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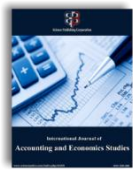

Exploring the linkages of food markets in BRICS and its significance for food security: A TVP VAR and coherence wave-let perspective

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Abstract

This study explores the connectedness of BRICS food markets. The food markets selected for the study are soybeans, wheat, rice, corn, and sugar. The selection of each food market is based on the product concentration of each country. The research focuses on analysing the connectedness between the prices of the BRICS food market during different periods. It employs the Granger causality approach to determine the direction of information flow. We use the TVP-VAR connection to examine the propagation of connectedness within the food market. The results revealed that the connectedness among BRICS food markets has increased during the period of crisis. Our results revealed that Russia and China are the largest senders of price shocks across the BRICS economy. To reduce food price shocks, BRICS officials should promote regional coordination, such as cooperative early warning systems, regional food reserves, and coordinated food policies. Promoting indigenous production and exploring alternative import partners is critical to food diversity. Agricultural research and development increase output, decrease prices, and improve food security. Furthermore, vulnerable populations require effective social safe-ty nets to protect them from price volatility. In addition, sustainable agriculture will protect the BRICS countries' food security from climate change and other shocks in the food markets.

Keywords: *Connectedness; Coherence Wavelet; Food Markets; Food Security.*

1. Introduction

The COVID-19 epidemic has resulted in a substantial human catastrophe; the global economy experienced an unparalleled shock due to the quick and widespread transmission of the highly lethal COVID-19 virus. It has an impact on large-scale disruptions for both enterprises and the livelihoods of numerous individuals. The Covid-19 pandemic has resulted in significant levels of uncertainty, leading to notable effects on several sectors like travel and tourism, catering, distribution networks, purchasing, manufacturing processes, financial strain, and the cost of goods (Chang et al. 2020; Fan et al. 2023). The effect of the pandemic on the financial system is prominently reflected in the financial markets (Sharif et al. 2020; Behera et al. 2023; Zhu et al. 2024). Moreover, the epidemic has begun to exert its influence on the economy, precipitating a significant downturn in both equities and commodities markets. Predicting the magnitude of the economic ramifications of the COVID-19 problem poses a significant challenge. However, it is worth noting that the present body of literature already encompasses many approaches and methodologies that can be utilized to comprehend and measure the economic impacts of the ongoing situation (Goodell 2021). This article aims to examine the connectedness among the major food markets in the emerging countries during different periods.

All relevant stakeholders in the commodity market, known for its dynamic nature, always remain prepared for unforeseen developments. Transactions in the commodities market take place exclusively inside the main economic sector, rather than incorporating manufactured items. The participants in the commodity market encompass a wide range of individuals, including but not limited to investors, portfolio managers, brokers, and traders. During the period of uncertainty, those mentioned players preemptively hinder one another's actions, resulting in a market that exhibits volatility and excessive noise (Moews and Ibikunle 2020). Commodity markets have a high level of development, characterised by the presence of mechanisms that effectively reduce volatility and facilitate the transfer of risk. For example, the globalisation of commodity markets enables individuals to gain access to financial derivatives (Samarakoon et al. 2023). This allows investors to move the risk associated with commodity exports to those who are seeking speculative opportunities. People widely recognize the ramifications of variations in agricultural commodity markets on the overall economy. The COVID-19 epidemic had a significant effect on both the demand and supply of agricultural products, potentially leading to crises in the global food chain. Nevertheless, there is a limited amount of literature available on the subject matter. The existing body of literature primarily focuses on examining the effects of the COVID-19 pandemic on commodity markets and commodity price returns (Iuga et al. 2024; Shah et al. 2023; Shruthi and Ramani 2020; Salisu et al. 2020). It has also been looked into how COVID-19 affects stock markets (Khan et al. 2024; He et al.

2020), how commodity futures and COVID-19 are related (Magalhães et al. 2022; Wang et al. 2020), and how the COVID-19 pandemic affects food security and the agricultural supply network around the world (Alabi and Ngwenyama 2022; Sridhar et al. 2022; Bakalis et al. 2020; Nchanji et al. 2020; Perdana et al. 2020; Shirsath et al. 2020; Udmale et al. 2020).

Over the past two decades, countries across the globe have witnessed a notable spike in the level of price volatility within agricultural commodities markets. The phenomenon of pricing has garnered significant interest in the economic literature. Various studies (Lloyd 2017; Assefa et al. 2015; Frey and Manera 2007; Meyer and Cramon-Taubadel 2004) have explored the interconnections of prices throughout different stages of agricultural markets. While there is a growing body of information on price transmission in agricultural commodities, there is insufficient investigation about examining the impact of price volatility in one market on other markets (Osei et al. 2024; Boyd and Bellemare 2020). Researchers and policymakers are interested in volatility transmission because it can cause big risks and uncertainty for everyone in the market. The price-level transmission phenomenon in agricultural goods has been the focus of most research to date. This is the study of how predictable price factors are linked to each other (Zheng and Pan 2022; Fousekis et al. 2016; Shrinivas and Gomez 2016; Bakucs et al. 2014). The effect of fluctuations in prices in the food market on the state of food security has not been well investigated, which has sparked a renewed interest in research on this topic. Also, it's important to know that changes in food prices may have different effects depending on whether a market is a net sender or receiver of connectedness (Arndt et al. 2008; Barrett & Dorosh 1996). COVID-19 food price spikes increased risks for producers and consumers.

Our research offers a novel approach, diverging from existing studies in the following significant ways. The primary objective of this research article is to expand upon the existing body of knowledge about the transmission of volatility across different markets, specifically focusing on food commodity prices in the BRICS economy. Even though there are studies that look at how price changes happen in the agricultural supply network (Abdallah et al. 2020; Chavas and Pan 2020; An et al. 2016; Serra, 2015; and Buguk et al. 2003), none of them look at how price changes happen between food markets in emerging nations. Second, our research strengthens the existing body of knowledge on price fluctuation volatility by extending the analysis to a higher frequency, daily dataset. While previous studies, such as those by Ferrer-Perez and Gracia-deRenteria (2020); Hassouneh et al. (2017); and Assefa et al. (2015), have primarily relied on monthly and weekly data due to availability constraints, our use of daily data allows for a more granular and dynamic examination of volatility transmission. Nevertheless, using these datasets might not accurately show how price changes work, since changes in the prices of agricultural goods can happen in just a few days (Meyer and Cramon-Taubadel 2004; Boyd and Brorsen 1988). In contrast, the dataset utilised in our research work comprises comprehensive daily price information from food markets. Third, our study aims to analyse the dimension of frequency co-movements among the selected commodities. To the best of our understanding, this research is the first look at empirical data regarding the transmission of price volatility, interconnectedness, and co-movements, utilizing the product concentration approach in the BRICS economy.

Furthermore, this study makes a valuable contribution to the current body of knowledge regarding the transmission of volatility in agricultural commodity prices within developing nations. Analyzing price connectedness in food markets is crucial for the BRICS economies for several reasons, such as food security, inflation management, and economic stability. If not addressed correctly, the phenomena of price connectedness have the potential to influence food accessibility, potentially leading to scarcity or even a food security crisis. Examining price fluctuations among BRICS nations is essential for formulating coordinated strategies that ensure food security for their citizens. The influence of food prices on the total inflation rates is substantial. Price connectedness in food markets can have a big effect on inflationary trends, which is why central banks need to keep a close eye on things and act quickly by putting in place the right monetary policies. The presence of price volatility within food markets has the potential to induce destabilizing effects on the whole economy. Price spillovers have the potential to give rise to inequalities in income, social unrest, and economic instability, posing a significant challenge to the growth and advancement of BRICS economies.

