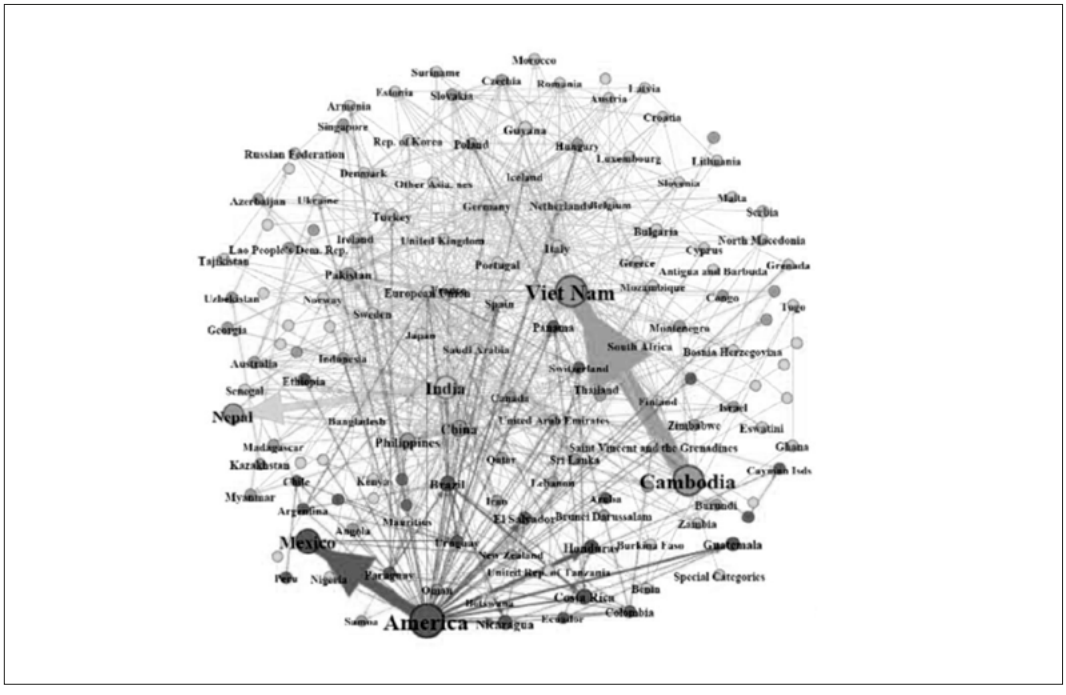


Figure 3 - Network of international rice trade relations in 2021.



3. Results and analysis

3.1. *Construction and characteristics of global grain trade network*

Based on the obtained trade data of wheat, corn and rice from 2012 to 2021, establish global major grain trade relations, and use complex networks to build global trade networks of wheat, corn and rice from 2012 to 2021. The visualization of the main global grain trade networks in 2021 is reproduced in Figures 1-3.

From 2012 to 2021, the trade relations of wheat, corn and rice, as the main grain products, had gradually increased, and the national trade network formed had become increasingly complex. Among them, the global trade network of corn was closer than that of wheat and rice, and the trade relationships were more complex.

In order to further analyze the characteristics and development trend of the international trade network of the three main types of grain, compare and analyze the topological characteristics of the complex trade network of wheat, corn and rice from 2012 to 2021. The network graph density, network average clustering coefficient and modular comparison were shown in the figures (Figures 4-6).

In the world's major grain trade networks from 2012 to 2021, the density of corn trade network was the highest, and kept rising, and finally reached the highest value of 0.065 in 2021, with the most dense global corn trade links. The network density of wheat and rice was relatively similar, and the overall trend of fluctuation was rising. They also reached the maximum of 0.043 and 0.038 in 2021, and the global trades of wheat and rice were closer.In terms of the connectivity of trading countries, the network average clustering coefficient of corn had always been the highest. But in recent years, the coefficient had shown a slow downward trend, from the highest value of 0.362 in 2016 to 0.329 in 2021.The clustering coefficient of the trade network of wheat and rice showed a cross-fluctuation development, but the inter-country aggregation of rice trade began to decline after 2020, and it was only 0.2 in 2021. On the whole, affected by the global COVID-19 in 2019, the degree of con-

Figure 4 - Comparison of network density of global wheat, corn and rice trade.

