



Confluence of COVID-19 and the Russia-Ukraine conflict: Effects on agricultural commodity prices and food security

Faruk Urak^{a,*}, Abdulkali Bilgic^b, Wojciech J. Florkowski^c, Gürkan Bozma^d

^a The Turkish Radio and Television Corporation, Erzurum Directorate, 25080 Palandöken, Erzurum, Türkiye

^b Department of Management Information Systems, College of Economics and Administrative Sciences, Bilecik Seyh Edebali University, A Block 3rd Floor, Room #323, Türkiye

^c The University of Georgia, Department of Agricultural & Applied Economics, 1109 Experiment Street, Griffin, GA, 30223, USA

^d Department of Economics, College of Economics and Administrative Sciences, İğdır University, İğdır, Türkiye

ARTICLE INFO

Keywords:

Staple commodity
 COVID-19
 Russia-Ukraine war
 Price volatility
 Volatility spillover

ABSTRACT

The study investigates the effects of the Russian-Ukrainian war, the COVID-19 pandemic, and exchange rate fluctuations on the average return, contagion dynamics, and persistence of risks associated with three staples in Türkiye: wheat, sunflower oil, and corn. The pandemic and the war disrupted the grain, oil seed, and fertilizer supply from Russia and Ukraine to Türkiye and several Middle Eastern and African countries, risking food insecurity. The specified VECM-Asymmetric BEKK-MGARCH model estimation uses data from January 2010 to May 2023. Results show that over time, short-term deviations move towards long-term equilibrium. The presence of reciprocal causality among wheat, corn, and sunflower oil prices underscores their mutual influence. The volatility pass-through between wheat, sunflower oil, and corn shows asymmetric transmission. Long-term uncertainty stemming from one market exacerbates that market's uncertainty but mitigates risks affecting other markets. The volatility can be reduced through domestic production expansion through comprehensive policies enhancing rural area development, assuring farmer access to inputs, and implementing market risk mitigating measures. Results also show that the effects of the pandemic and the Russia-Ukraine war have been amplified by exchange rate fluctuations. Market risk mitigation could involve the agricultural exchange to support an expanded number of licensed grain warehouses. In a broader scholarly context, this study stresses the interaction between global shocks, market uncertainty, and safeguarding the nation's food security.

1. Introduction

The promising outlook for the global economy in the early months [Official Newspaper of, 2022](#) has raised hopes for a recovery in the post-COVID-19 period. Many countries have implemented coordinated strategies to contain escalating inflation and stimulate economic recovery ([Ozili, 2022](#)). Nevertheless, Russia's invasion of Ukraine on February 24, 2022, resulted in lost lives, destruction of critical infrastructure, and lowered agricultural production in Ukraine. Supply chain disruptions have been particularly significant in countries that rely heavily on imports of staple foods, such as sunflower oil, corn, and especially wheat ([Jagtap et al., 2022](#)). Russia and Ukraine accounted for approximately a quarter of global wheat exports at the onset of war in

2022 ([Cohen & Ewing, 2022](#)). The pre-existing problems of the COVID-19 pandemic have been exacerbated by the war, resulting in supply and demand imbalances that have affected tourism, manufacturing, financial markets, and commodity prices ([Chang et al., 2020](#); [Ozili & Arun, 2020](#); [Vijlder, 2020](#); [Küçük et al., 2022](#)). The ongoing conflict between Russia and Ukraine puts global food security at risk, disproportionately impacting disadvantaged groups ([Behnassi & El Haiba, 2022](#); [Jagtap et al., 2022](#)). For instance, the price of wheat surged from \$281 per ton in early February 2022 to \$490 per ton in early March 2022. The global grain price increase was a direct result of disruptions in the exports originating from Russia and Ukraine ([FAO, 2022a, 2022b](#); [Polat et al., 2023](#); [World Bank Group, 2022](#)).

The effects of the Russia-Ukraine conflict extended across various

Peer review under responsibility of Borsa İstanbul Anonim Şirketi.

* Corresponding author.

E-mail addresses: faruk.urak@trt.net.tr (F. Urak), abdulkali.bilgic@bilecik.edu.tr (A. Bilgic), wojciech@uga.edu (W.J. Florkowski), gurkan.bozma@igdir.edu.tr (G. Bozma).