As one of the world’s leading agricultural producers, Brazil is renowned for its exports of soybeans, corn, and beef. It contributes significantly to the global food supply, with its agricultural sector benefiting from advanced farming techniques and favorable climate conditions (Hansberry 2024). Russia's pivotal role in the global food market has been underscored by its status as a top exporter of grains and fertilizers, particularly wheat. The ongoing geopolitical tensions, particularly due to the war in Ukraine, have further accentuated Russia's influence on global food prices. Moscow is also exploring initiatives to establish a BRICS grain exchange to control agricultural pricing, enhancing its strategic position in international trade (Farmonaut 2024). India stands as a major player in food production, particularly in rice and pulses, while also being the largest producer of milk. It contributes around 2.3% of global food exports and has been proactive in addressing global food security through various initiatives. India’s agriculture is vital not just for its population but also for the Global South, facing food insecurity challenges (ET 2024). China plays a dual role as a significant importer and producer of food. It is the leading buyer of various agricultural commodities, including soybeans and corn, which underlines its extensive food security measures amidst a growing population and increasing dietary demands (Food Export Association of the Midwest USA and Food Export USA–Northeast 2024). South Africa plays a vital role within Africa, being a significant exporter of agricultural products, but also grappling with local food security issues. Its agricultural expertise positions it as a key collaborator in regional and global food security efforts.

This study focuses on the BRICS nations, which account for 40% of the world's population and face considerable food security challenges that necessitate coordination (Mielniczuk 2013). They represent 25% of global GDP, proving their economic and agricultural potential (Jana and Karmakar 2017). Their agricultural and technological dependency necessitates collaborative food security solutions (Mielniczuk 2013). This multifaceted problem contributes to an understanding of how market connections influence countries with varying agricultural growth and expertise. Furthermore, researching market linkages within the BRICS framework aids in explaining the worldwide consequences of food price volatility, as well as the dynamics of South-South cooperation in global growth. In contrast to previous studies that focused on specific subjects such as food security or market dynamics, this study uses a deep framework to investigate BRICS countries' interconnections and their impact on global food security. Our findings demonstrate how market ties influence food policy and international cooperation to address issues such as unstable economies. This study is useful since it looks at the different social and economic conditions in the BRICS countries. This provides scholars and government officials with novel approaches to think about increasing the country's resilience. We investigated BRICS food market linkages using TVP VAR and Coherence Wavelet Analysis. Both techniques demonstrate how market links shift over time in response to environmental and economic conditions in various ways. TVP VAR demonstrates how food markets adapt to changing conditions. The frequency-based link at different times can be discovered using Coherence Wavelet Analysis. Basic approaches may disregard these findings. This research is significant due to its application of advanced analytical techniques, drawing from fields such as econometrics and astrophysics, to generate novel insights. The findings can help emerging economies to share information and resources to stabilize prices and avoid shortages, thereby improving food security.

Our literature study has expanded its emphasis to include the vital crossroads of accounting and the changes in food market pricing. Most studies on food price transmission are done from an economic standpoint; nonetheless, accounting techniques provide vital additional

insights for the application of BRICS food security policy (Magazzino et al., 2024). Effective risk management, inventory valuation, and the implementation of hedging strategies in response to the price shocks found by our research all require complex accounting systems (Y. Guo et al., 2024). By evaluating how price volatility affects financial statements, management accounting choices, and food security investments, our study of the interrelationship of BRICS markets directly guides full-cost accounting systems. Price volatility transfer from Russia and China calls for more sophisticated financial reporting techniques that correctly reflect market risks. Studies indicate that locations with all-inclusive accounting systems are more resilient to changes in food prices (Roosevelt et al., 2023). Improved resource management and openness help achieve this resilience. Accounting professionals who are creating reactive reporting systems under market volatility could greatly benefit from the TVP-VAR approach, as it provides a crucial framework (Ari et al., 2025). BRICS countries need established metrics for natural capital evaluation, which affects the sustainability of agricultural output; therefore, addressing environmental accounting challenges strengthens the study's relevance. This multidisciplinary approach shows how accounting openness improves market stability and enables more efficient resource allocation choices among BRICS countries facing similar food security issues. It also links accounting concepts, which are vital for efficient policy execution, with economic research.

Furthermore, there have been previous empirical investigations of the dynamic relationship in agricultural markets for developing economies. However, it is important to note that there is currently a scarcity of academic literature specifically addressing price connectedness in food markets under the COVID-19 pandemic. This study addresses the existing gap in the academic literature by investigating the transmission, connectedness, and co-movements of emerging economies throughout the COVID-19-time horizon, especially in BRICS. The research indicates that complicated accounting systems are essential for effective risk management, inventory valuation, and the execution of hedging strategies in response to price shocks. Our study also tries to connect the full-cost accounting systems by measuring the impact of price volatility on financial statements, management accounting choices, and investments in food security. The TVP-VAR approach provides useful information, so accountants can greatly gain from it while creating reactive reporting systems under market volatility. This multidisciplinary approach emphasizes how accounting openness improves market stability, supports more efficient resource allocation choices, and aids in the implementation of strong food security measures throughout the BRICS countries.

The next sections are structured in the following manner. Section 2 outlines the study's methodology. Section 3 presents a comprehensive analysis of the data. The results of the analysis are discussed in Section 4, whereas Section 5 covers the study's conclusion and potential avenues for future research.

2. Methodology

2.1. Granger causality

The Granger Causality Test, developed by Granger in 1969, helps determine a causal connection among variables. This technique determines whether changes in one variable have an impact on changes in another series, thereby examining the direction of causality. The basic idea behind the test is to assess the extent to which historical data from one time series can be utilised to forecast future data points in another time series. It does not imply a causal relationship in the sense of one variable causing changes in another; rather, it tests the predictive power of one variable for another.

The Granger causality equation is a statistical model used to analyze the causal relationship between two time series variables. It is represented by the equation:

$$Y_t = \alpha + \beta_1 Y_{(t-1)} + \beta_2 X_{(t-1)} + \varepsilon_t \quad (1)$$

Where:

- Y_t represents the dependent variable at time t. α is the intercept term.
- $Y_{(t-1)}$ is the lagged value of the dependent variable at time t-1.
- $Y_{(t-1)}$is the lagged value of the independent variable at time t-1.
- β_1 and β_2 are the coefficients representing the causal effect of the lagged values on the dependent variable.
- ε_t is the error term or residual?

2.2. TVP VAR connectedness

This method for finding connections, called Time-Varying Parameter Vector Autoregression (TVP-VAR), is very useful for studying how food prices in the BRICS countries change over time and affect each other. This method records how these interactions change over time so that it can help us understand how shocks spread and the chance of systemic risk. It achieves this by accounting for time-varying factors. Traditional VAR models assume that parameters stay the same over time, which might not accurately show how interdependencies change in the fast-paced and unstable food markets. Therefore, we employed Granger causality tests within a time-varying parameter vector autoregression (TVP-VAR) framework. This approach allows for the estimation of time-varying coefficients, capturing the changing nature of causal relationships between variables over time (Antonakakis et al. 2020). This flexibility is crucial for understanding how market linkages evolve in response to various shocks, such as economic crises or policy interventions.