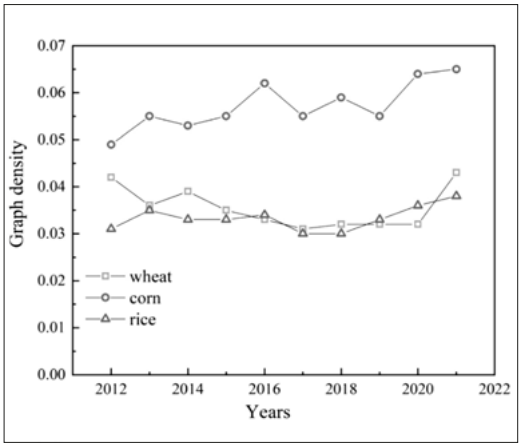


Figure 5 - Comparison of average clustering coefficients of global wheat, corn and rice trade.

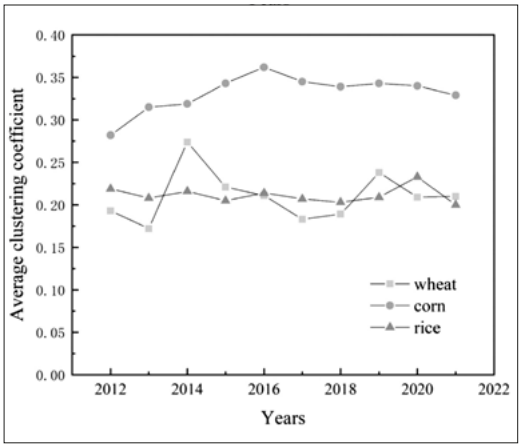
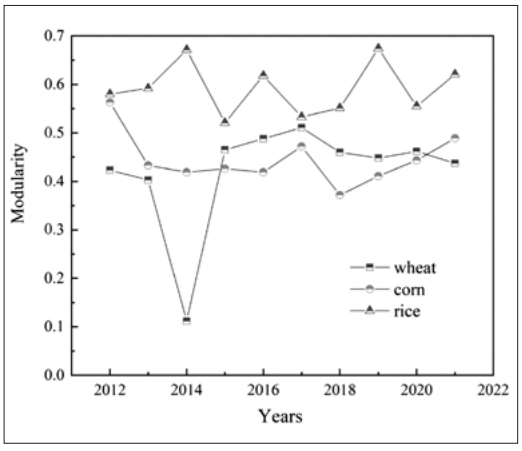


Figure 6 - Comparison of modularity of global wheat, corn and rice trade networks.



nectivity among the trading countries of global wheat, corn and rice had gradually declined, and the links among the trading countries need to be further strengthened. In the comparison of network modularization, the trade network of rice was higher than that of wheat and corn, and the degree of collectivization in global trade was more significant. However, its volatility was also high, with the lowest value of 0.52 in 2015 and the highest value of 0.674 in 2019. The trade network modularization of wheat had been higher than that of corn since 2015, but it had shown a slow downward trend and dropped to 0.437 in 2021, weakening the degree of grouping of trading countries.

3.2. *Important nodes in the grain trade network*

(1) Main nodes of grain export trade

Grain export is an important way to ensure global food supply. Grain exporting countries have a certain amount of grain resources, and they are also the important trade choices for grain importing countries. Select the weighted outdegree in the complex network to analyze the global export trade volume of wheat, corn and rice in 2012, 2015, 2018 and 2021 (unit: USD), and obtain the top 10 countries in the world's major grain export trade volume (Figures 8-10).

In the global export trade of wheat, corn and rice in 2012, 2015, 2018 and 2021, Canada, America, Australia and Russia had always maintained the top five in the global export trade volume. Canada was the world's largest wheat export trading country in 2012, 2015 and 2021. Canada was the world's largest wheat export trading country in 2012, 2015 and 2021. The export trade volume of wheat in America had gradually declined, from the second place in the global export trade volume in 2012 to the fourth in 2021. Ukraine's wheat export trade volume had gradually increased. In 2012, its export trade volume ranked the seventh, and then gradually rose to the second in 2021, then Ukraine became the second largest country in wheat export trade volume. Romania, Germany, France and Kazakhstan also had higher wheat export performance, but their export trade volume only ranks among the top 10 in the world in some years. America was the largest exporter of corn, and had always maintained the first place in global corn export trade volume in 2012, 2015, 2018 and 2021. Argentina, Ukraine and Brazil had also remained among the top 4 in the global corn export trade volume, and the major trading countries were relatively stable. France and Russia successively ranked among the top 10 in the world in terms of corn export trade in 2012, 2015, 2018 and 2021, but their rankings were unstable, with a slight decline in 2021. In addition, Romania, Serbia, the Netherlands and South Africa had certain performance in corn export trade, but the rankings of export trade volume were also unstable.