<https://doi.org/10.1016/j.bir.2024.02.008>

Received 17 October 2023; Received in revised form 21 February 2024; Accepted 21 February 2024

Available online 28 February 2024

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sectors such as commodities, energy markets, and trade (Umar et al., 2022), displaced populations (Jagtap et al., 2022), and eroded market confidence (Adekoya et al., 2022; Boubaker et al., 2022; Boungou & Yatié, 2022; Saâdaoui et al., 2022). Food prices rose (Nicas, 2022) as did the prices of coal, natural gas, and wheat (Mbah & Wasum, 2022). Wide-spread price increases affected global food security and exacerbated the effects of the COVID-19 pandemic (Jagtap et al., 2022). The Russia-Ukraine war strongly affected Türkiye, given their shared location in the Black Sea basin (Lin et al., 2023). Türkiye controls maritime shipping from the Black Sea to the Mediterranean and has been a major importer of wheat and sunflower oil from Russia and Ukraine. Food imports from Russia and Ukraine collectively represent more than 40% of Türkiye's overall imports (TSI, 2022a, 2022b) and the war contributed to food inflation (Öztürk & Faizi, 2023). Türkiye imported agricultural products worth \$17.8 billion from Russia and \$2.6 billion from Ukraine (World Integrated Trade Solution, 2016). The imports from Russia constituted 8.12% of Türkiye's total imports in 2016, and this share nearly doubled to 14.9% in 2023 (Öztürk & Faizi, 2023). Russia and Ukraine are also important destinations for Türkiye exports and accounted for \$5.8 billion (2.6% of total exports) and \$2.8 billion (1.3% of the total exports), respectively, in 2021. The impact of war was evidenced in the contraction of economic confidence and the Purchasing Managers' Index (PMI) between January and February 2022 as Türkiye grappled with the immediate aftershocks of Russia's invasion (Ozili, 2022). The importance of mutual trade, especially Türkiye's imports of staple commodities, synthetic fertilizers, and energy feedstocks motivate the analysis of the overlapping effects of the COVID-19 pandemic and the Russia-Ukraine war on the prices of wheat, corn, and sunflower oil.

Global unrest and supply chain disruptions pose a risk to national food security. Uncovering long-term contagion risks bridging the COVID-19 pandemic, the Russia-Ukraine conflict, and agricultural commodity markets help to inform decision makers, shape policies and guide agricultural decisions. Therefore, the focus of the current study is to investigate the effects of the Russian-Ukrainian conflict, the COVID-19 pandemic, and exchange rate fluctuations on the average return, contagion dynamics, and persistence of risks associated with three staples in Türkiye: wheat, sunflower oil, and corn. The empirical analysis highlights the role of the COVID-19 pandemic, the Russia-Ukraine war, and the exchange rates in the volatility of three commodity prices. The study provides insights for the formulation and implementation of policies needed to strengthen Türkiye's economic resilience to exogenous shocks. The results are also relevant to protecting Turkish households' food security and social stability.

2. Literature review

The COVID-19 pandemic caused market uncertainty, increased distribution costs, induced panic-driven demand, and led to a substantial increase in the short-term price volatility of agricultural commodities (Adewopo et al., 2021; Umar et al., 2021). The pandemic disrupted the retail supply chain of staple foods, negatively affecting consumers and small-scale producers (Mishra and Rampal, 2020; Narayanan & Saha, 2021) and inducing social and economic instability (Kruczkiewicz et al., 2021; Farid et al., 2022; Goodell, 2020). Vulnerable population segments have been threatened by food insecurity (Fitzpatrick, Harris, Drawve, & Willis, 2021). Global markets recovery from the COVID-19 pandemic (Chishti et al., 2023; David et al., 2021; Iqbal et al., 2022;

Yarovaya et al., 2022) was set back by the Russian invasion of Ukraine (Capitani & Gaio, 2023; Shen & Hong, 2023; Yousaf et al., 2022; Zhou et al., 2023). The economic impact of the Russia-Ukraine war is projected to last longer than that of COVID-19 (Chishti et al., 2023). Lin et al. (2023) and Xu et al. (2023) examine the possible lasting influence of the war on worldwide grain markets, food prices, and global food security. Abay et al. (2023) assert that rural areas have a higher concentration of impoverished families susceptible to food insecurity than urban areas, but it is the urban poor who are most significantly impacted by the Russia-Ukraine war through the subsequent increase in food prices.

The role of agricultural commodities in safeguarding food security, especially in low-income countries, has garnered global attention since the start of the Russia-Ukraine war (Aliu et al., 2023; Arndt et al., 2023). The prolonged hostilities in Ukraine, coupled with international sanctions on Russian grain and fertilizer exports, threaten global food supplies and put food security at risk (FAO, 2022a, 2022b). Increased transportation costs could contribute to food insecurity in nations heavily reliant on imports from conflict-affected regions (Travnikar & Bele, 2022). Russia and Ukraine collectively contribute to 12% of the world's calorie exports and rank among the top five suppliers of barley, wheat, corn, and sunflower. Ukrainian sunflower seed oil constitutes half of the global market supplies and Ukraine exports corn to the European Union (EU), China, Egypt, and Libya (Glauber & Laborde, 2023). The threat of the complete cessation of agricultural production in Ukraine could have far-reaching consequences for grain and oil seed supplies (Laber et al., 2023). The reduced food exports from Russia and Ukraine, coupled with soaring energy prices, could cause a 60–100% increase in food costs by 2023 compared to 2021, placing 61 to 107 million people at risk of malnutrition in 2023, and result in an additional 0.42 to 1.01 million deaths per year (Alexander et al., 2023). The adverse impact of the war could push an additional 27.2 million people into poverty while 22.3 million people could face hunger. The agri-food systems are vulnerable to escalating fuel and fertilizer costs, whereas food price inflation lowers diet quality (Arndt et al., 2023).