Let's denote the multivariate time series as Yt, where t represents time, and it has N variables. The TVP VAR model can be expressed as follows:

$$Y_t = \mu_t + A_t Y_{t-1} + \varepsilon_t \quad (2)$$

Where:

- Yt is an N×1 vector of variables at time t.
- μt is an N×1 vector representing time-varying means.
- At is an N×N matrix of time-varying coefficients.
- εt is an N×1 vector of white noise residuals.

2.3. Coherence wavelet analysis

Coherence wavelet analysis is used to examine the connectivity and co-movements of food markets in the BRICS countries. By applying this technique, researchers can gain insights into how these markets are interconnected and how they influence each other. This type of analysis is valuable for understanding the dynamics of market co-movements, which can have significant implications for food security. By identifying patterns of connectivity and co-movements, policymakers and stakeholders can better understand the potential impact of market fluctuations on food availability and affordability in the BRICS countries. Coherence wavelet analysis was employed to investigate the time-frequency characteristics of the relationships between BRICS food markets. Unlike traditional frequency domain methods, wavelet analysis provides a time-localized perspective, allowing us to identify periods of strong and weak linkages across different frequency bands. For instance, we can identify if specific market pairs exhibit high coherence at high frequencies (short-term fluctuations) during periods of crisis, indicating heightened short-term price transmission. Conventional methods may not capture the dynamic nature of market interactions, but this time-frequency resolution offers valuable insights.

3. Data

The study investigates the relationship between food commodities in the BRICS countries by evaluating the prices of the major food commodities in their bilateral trade: soybeans for Brazil, wheat for Russia, rice for India, corn for China, and sugar for South Africa. The dataset's observation period spans from April 1st, 2016, to September 10th, 2023, and the data was sourced from investing.com, a recognized financial data provider. Before the study, we had to perform substantial preprocessing, including missing values and outlier checks, to ensure that the data was complete. To make our study more robust, we separated the data into three time periods: pre-COVID, during COVID, and post-COVID, based on the structural breaks identified using CUSUM and Bai-Perron tests. This strategy provides a more realistic picture of how global dynamics evolve in response to global events. Subsequently, the price series was transformed into logarithmic returns. Specifically, soybeans, wheat, rice, corn, and sugar, our work focuses on internationally standardized, exchange-traded agricultural commodities with strong futures markets and efficient price discovery mechanisms, as these are the most often traded commodities. Though essential for food security, meat, milk, and dairy products were purposefully left off the BRICS countries' commodity lists because there were no uniform financial market tools. On the other hand, animal products show great variation in quality criteria, storage needs, and regional trade preferences. Such variation differs from the selected goods, which have sufficient market depth for meaningful pricing study, ongoing transaction data, and globally recognized contract criteria. Diets derived from animals include necessary minerals, high-quality proteins, and micronutrients that are difficult to get just from plant-based diets. Consumption of these goods varies greatly throughout the BRICS countries since different cultural, economic, and nutritional habits influence their availability. Future research should include these commodity markets to improve knowledge of the links between food security and other factors, particularly considering the BRICS countries' joint efforts addressing nutritional security concerns together with price stability concerns.

4. Results

We employed daily data for our analysis. To ensure reliable and meaningful econometric results, daily price data were transformed into log returns. The detailed results of summary statistics, Granger causality, and TVP VAR-based connection indices are explained in this section.

Table 1: Descriptive Statistics

Pane1: Pre-Covid -19 period

Sum. Statistics	Soybeans	Wheat	Rice	Corn	Sugar
Mean	0.000231	0.000132	0.000045	0.000138	-0.00029
Maximum	0.057586	0.068503	0.0729	0.044731	0.10814
Minimum	-0.054411	-0.060343	-0.066939	-0.061181	-0.050789
Stdev	0.012826	0.017735	0.014653	0.013551	0.019019
Skewness	0.015886	0.346633	0.376472	-0.193829	0.298918
Kurtosis	1.921039	1.294871	2.293368	1.385381	1.778184
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	694	694	694	694	694
ADF Test	‘0.00’	‘0.00’	‘0.00’	‘0.00’	‘0.00’
ARCH-LM test	0.0000	0.0000	0.0000	0.0000	0.0000

Panel 2: During COVID-19

Sum. Statistics	Soybeans	Wheat	Rice	Corn	Sugar
Mean	0.000301	0.000635	0.00049	0.000606	0.000611
Maximum	0.076222	0.077611	0.098676	0.062084	0.077458
Minimum	-0.068603	-0.061187	-0.299703	-0.190997	-0.078285
Stdev	0.011838	0.018466	0.018205	0.017868	0.017751
Skewness	0.197111	0.301756	-5.193643	-1.546712	0.12794
Kurtosis	5.403905	0.849184	82.63449	18.214294	1.415285
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	757	757	757	757	757
ADF Test	‘0.00’	‘0.00’	‘0.00’	‘0.00’	‘0.00’
ARCH-LM test	0.0000	0.0000	0.0000	0.0000	0.0000

Panel 3: Post-Covid -19 period

Sum. Statistics	Soybeans	Wheat	Rice	Corn	Sugar
Mean	-0.000061	-0.000168	0.000733	-0.000546	0.000785
Maximum	0.076222	0.073363	0.04919	0.076574	0.042576
Minimum	-0.068603	-0.08249	-0.05525	-0.183406	-0.070839
Stdev	0.016603	0.024828	0.011765	0.02102	0.0153
Skewness	0.013006	0.1263	0.270292	-2.222362	-0.26214

Kurtosis	2.13877	0.685304	2.07474	17.830337	1.220959
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	423	423	423	423	423
ADF Test	'0.00'	'0.00'	'0.00'	'0.00'	'0.00'
ARCH-LM test	0.0000	0.0000	0.0000	0.0000	0.0000

Source: Author's computation

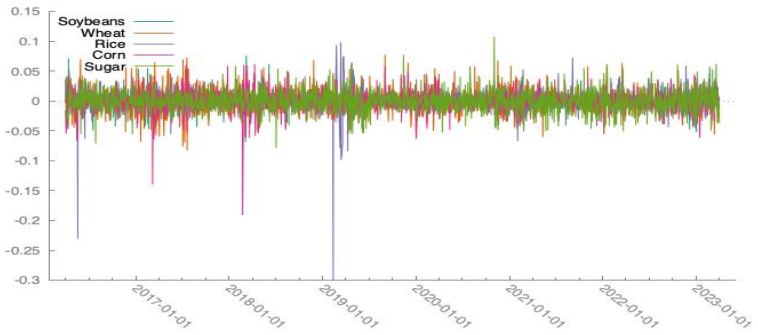

Fig. 1: Stationarity (Returns) of Food Markets.