The global export trade of rice was mainly concentrated in the America, India and China. The export trade volume of rice in the America had always been the highest in the world, followed by India; China's rice export trade volume always ranked the top 4 in the world, but in recent years, the export trade had declined slightly. In 2018 and 2021, the rice export trade volume ranked the fourth in the world. In addition, Brazil, Italy and Guyana always maintained the top 10 in the world in rice export trade, and were also major suppliers of rice trade. Russia, Spain and Thailand had certain performance in rice export trade, but the rankings of export trade volume were relatively unstable.

(2) Important nodes of trade network

The main global grain trade network is complex, and trading countries have different roles and positions in the network. Identifying the important nodes in the grain trade network is conducive to the selection of grain import and export trade relations of different countries and the maintenance of the trade network. Select the betweenness centrality in the global grain trade network to rank the nodes, and obtain the core trading countries with strong connectivity in the grain trade network (Tables 1-3).

In the global wheat trade network, Italy, the America, France and Germany were important core nodes from 2012 to 2021, and the ranking of the centrality of the intermediary had remained the top 5 in the world for many years. They had

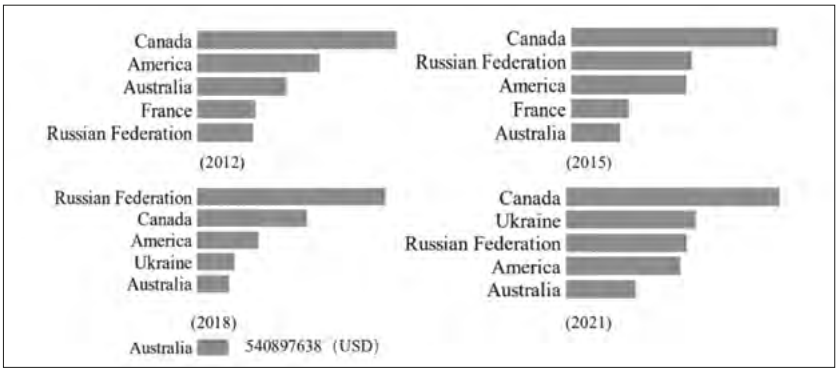


Figure 7 - Major exporting countries of wheat in the world.

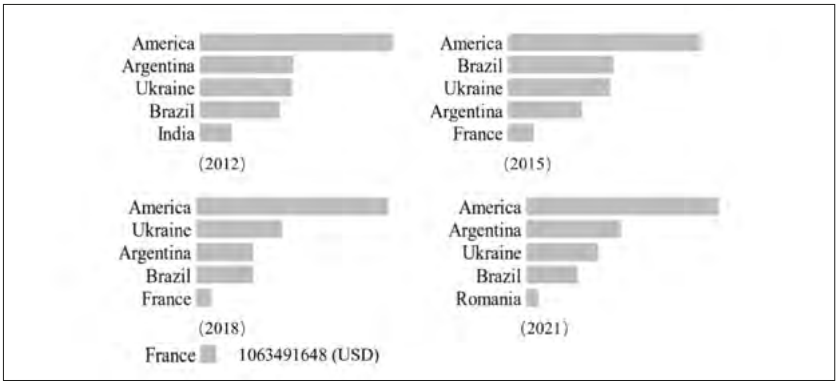


Figure 8 - Major exporting countries of corn in the world.