Table 1 presents the summary statistics for the daily returns of food market indices within the BRICS economies, calculated across various time horizons. The mean log returns of all markets except sugar are positive for the pre-COVID period. The returns of all markets are positive for the COVID period. This demonstrates that demand for food markets persists even during lockdowns. The food market experienced a growth rate of 3.4% in the fiscal year 2020-21, despite a fall of (-7.2%) in total economic growth during the corresponding time (Impact of Covid-19 on Agriculture 2021). Further, the returns for soybean, wheat, and corn are negative for the post-COVID period. The COVID-19 pandemic significantly increased volatility in agricultural markets, leading to price crashes for commodities like corn and wheat. Negative sentiment surrounding the pandemic has been shown to cause substantial fluctuations in agricultural prices, particularly affecting the lower and upper quantiles of price distributions (Iuga et al. 2024; Fox 2022). Investors' sentiment about supply stabilization and government intervention might be the reason for the trend. The standard deviation indicates high wheat volatility during the COVID period. All markets except corn are positively skewed for the pre-COVID period. During COVID, rice also became negatively skewed. In the post-COVID period, rice became positive, and sugar changed to a negative skew. The positively skewed markets indicate the probability of positive returns. The leptokurtic nature of the distribution is evident for all the markets, which indicates the food markets are highly volatile, which means the market can generate extreme returns. The Augmented Dickey-Fuller (ADF) test also showed that all the return series are stationary, which is crucial for the validity of the connectedness analysis.

The connectedness of food markets across different countries exhibits significant complexity, influenced by various factors over distinct time horizons. Research reveals the interconnectedness of food commodities in both the short and long term, exhibiting dynamic fluctuations during crises (Owusu et al. 2022). Additionally, the global food trade network has evolved to become more intricate and stable, reflecting a shift from unipolar to multipolar trade relations (Wang and Dai 2021). This interconnectedness is further complicated by geopolitical factors, public health crises, and climate change, which affect the resilience of food systems globally (Xu et al. 2024). The ADF results for all panels are significant, which indicates the log returns are stationary. We have examined the ARCH effect by applying the ARCH-LM test. According to Engle (1982), the rejection of the null hypothesis on the ARCH effect signifies the presence of conditional heteroscedasticity. Figure 1 displays the return series for food markets within the BRICS nations. Stationary series can be forecasted and generalized.

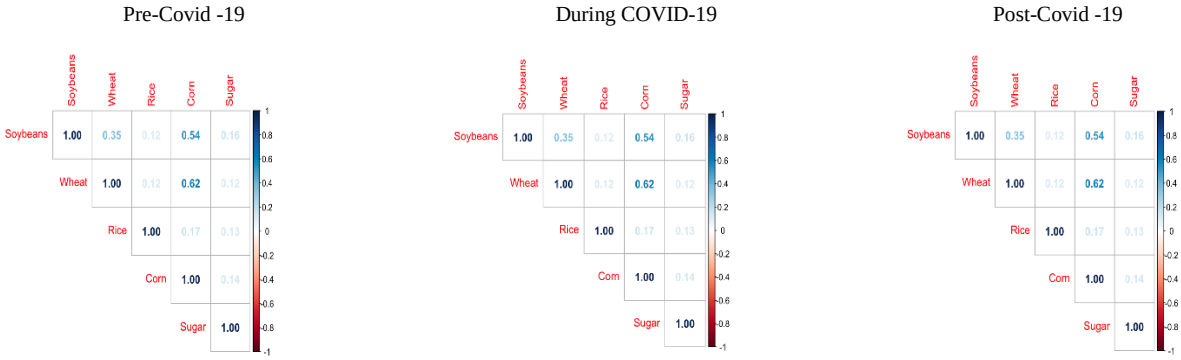

Fig. 2: Correlation Matrix between Equity and Commodity Market

Figure 2 shows that there is a positive correlation among the food markets of BRICS for the pre-COVID period. Among all, the price of corn is more correlated with wheat, followed by soybeans. The correlation between food markets decreased during COVID-19. However, the COVID-19 scenario continues the trend that corn, wheat, and soybeans demonstrated in the prior period. In the post-COVID period, the correlations between food markets reduced compared to the COVID period. The change in the consumption pattern in the post-COVID period is a reason for the low correlation among food markets (Eftimov et al. 2020). The epidemic has wide-ranging impacts on diverse dimensions of life for humans, encompassing the domain of food intake as well.

Table 2: Granger Causality Among Food Markets

Hypothesis	Pre-Covid		During Covid		Post-Covid	
H0	'F value'	'P value'	'F value'	'P value'	'F value'	'P value'
No Granger causality from Soybean to Wheat	2.074	0.1503	2.4631	0.06133	5.0418	0.025 *
No Granger causality from Wheat to Soybean	2.6019	0.1072	0.3926	0.7584	8.8759	0.00305**
No Granger causality from Soybean to Rice	0.2984	0.5851	0.3492	0.7897	0.013	0.9092
No Granger causality from Rice to Soybean	0.305	0.581	0.7811	0.5047	0.1447	0.7038
No Granger causality from Soybean to Corn	0.5374	0.4637	2.1096	0.09762	1.7849	0.1823
No Granger causality from Corn to Soybean	0.3198	0.5719	1.9936	0.1135	0.0919	0.762
No Granger causality from Soybean to Sugar	0.7235	0.3953	0.1097	0.9545	0.7015	0.4027
No Granger causality from Sugar to Soybean	1.7254	0.1894	4.1598	0.00617	0.0151	0.9021
No Granger causality from Wheat to Rice	8e-04	0.978	1.632	0.1805	0.33	0.566
No Granger causality from Rice to Wheat	0.0273	0.8687	0.4284	0.7327	0.5854	0.4446
No Granger causality from Wheat to Corn	0.7372	0.3909	0.8452	0.4694	3.0539	0.08128
No Granger causality from Corn to Wheat	0.5962	0.4403	1.7907	0.1475	6.6044	0.0105*
No Granger causality from Wheat to Sugar	0.46	0.4978	0.919	0.4312	0.9653	0.3264
No Granger causality from Sugar to Wheat	0.0018	0.9662	0.3517	0.00119**	0.1077	0.7429
No Granger causality from Rice to Corn	1e-04	0.9927	0.7806	0.505	0.054	0.8164
No Granger causality from Corn to Rice	0.1807	0.6709	0.1434	0.9339	0.3278	0.5673
No Granger causality from Rice to Sugar	3.3245	0.06869	0.7014	0.5514	1.4157	0.2348
No Granger causality from Sugar to Rice	0.2896	0.5907	2.6632	0.047 *	1.1083	0.2931
No Granger causality from Corn to Sugar	2.348	0.1259	0.9919	0.396	0.1647	0.685
No granger causality from Sugar to Corn	1.2029	0.2731	6.9081	0.00013***	0.1657	0.6842

Notes: (i) *Denote significance at 10% significance level; **Denote significance at 5% significance level, and ***Denote significance at 1% significance level.

Table 2 presents the results of the Granger causality test for the food markets in BRICS. It has been used to determine how one market influences another and how much influence one market has on another (Gupta and Guidi 2012; Huang et al. 2000). The significant values are indicating that the past values of the former contain information that can significantly enhance the prediction of latter's future values, beyond what can be achieved using only past values of the latter. It is observed that there is no Granger causality existence at the pre-COVID period. In the COVID period, it is noted that sugar Granger causes wheat, sugar Granger causes rice, and sugar Granger causes corn. It is revealing that sugar is affecting wheat, rice, and corn. It suggests that there may be some predictive power between the prices of these foods. In the post-COVID period, there is soybean and wheat, and corn and wheat. Granger causality wasn't present before COVID, but it was present during and after COVID. This could be because of changes in the market or shocks from outside the country. The COVID-19 pandemic introduced unprecedented volatility and interconnectedness among global markets, altering the relationships between economic indicators and stock indices (Marpaung and Pangestuti 2024). Global economic recovery, stimulus measures, supply chain disruptions, and investor risk perceptions are some of the reasons behind the absence of information flow (Farid et al. 2022).