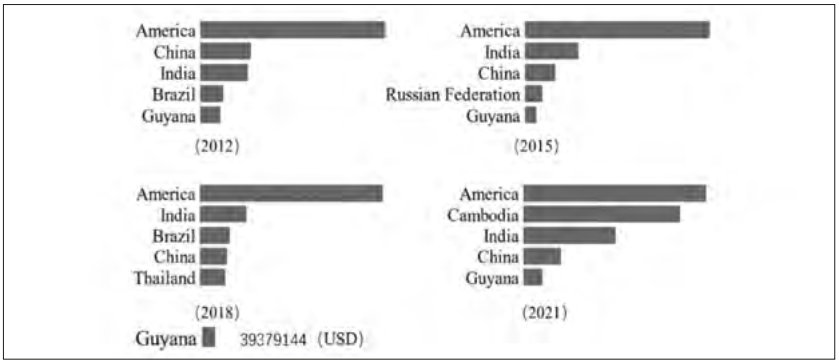


Figure 9 - Major exporting countries of rice in the world.

strong connectivity in wheat import and export trade and were more closely connected with other trading countries. Netherlands only ranked in the top 5 in the betweenness centrality ranking from 2015 to 2018. After 2018, its position and role declined in the wheat trade network. Other countries, such as Russia, South Africa and China, had ranked among the top 5 in the world in terms of intermediary center value in individual years, but their trade connectivity fluctuated greatly, and their core position in the trade network need to be stabilized and improved.

In the global corn trade network, the America and the Netherlands had always maintained the core position from 2012 to 2021, with the betweenness centrality value ranking top 5 in the world continuously. Except for 2015 and 2019, the betweenness centrality value of the America had always ranked first in the world, and America had the strongest trade connectivity in the global corn trade. The Netherlands also played an important core role in the corn trade

Table 1 - Ranking of countries with betweenness centrality in the global wheat trade network.

Ranking	2012	2013	2014	2015	2016
1	Italy	Italy	Germany	Netherlands	USA
2	France	Germany	Italy	Italy	Italy
3	Germany	Canada	France	Turkey	France
4	Israel	America	America	France	Germany
5	Lebanon	Russian Federation	Iran	America	Netherlands

Ranking	2017	2018	2019	2020	2021
1	Italy	France	America	France	America
2	France	South Africa	South Africa	America	Italy
3	America	China	France	Germany	France
4	Netherlands	Netherlands	Italy	Italy	Germany
5	Russian Federation	Austria	Germany	China	Egypt

Table 2 - Ranking of countries with betweenness centrality in the global corn trade network.

Ranking	2012	2013	2014	2015	2016
1	America	America	America	Netherlands	America
2	Netherlands	South Africa	Netherlands	America	Netherlands
3	South Africa	Germany	France	South Africa	France
4	Germany	Netherlands	Germany	France	South Africa
5	Spain	China	Rep. of Korea	China	United Arab Emirates

Ranking	2017	2018	2019	2020	2021
1	America	America	Netherlands	America	America
2	Netherlands	South Africa	America	South Africa	South Africa
3	South Africa	France	South Africa	Netherlands	France
4	France	Netherlands	France	France	Netherlands
5	Germany	Canada	China	United Arab Emirates	Canada

Table 3 - Ranking of countries with betweenness centrality in the global rice trade network.

Ranking	2012	2013	2014	2015	2016
1	Italy	Egypt	United Kingdom	Germany	Italy
2	America	Italy	Italy	Italy	Spain
3	Turkey	Pakistan	Ireland	Ghana	Netherlands
4	Sudan	South Africa	China	South Africa	South Africa
5	Egypt	Germany	South Africa	Netherlands	Belgium

Ranking	2017	2018	2019	2020	2021
1	Netherlands	Italy	Italy	Netherlands	Italy
2	Spain	Netherlands	Germany	Italy	Netherlands
3	Italy	France	Netherlands	United Kingdom	France
4	Germany	China	India	Germany	America
5	America	Austria	China	United Arab Emirates	India

network, but its ranking had certain volatility. South Africa also had a high core position in the global corn trade network. Except for 2014, its betweenness centrality ranking had maintained the top 5 in the world, and the connectivity of corn trade was also strong, with the trend of increasing influence in recent years.

In the global rice trade network, only Italy had maintained the top five in the betweenness centrality ranking from 2012 to 2021, and ranked first in some years. The second was the Netherlands, which had a relatively stable core position in the rice trade network. Its betweenness centrality ranked among the top 5 in the world from 2015 to 2021. The important connectivity of other trading countries in the rice trade network were unstable,

such as South Africa and Germany, which only showed some core influence in some years. On the whole, the important nodes with core role and influence in the global rice trade network were not significant, and the connectivity of trade nodes needs to be strengthened.