Table 3: TVP VAR Connectedness Index

Panel 1: Pre-COVID-19 period

	Soybeans	Wheat	Rice	Corn	Sugar	FROM
Soybeans	66.53	9.54	2.55	18.77	2.6	33.47
Wheat	8.89	64.07	1.8	21.67	3.57	35.93
Rice	2.69	2.51	88.69	4.09	2.02	11.31
Corn	16.55	20.19	3.31	58.01	1.93	41.99
Sugar	3.58	4.39	2.84	3.27	85.92	14.08
TO	31.7	36.63	10.5	47.81	10.12	136.77
NET	-1.76	0.7	-0.81	5.83	-3.95	TCI: 27.35

Panel 2: During the COVID-19 period

	Soybeans	Wheat	Rice	Corn	Sugar	FROM
Soybeans	65.3	11.25	3.29	18.19	1.97	34.7
Wheat	9.95	63.01	5.92	19.63	1.49	36.99
Rice	1.91	2.67	90.58	2.95	1.89	9.42
Corn	16.19	18.24	4.84	59.28	1.45	40.72
Sugar	5.33	5.01	5.35	5.19	79.11	20.89
TO	33.38	37.17	19.41	45.97	6.8	142.73
NET	-1.32	0.18	9.99	5.24	-14.09	TCI: 28.55

Panel 3: Post-COVID-19 period

	Soybeans	Wheat	Rice	Corn	Sugar	FROM
Soybeans	89.59	1.65	2.28	2.65	3.82	10.41
Wheat	2.14	67.73	2.01	20.04	8.08	32.27
Rice	1.57	1.47	87.71	3.99	5.26	12.29
Corn	0.96	19.73	3.78	71.03	4.5	28.97
Sugar	1.28	7.29	3.67	2.18	85.58	14.42
TO	5.95	30.15	11.74	28.87	21.65	98.36
NET	-4.45	-2.12	-0.56	-0.1	7.23	TCI: 19.67

Table 3 shows the results of the TVP-VAR connectedness index. To provide a more comprehensive examination, we undertake a time-varying analysis of the connectedness effects on volatility. The length period of the moving rolling window is not required by this model (Zhang and Hamori, 2021; Liu et al., 2022). Furthermore, the model exhibits insensitivity toward outliers. We determine the appropriate lag order of the TVP-VAR model by applying the Bayesian information criterion. All variables exhibited a lag order of one. The data reveals that the total connectivity index increased from 27.35% in the pre-COVID period to 28.55% in the COVID period and again stabilized in the post-COVID period. The food market was affected by COVID-19. The positive values are indicators of information senders, and the negative values are indicators of information receivers. Soybeans, rice, and sugar are the receivers of information for the pre-

Covid period. Wheat and corn are the senders of information in the pre-COVID period. Corn is the largest sender of spillover, followed by wheat and soybeans for the pre-COVID period, while rice is the weakest sender of spillover. During COVID period, wheat, rice and corn are the senders of spillover, whereas the remaining markets are the recipients of volatility spillover. We observe that markets with negative net spillovers, such as soybeans and sugar, exhibit lower resilience compared to rice and corn. These resilient markets display a robust capacity to absorb shocks originating from other markets, while transmitting minimal shocks themselves. In net spillover transmitter markets, the value of wheat is comparatively lower than that of rice and corn. This suggests that investors engaged in rice and corn are subject to a higher level of risk compared to those who have invested in wheat. In the post-COVID period, the scenario of the Indian market changed. All the markets except sugar shift to become the receivers of spillover. Figure 3 shows the total connectedness of markets. The total connectedness index of all markets is fluctuating between 20% to 50% except during the time of Covid-19. At the time of COVID-19 the connectedness reached above 75 %. The overall connection index experienced a modest fall as the outbreak progressed, but thereafter exhibited a gradual recovery. As anticipated, the dynamic total connectedness index exhibits sequential variability. During periods of market stress, including the early phases of the COVID-19 epidemic, the worth of dynamic total connectedness experiences a corresponding increase. The lower price volatility observed in the post-COVID era can be attributed to the emergence of the COVID-19 pandemic, which has had a significant influence on the growth prospects of almost two-thirds of developing economies that heavily rely on commodity exports (World Bank Group, 2023). The conclusions drawn in our study align closely with the findings reported by Balcilar et al. (2021). The connectedness between equity and commodity markets is more complex.

We must acknowledge the common use of average outcomes to synthesize the underlying connections. These findings do not apply to the examination of a single incident or significant disruption, such as the global COVID-19 epidemic. Therefore, it is imperative to utilise the dynamic or time-varying concept of complete connectivity to assess market dynamics and the evolution of roles over time. The exploration of changing the roles of net transmitter and net recipient is a compelling scenario that demonstrates the practicality of this paradigm. Figure 3 illustrates the intertemporal rise of the TCI.

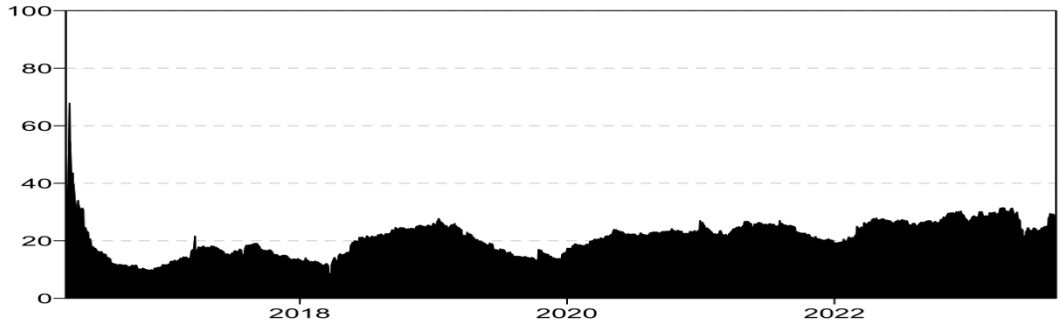

Fig. 3: Total Connectedness Index.

The TCI fluctuates across the observed period. TCI values increased significantly between 2018 and the first quarter of 2019, eventually hitting their peak. The TCI values then showed a declining trend toward the end of 2019. However, in the first quarter of 2020, the TCI spiked in reaction to the COVID-19 pandemic. Following that, there was a short period of decline. The observed increase in the TCI's worth can be attributed to intermarket spillovers. The observed increase in TCI value at the beginning of 2020 is consistent with previous research findings (Balcilar et al. 2021; Zhang and Broadstock 2020).

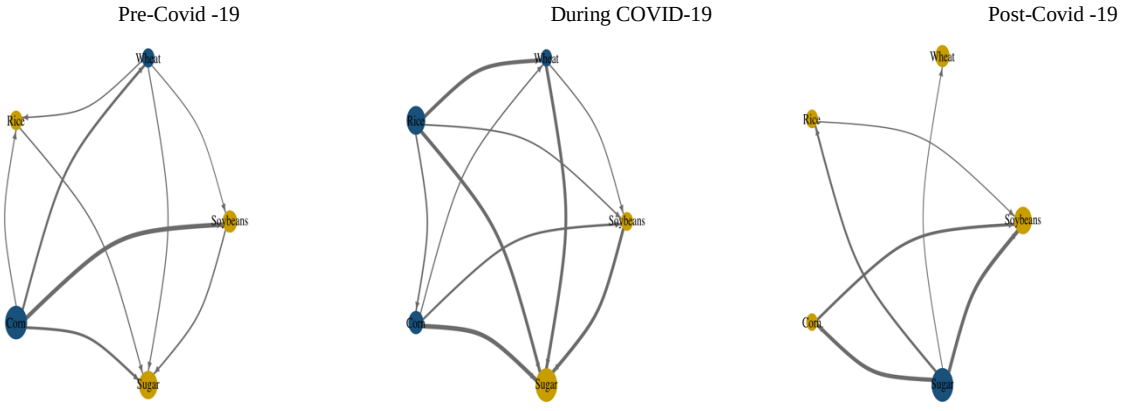

Fig. 4: Connection Network Among Food Markets

Figure 4 shows the strength of connectedness among the food markets of BRICS in different time horizons. We find a strong connection between soybeans and corn during the pre-COVID period. However, this strength is absent in the COVID period. The connection among other markets becomes stronger. BRICS countries' agriculture markets were very connected during the COVID-19 pandemic because they play big roles in global agriculture, trade with each other, worry about food security, respond to policy changes, have complementary growing seasons, depend on each other economically, and take part in international forums (Mehta et al. 2021). In the post-COVID scenario, the connectedness among the markets has diminished. The level of connectedness among agricultural markets in BRICS countries may have weakened in the post-COVID period due to geopolitical factors and economic ties (Workie et al. 2020).

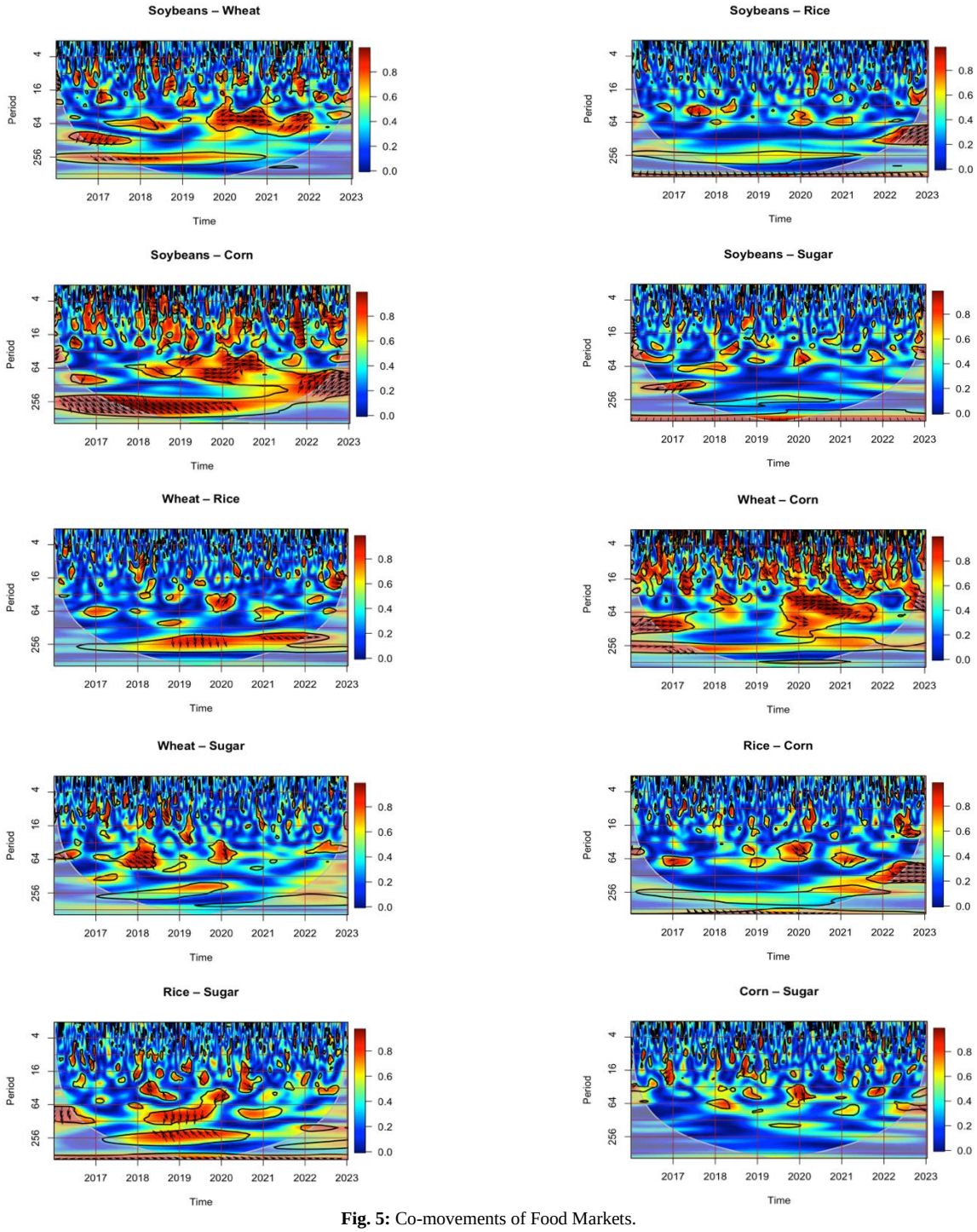

Fig. 5: Co-movements of Food Markets.

We presented the wavelet analysis as a contour plot with three dimensions and various colors for easy visualization. The wavelet coherence plot illustrates the period from 2016 to 2023 along the horizontal axis. In the analysis of various time and frequency bands, the intensity of co-movement (whether strong or weak) is depicted through color gradation. Conversely, arrow directions illustrate the causation aspect, distinguishing between leading and lagging relationships, as well as the nature of the relationship (positive or negative). The wavelet coherence in the time-frequency domain between the Indian equity and commodity markets is shown in these pictures, which look like heat maps. Each plot serves as a heat map, offering insights into the level of co-movement within the time-frequency domain of a specific market and its correlation with other markets.

The heat maps employ a color spectrum from light/blue to dark/red, symbolizing varying degrees of power ranging from low to high. The color codes in these heat maps show how much movement there is in the time-frequency domain of one stock market with other stock markets in different areas. The color codes also show that the wavelet squared coherency value is going up, which means that more co-movements range from weak to strong correlations. It can be highly visualized in soybean and wheat, soybean and corn, wheat and rice, wheat and corn, and rice and corn. But the direction of these co-movements plays an important role. In the following analysis, we focused on the direction of these co-movements.