3.3. *Supply risk of grain trade*

Trade import is an important way to meet a country's grain demand, but it is also accompanied by certain trade risks (An *et al.*, 2014). When the grain export trade volume decreases or the trade is interrupted due to natural, social and other factors, the importing trading countries will have different degrees of food supply risk (Butcher *et al.*, 2016). In particular, when the import trade volume is high, but the import trade partners are concentrated, it is more likely to lead to the potential trade supply risks. Therefore, the analysis of trade structure and trade network influence of major grain import trading countries is conducive to identifying the potential grain supply risks in trade imports and effectively avoiding the possible trade supply risks (García *et al.*, 2013; Eheliyagoda *et al.*, 2019).

The market structure of grain import trade and the position and role of trade importers in the global grain trade network are important factors affecting the choice of trading partners and the stability of grain imports. This paper mainly selects Herfindahl-Hirschman Index and betweenness centrality of network nodes as the analysis indicators to establish the supply risk assessment index system (1) (Verger and Boobis, 2013; Nansai *et al.*, 2017)

$$SR_n=\alpha \cdot HHI_n+BC_n \quad (1)$$

Where SR_n is the supply risk value of grain import trade calculated by the trading country n, HHI_n is the Hefindar-Hechman index value of trade import market structure, BC_n is the Reverse processed value of betweenness centrality output from the complex network, and α is the adjustment variable, making MAX (HHI_n)=-MAX (BC_n) (Zhang *et al.*, 2014).

We selected the weighted indegree index in the complex network to rank the import trade volume of wheat, corn and rice, and selected the top 10 countries in the import trade volume of wheat, corn and rice to carry out the supply risk assessment of grain trade. They were Nigeria, Egypt, China, Italy, Saudi Arabia, Ethiopia, Pakistan, Ecuador, Morocco and Jordan in wheat import trade, China, Japan, Mexico, South Korea, Vietnam, Egypt, Spain, Colombia, Netherlands and Italy in corn import trade, and Vietnam, Mexico, Nepal, Philippines, Costa Rica Nicaragua, Honduras, Pakistan, Guatemala, Türkiye in rice import trade. The supply risk assessment in 2021 for the major import trade countries of wheat, corn and rice were shown in the figures (Figure 11).

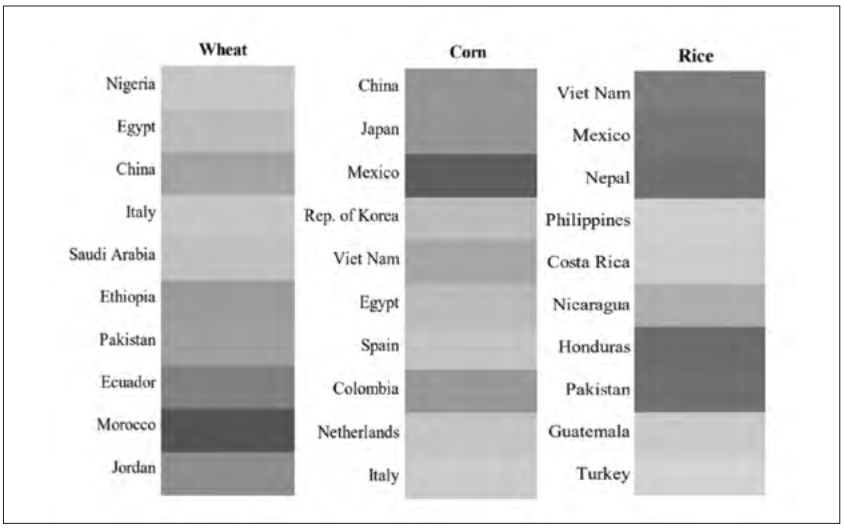


Figure 11 - Supply risk assessment of major grain importers in the world.