In the analysis of association and causality, the direction of the arrow serves as a key indicator. This arrow signifies whether a variable is leading or lagging about another. Specifically, a right-pointing arrow signifies a positive association, indicating that the variables are in phase. Moreover, a right-pointing arrow pointing upwards suggests a positive association with the first variable leading, while a right-pointing arrow pointing downwards implies a positive association with the first variable lagging. Conversely, a left-pointing arrow indicates a negative association, signifying that the variables are out of phase. If the left arrow is pointing upwards, it denotes a negative

association with the first leading variable, whereas a left arrow pointing downwards indicates a negative association with the first lagging variable. This directional analysis provides valuable insights into the relationship and temporal sequence of the variables under consideration.

Figure 5 confirms the co-movements of food markets of the BRICS economy. The markets are moving similar way at the time of Covid-19. Especially between soybeans and wheat, soybeans and corn, wheat and rice, and wheat and corn. The co-movements between soybeans and rice, soybeans and sugar, wheat and sugar, rice and corn, and corn and sugar are very less. High co-movements between the volatility of two commodities indicate a stronger correlation in their price movements. This suggests that the two commodities are more likely to move in the same direction and experience similar levels of volatility. This can be an important consideration for investors and traders who are looking to diversify their portfolios, as high co-movements between two commodities may reduce the effectiveness of diversification in mitigating risk. On the other hand, lower co-movements between the volatility of two commodities indicate a weaker correlation in their price movements. This suggests that the two commodities are less likely to move in the same direction and may experience different levels of volatility. Lower co-movements can be beneficial for diversification purposes, as it may allow investors to spread risk more effectively across different assets.

5. Discussion

The interdependence of BRICS food markets stems from the global supply chain's dynamics. Recognized for their considerable contributions to the world's food supply, the BRICS countries play an important role in the international agricultural market. Consider Russia's status as a leading wheat supplier and Brazil's significance as a soybean and corn exporter. The BRICS countries are all exposed to the fluctuations in food commodity prices induced by factors such as global weather patterns, trade policies, and geopolitical tensions. If the Russian ruble's price rises sharply, the South African rand and other nations that rely on wheat imports may face price increases. The interwoven nature of the BRICS economy highlights how changes in one area can have far-reaching consequences for the others. Market dynamics have also shifted because of the COVID-19 epidemic, underlining the vulnerability and interdependence of food systems. Changes in customer behavior, transit delays, and labor shortages significantly impacted supply chains during the epidemic. Price volatility increased as nations retreated domestically. Food price changes highlighted the need for BRICS countries to collaborate; as a result, soybeans, wheat, and maize became increasingly central sites of information flow and causality. Food supply volatility can be driven by both local and international issues, thus, policymakers in the BRICS countries must grasp this. Thus, ensuring food security is a collaborative effort that necessitates coordinated methods. The observed interconnectivity of food prices is also strongly influenced by market structure. The oligopolistic structure of agricultural markets contributes to price synchronization, particularly when a small number of nations control a major amount of the supply of a specific product. Market prices in networked economies are unintentionally influenced by key actors' pricing practices or trade agreements. The extent of trade ties, both bilateral and multinational, serves to strengthen this bond. For example, BRICS nations that use Brazilian products are likely to suffer price rises if agricultural exports to China rise, putting upward pressure on Brazilian prices. As a result, geopolitical issues, trade agreements, and regional cooperation all have a direct impact on food pricing in the BRICS countries.

The massive impact on food security is a significant issue that arises as a result of this interconnectedness. Because the BRICS countries account for over 46% of the world's population, their agricultural policies have far-reaching repercussions that go beyond economics. For already poor groups, price increases can be disastrous, exacerbating food insecurity. Food insecurity in one of the BRICS countries may have an impact on the others due to their intertwined economies. For example, if a drought significantly reduces China's maize supply, the resulting price hikes may limit access for populations across the BRICS region. The implementation of price stability mechanisms and the establishment of strategic food stockpiles are two examples of proper risk management approaches that are urgently required, considering this interconnected threat.

Nonetheless, the limitations of previous studies must be addressed. Although Granger causality tests reveal interdependence, they do not account for fundamental economic factors such as currency fluctuations or shifting trade routes, which could significantly alter these relationships. Future studies should thoroughly evaluate the data utilizing various frameworks, such as neural networks or coherence wavelet analysis, to identify complex non-linear connections that conventional econometric models may miss. The bigger contexts that may influence future patterns should also be carefully considered. Unpredictable developments are expected in agricultural markets due to global issues such as climate change, trade tensions, and the ongoing consequences of the COVID-19 pandemic. To create resilience against future shocks, BRICS policymakers must support agricultural diversity and innovation while remaining agile and sensitive to global trends. During the COVID-19 pandemic, the role of sugar in influencing other commodities became particularly significant due to a variety of underlying factors. Policy changes, such as lockdowns and restrictions on movement, disrupted the supply chains, affecting the production and distribution of sugar and related commodities. Sugar's effect on wheat, rice, and corn during COVID-19 shows the complicated interaction between supply and demand. Consumer hoarding habits brought on by the epidemic caused simultaneous stockpiling of staple items, with sugar serving as a main signal. This was one element on the demand side. Supply-side elements were the different impacts of COVID-19 on labor-intensive sugar production, which caused favorable substitution effects. Furthermore, the increased connection between sugar and oil prices during the epidemic gave rise to additional transmission mechanisms affecting other agricultural products using biofuel routes and input costs. Traders' use of sugar futures as a replacement investment during market volatility intensified these links through financial speculation. These multidirectional causal pathways, which go beyond simple statistical association by explaining, clarifying the predictive usefulness of sugar. Trade disruptions, including border closures and shipping delays, further exacerbated these challenges, leading to fluctuations in sugar prices and availability. Additionally, shifts in consumer behavior, with increased demand for processed and comfort foods, impacted the demand for sugar, thereby influencing its market dynamics.

BRICS countries could use several strategies to successfully reduce food price volatility. First and foremost, agricultural productivity must be increased by investment in technology and infrastructure. This involves implementing precision farming techniques, upgrading irrigation infrastructure, and investing in R&D to create more hardy crop varieties. Second, creating strategic food reserves can help stabilize prices during supply shocks by providing a buffer stock to draw on in times of scarcity. Furthermore, promoting regional trade agreements among BRICS countries can lower trade barriers, allowing for more efficient cross-border food trading and lowering reliance on foreign markets. Implementing these steps, however, presents its own set of obstacles. Trade restrictions, such as tariffs and quotas, can impede the free flow of goods, making it harder to keep food prices steady. Political concerns also play an important role, as governments may emphasize national interests above regional collaboration, resulting in protectionist policies that heighten volatility. Furthermore, harmonizing the different agricultural policies and economic priorities of the BRICS countries necessitates tremendous diplomatic effort and cooperation. Addressing these difficulties requires a collaborative strategy in which BRICS countries collaborate to align

policies, share best practices, and strengthen confidence. By promoting a cooperative atmosphere, these countries may effectively implement methods to reduce food price volatility and assure food security for their citizens.

Our study of the interconnection of the food markets of the BRICS nations reveals direct effects on important accounting techniques and more general economic theory. Managing food reserves, pricing hedging options, and accounting for supply chain costs call for advanced accounting techniques, given the recognized volatility transmission patterns. Our results are relevant to inflation modeling since they show the transmission of food price shocks across countries, influencing the monetary policy frameworks used by central banks and the evaluation of utility losses. Full-cost accounting's effects are important because price fluctuation influences financial statement preparation, inventory valuation techniques, and strategic budgeting choices for food security investments. Our study provides accounting professionals with empirically based tools for evaluating food security concerns and creating appropriate disclosure systems inside the linked BRICS countries, therefore improving the multidisciplinary contribution to accounting literature outside traditional economic analysis. Measuring the correlations among these factors helps one accomplish this.

6. Conclusion and policy implications

The article offers a comprehensive examination of the realised price volatility relationships between food markets in the BRICS economy. This research study provides valuable insights into the expanding literature on the impacts of the COVID-19 pandemic on the interconnectedness of different asset categories. Initially, we use the Granger causality test to determine how information spreads within the food market. From the results of the Granger causality test, it is found that soybean, wheat, and corn have information flow in the post-COVID-19 scenario (present period). It means that the food prices of Brazil, Russia, and China have some causal links. By analysing the links, policymakers can take proactive measures to address issues such as food price spikes or supply disruptions before they escalate into full-blown food security crises. From the perspective of investors, the presence of Granger causality between two food markets suggests that there may be a relationship between the fluctuations in their prices. This information can be used by investors to diversify their holdings. Investors can diversify their risk and lessen the effect of price volatility in one commodity on their entire portfolio by holding both commodities. Additionally, we utilize the TVP VAR index to assess the connectedness in the food markets. The TVP-VAR connectivity approach is employed to evaluate the extent of connectedness between different market segments; hence, it examines the interdependencies among markets and illustrates the effects of the COVID-19 pandemic. The findings suggested that wheat (food market of Russia) is the largest sender of spillover, followed by corn (food market of China). It tends to experience price movements or fundamental changes before other commodities in the same market. Its price movements or supply and demand volatility can affect the agricultural sector in these nations. The observed parallel movements in markets during the COVID-19 period, particularly between soybeans and wheat, soybeans and corn, wheat and rice, and wheat and corn, suggest a strong interdependence among these commodities. But the small amounts of movement that happen together between soybeans and rice, soybeans and sugar, wheat and sugar, rice and corn, and corn and sugar show that these pairs have some independence or different responses. Policymakers in BRICS countries may need to consider the impact of policies related to the leading senders on overall food stability. For instance, trade policies, subsidies, or regulations affecting these markets can have far-reaching consequences for food security and economic stability in these nations. Also, we found that Russia and China are the largest senders of spillover in food markets. Significant geopolitical and structural elements guide our classification of Russia and China as the main transmitters of volatility within the BRICS food market framework. Russia's key role as a major global grain exporter, which significantly affects the world's wheat exports, highlights the relevance of its ranking. The conflict between Russia and Ukraine intensified this impact through the utilization of blockaded ports, disrupted supply lines, and food shipments to acquire geopolitical leverage. China's prominence comes from its position as the world's largest grain importer. China's policy choices are now significantly affecting world prices since it is experiencing structural domestic supply shortages, particularly in corn. The contextual factors explain why price shocks coming from these countries spread widely through linked food markets. The evidence suggests that the BRICS economies show systematic patterns of volatility transmission rather than serendipitous ones.

Our research advances beyond practical policy recommendations by integrating theoretical frameworks for modeling price transmission mechanisms across interconnected markets. We propose expanding econometric volatility modeling to incorporate time-varying parameters that capture structural breaks during crisis periods, enhancing predictive capacity for policymakers. The TVP-VAR framework should be refined to incorporate threshold effects that reflect non-linear relationships between food commodities during extreme market conditions. Additionally, we recommend developing hybrid theoretical models that integrate wavelet coherence analysis with traditional price transmission approaches, allowing for simultaneous examination of frequency-domain relationships and time-domain dynamics. This theoretical enhancement would significantly strengthen early warning systems for food market instability and improve the precision of intervention timing for regional food reserves and coordinated trade policies. Policies should be in place to control the risks associated with price volatility in the major sender commodity. Risk management measures can include developing strategic food reserves, adopting price stabilization mechanisms, and providing help to vulnerable groups during price surges. Encouraging variety in agriculture can lessen the reliance on a particular commodity. Policies that encourage agricultural diversity and support the production of alternative crops can boost food security and reduce vulnerability to commodity-specific shocks. It's vital to understand that the policy actions will rely on the type of the greatest sender commodity, its position in the domestic and international markets, and the distinctive economic and social situations inside each BRICS country. Fluctuations in food prices in Brazil, Russia, and China are interlinked due to various economic and policy factors, which often stem from global events and local market conditions. One primary driver is the interconnectedness of global supply chains, where disruptions, such as those caused by the COVID-19 pandemic and geopolitical tensions like the Russian invasion of Ukraine, have significantly impacted food production and distribution networks. These disruptions resulted in a surge in food prices, underscoring the reliance of national markets on international trade routes and supply chains for essential commodities such as grains, fertilizers, and other food products. In Brazil, the rise in food prices can be attributed to increased production costs driven by higher demand for fertilizers and raw materials, alongside a growing export market that skews local availability and prices. Conversely, Russia's export restrictions on agricultural products and fertilizers have aggravated the situation further, squeezing international supply and driving prices upward globally. China's policies, marked by significant governmental interventions to control domestic food prices, also exert influence over global markets through its massive import requirements. Moreover, domestic policies, including subsidies, tariffs, and export bans, compounded the effects of global supply shocks, creating waves of inflation that ripple through both national and international markets. Global events, such as climate change leading to extreme weather, also affect crop yields and availability, thereby influencing prices. These complex interactions create a feedback loop where local policies ripple across borders, affecting food security and prices in an increasingly globalized economy. As such, the causal links between these countries' food prices highlight the intricate web of dependencies in the global agricultural market. To protect food security and lower the risks that come with price changes, a multi-

faceted approach should be used. Policymakers should think about putting in place coherent food policies that not only respond to changes in the market but also plan for possible crises. This includes enhancing intra-BRICS trade to ensure food availability, investing in agricultural research and development to promote innovation, and fostering cooperation on food systems at regional and global levels. Future studies should investigate how climate change could modify the connection patterns revealed in our work. Examining theories about the spread of volatility during extreme weather events can help clarify this. This paper seeks to investigate whether climate-induced supply shocks change or strengthen the directional flow of price volatility in BRICS food markets. We will evaluate whether Russia and China's positions as main transmitters of instability are strengthened under climate change. Researchers must assess how yield variations among BRICS countries could be affected by one- to three-degree Celsius temperature rises, thereby creating new volatility transmission paths within the price interconnectivity system. A major question is whether diversity in food systems reduces volatility spillovers during climatic shocks. Several studies must be conducted to evaluate the effect of sustainable farming practices on the persistence of volatility in linked markets and to investigate how accounting rules might evolve to include climate risk calculation in agricultural financial reporting. Under different warming paths, researchers might create integrated climate-economic models combining TVP-VAR techniques with climate projection data to forecast food security situations. This will allow the application of proactive policy measures to maintain stability in the BRICS food systems.

Authors' contributions

This article is the result of significant work by all the authors. Muthumeenakshi M took the lead in writing the initial draft, introduction, and literature review, and also played a key role in revising
the entire manuscript. Yedhu Harikumar handled the data collection and analysis and wrote the discussion section. Finally, Manoharan M contributed to the econometric methodology and data section.

Disclosure statement

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Data availability

The datasets used during the current study are available from the corresponding author on reasonable request.

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