In the supply risk assessment of global wheat trade in 2021, Morocco's supply risk value was the highest, 1.999, followed by Ecuador's 1.6556 and Jordan's 1.5627. Morocco, Ecuador and Jordan ranked 9, 8 and 10 in in terms of wheat import trade volume, but their wheat import trade market structure were relatively concentrated. In particular, Morocco's wheat import was mainly concentrated in three countries, with the highest HHI index of 0.9854. At the same time, the lack of role and status in the wheat trade network had further increased the risks of grain supply in Morocco, Ecuador and Jordan. The supply risks of wheat in Nigeria, Saudi Arabia and Italy were low, 1.1219, 1.1824 and 1.1336 respectively.Although Nigeria is the country with the highest volume of wheat import trade, its grain import market structure was relatively optimized, and its HHI index was the lowest. At the same time, Nigeria had strong connectivity with trading countries in the import trade network, and the betweenness centrality was high, which largely reduced the potential supply risk caused by the interruption of trading partners in the process of wheat import, to a large extent.

In the import trade of corn, Mexico had the highest supply risk of 1.999, followed by Japan and China, with supply risk values of 1.5568 and 1.5536. China, Japan and Mexico were the top three countries in the global corn import trade, but the trade supply risks were high. The high supply risk of Mexico and Japan mainly came from the dual effects of the high concentration of the import market and the lack of influence in the corn trade network. Mexico, in particular, had the highest concentration of corn import market, mainly in Brazil and the United States, while betweenness centrality was the lowest. China had an important position and influence in the global trade network of corn, but its corn import market structure was highly concentrated, second only to Mexico, and its HHI index was 0.5708, which was the main factor of its high supply risk. Italy was the country with the lowest supply risk, with a risk value of only 1.1245. It had 41 corn import partners and the concentration of trade market was lowest, further reducing the potential risk caused by the interruption of import trade.

Among the major trade countries of rice import, Honduras had the highest supply risk of grain trade, with 2, followed by Nepal, Pakistan, Mexico and Vietnam, with 1.9916, 1.9913, 1.9473 and 1.9122 respectively. In the higher supply risk of wheat, there were certain differences in its internal risk factors. Honduras had the highest concentrated of rice import market structure, with the HHI index of 0.999, and its imports mainly came from the United States and Ecuador. However, it had the lowest betweenness centrality in the rice trade network, and was not closely connected with other trading countries, with a low status and role in trade, making the supply risk of grain trade the highest. The supply risks of Mexico and Nepal were similar to Honduras, both of which were affected by the concentration of rice import market structure and the limitation of trade status and role in the network. Vietnam and Pakistan had a high node role and position in the trade network, respectively 0.0079 and 0.0086. Their supply risks mainly came from the concentration of the import trade market structure. Vietnam, in particular, ranks the first in the world in rice import trade, but its import trade market structure HHI index is as high as 0.92, with only five import trading countries. Türkiye had the lowest supply risk of grain, only 1.4478. Although its rice import trade volume ranked 10 in the world, its import market structure had the lowest concentration and has a high trade status and influence in the trade network.

4. Conclusion and policy recommendation

4.1. *Conclusion*

(1) In the global grain trade, corn had the largest number of trading countries and trade relations, and had gradually increased. The global trade network of corn was the most closely developed, the connectivity of trading countries was the highest, and the development of global trade was relatively mature. Rice had more trading countries and trade relations than wheat, but it was similar to wheat in terms of connection closely degree of global trade relations. The connectivity of global wheat trade was volatile, and there was a certain potential risk of trade disrup-

tion, while the connectivity between the global trading countries of rice was relatively stable. In the development of global trade conglomeration, rice had the highest degree of development and the strongest trade conglomeration, but the volatility was also large.

(2) Canada, the United States, Australia and Russia were the main wheat export suppliers, and their export trade volume had been high for many years. Ukraine's wheat export trade volume had gradually increased, and it became the second largest wheat export trade country in the world in 2021. It was the new choice partner for wheat import trade. The global corn export trade countries were relatively concentrated and stable, mainly concentrated in the United States, Argentina, Ukraine and Brazil. Among them, the United States was the world's largest corn export trade country, with the most abundant corn export trade resources. The rice export trade was the most concentrated, mainly in the United States, India and China. However, the world export trade volume ranking of of rice trading countries was relatively unstable and volatile. The United States was the major grain exporter and trade supplier of wheat, corn and rice, and also was the major trade partner of grain supply.

(3) Italy, the United States, France and Germany were the important countries in the global wheat trade. They had high trade connectivity in the trade network and were important choice partners in the wheat trade. The Netherlands, Russia, South Africa and China had only held a key position in global wheat trade in some years, and the influence of trade networks was relatively unstable. The key nodes of global corn trade were relatively concentrated, mainly the United States, the Netherlands and South Africa, with the highest trade connectivity in the global corn trade. The important nodes with core role and influence in the global rice trade network were not significant, mainly the Italy and the Netherlands. The global rice connectivity of South Africa and Germany was unstable, and the role and influence of trade need to be improved. In general, the United States, Italy, the Netherlands, South Africa and Germany had a relatively high trade status and role in global grain network, and had a relatively significant control over grain trade resources.

(4) Grain import is an important mode of demand and supply, and there is a certain risk of potential supply interruption in global grain import trade. In the global wheat import trade, the supply risk of wheat gradually increased with the import volume from high to low. The high risk was mainly concentrated in the evaluation countries in the second half, including Morocco, Ecuador and Jordan. The higher supply risk mainly came from the concentration of import trading partners and the import market structure was unreasonable. The high supply risk of global corn trade was mainly concentrated in countries with high import trade volume, including Mexico, Japan and China. With the decrease of corn import trade, the supply risk of trade was also gradually reduced. The high supply risk of corn was affected by the concentration of the import trade market and the lack of its own influence in the trade network. The supply risk of global rice was higher than that of wheat and corn as a whole, and the high risk was mainly concentrated in the trading importing countries in the first and later stages, including Nepal, Pakistan, Mexico, Vietnam and Pakistan. There were certain differences in the internal performance factors of the high supply risk.

4.2. *Policy recommendation*

(1) With the gradual increase of global grain trading countries and trade relations, grain trade has formed a complex network system. Different trading countries have different positions and roles in the network, and have different degrees of control over grain trade resources (Shutters and Rachata, 2012). On one hand, the grain importing countries, especially the developing countries, should continuously strengthen the links with the key grain trading countries in the trade network, strengthen the cooperation and communication, and ensure the stability of the grain import trade. On the other hand, we should continue to expand relations with trading countries close to our geographical location, establish strategic cooperative relations, and give play to the advantages of proximity. At the same time, we should pay

attention to the reduction of the import cost of grain trade, ensure the security, stability and smoothness of the trade process, and continue to promote in-depth cooperation in grain trade.

(2) The grain import trade market was an important factor affecting trade supply risk. Major import trading countries should pay attention to optimizing the own grain import trade pattern, strengthen communication and cooperation, expand multilateral grain trade relations, and reduce the potential supply risks caused by the concentration of grain import trade market. Natural disasters, wars, fluctuations in grain producing countries and so on may cause the interruption of grain import trade (Pibylová *et al.*, 2006). Therefore, grain importing countries, especially the less developed countries, should pay attention to improving their position and influence in the global grain trade network, strengthen their grasp of the global grain trade resources, prevent potential supply risk of grain trade caused by external environment or trading partners and improve their own risk response capacity.

(3) The global grain trade network had a complex structure, and different trading countries had different abilities to access and control grain resources. Countries should advocate to maintain smooth international grain trade, effectively carry out international grain trade, attach importance to the establishment of own grain supply security system, and actively respond to natural, social and other factors that restrict national grain supply. At the same time, countries should establish and improve the early warning mechanism of the grain import market, especially in the face of the interruption of grain supply caused by sudden international wars, actively predict the risk of import, and make full preparations for possible fluctuations or interruptions in grain supply (Wu *et al.*, 2020).

(4) Less developed countries had limited trade resources and information in the global grain trade pattern, and were more vulnerable to fluctuations in grain import and potential trade risks. Therefore, they should strengthen the awareness of grain trade supply security. At the same time, they should pay attention to the formulation of grain trade security strategy. On the one hand, they should constantly improve the comprehensive supply capacity of domestic grain, on the other hand, they should constantly optimize the international grain import market, develop multilateral grain import partners, stabilize the import cooperation relationship with trade partners, and ensure the stability and security of grain import.

However, due to limitations in time and research scope, there were still certain deficiencies in our analysis of the global grain trade network and research on grain supply security. In the process of assessing the risk of grain supply, due to limitations in data acquisition, there was no in-depth analysis and comparison of grain supply risks between regions or regions. In future research, we will attempt to analyze the supply risks of grain trade between different regions or regions worldwide, and further study the performance and internal influencing factors of grain supply risks in different regions or countries, in order to achieve more in-depth research on grain trade security.

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