Türkiye is one of the most severely affected nations by the Russia-Ukraine war (Lin et al., 2023). The ongoing conflict has led to increased prices of agricultural commodities, reduced trade, and threatens food security (Lopes & Martin-Moreno, 2022). Other countries in the region like Egypt, heavily dependent on grain imports from Ukraine and Russia, also have faced increased risk of food insecurity (Feng et al., 2023). Besides grain imports, the war impacts agricultural production by disrupting fertilizer exports from Russia (Hellegers, 2022). The fertilizer supply disruption reduces crop yields contributing to further food price increases and jeopardizing food security (Shahini et al., 2022). The world-wide detrimental effects of the war have been reflected in an increased and direct correlation between the global food price index, world oil price index, world daily price index, and world grain price index (Ozili, 2022).

The disruption of Russian commodity exports results from the imposition of Western sanctions following its invasion of Ukraine (Sokhanvar & Bouri, 2023). The sanctions affected crude oil prices which became a medium through which yield spreads were transmitted to wheat and soybean markets. The volatility spread index increased significantly, surging from below 35%–85% soon after the invasion began and surpassed the level observed during the COVID-19 pandemic. The increased volatility suggests that war has a relatively greater effect on volatility

transmission across commodities markets. For example, metal and sugar markets exhibited net transmission of volatility, while the significance of wheat and oats as net receivers has been growing (Wang et al., 2022).

According to Zhang et al. (2023), 279 nations and territories have reported varying degrees of effects on outside food sources due to the Russia-Ukraine war. Yazbeck et al. (2022) found that 68.7% of families in Lebanon shopped less frequently following Russia's invasion into Ukraine. Several countries in the Middle East, including Lebanon, Libya, Sudan, and Yemen might be severely impacted by the Russia-Ukraine war because of their grain imports from the parties involved in the conflict (Al-Saidi, 2023). Ben Hassen and El Bilali (2022) stress that the ongoing war is likely to obstruct the export route from Ukraine, impacting the shipment of grains and fertilizer and causing price increases. Nasir et al. (2022) emphasized the considerable influence of diminished grain, soybean, and corn production in Ukraine on not only global food prices but food security as well.

The above review of earlier studies links disruption of grain production and trade to unstable food prices. The volatility in grain prices inevitably impacts consumer food security underscoring the critical importance of grain price stability. In an environment characterized by unforeseeable global events, the examination of linkages across agricultural commodity markets and prices, the uninterrupted supply and formulation of effective policies are of vital importance for Türkiye. Policymakers, grain traders, brokers, and food processors and distributors could benefit from the analysis of agricultural commodity price interactions through improved decisions using the information from the current study. In this context, the current study not only fills a gap in the literature but also contributes to the formulation of policies that serve the creation of an uninterrupted agricultural commodity supply and the enhancement of economic competitiveness of the country through price stability.

3. Data and methods

3.1. Data

Daily wheat, sunflower oil, and corn price data were collected from the Adana Commodity Exchange market database.¹ To account for the effects of inflation, the Producer Price Index (PPI) was used to adjust the prices.² The current study covers the period from January 2010 to May 2023 to allow for a comprehensive analysis of market volatility within commodity markets. The daily real dollar exchange rate series was sourced from the Electronic Data Delivery System (EVDS) curated by the Central Bank of the Republic of Türkiye (CBRT). Comparisons are drawn between the pre- and post-pandemic periods, as well as the pre- and post-war periods, and provide insights into the interactions that govern those markets.

The current research aims to demonstrate the various aspects of

¹ The study's estimation procedure was executed using RATS 10, a statistical software known for its proficiency in time series analysis and econometric modeling. By utilizing the capabilities of RATS 10, the researchers aimed to employ advanced econometric techniques and investigate the inherent complexities of the dataset. It is important to note, however, that certain limitations were encountered during the data collection process. Unfortunately, we lost some match-related observations because all three agricultural products had to be traded on the stock exchange on the same day in order to be included in the analysis. Such a condition, which was designed to ensure coherence and comparability, resulted in excluding a subset of observations. This exclusion, although intended to maintain methodological rigor, potentially impacts the overall representativeness and generalizability of the findings.

² Return on each agricultural product can be calculated as $r_{i,t} = \frac{Pr_{i,t} - Pr_{i,t-1}}{Pr_{i,t-1}} \cong \Delta \ln Pr_{i,t} = \log_e \left(\frac{Pr_{i,t}}{Pr_{i,t-1}} \right)$, $i = w, sf, c$. $Pr_{i,t}$ and $Pr_{i,t-1}$ show the real price (current and lag) of the relevant agricultural commodity in question in periods t and $t-1$, respectively.

market volatility, elucidate underlying complexities, and offer valuable insights into the impact of significant events such as the COVID-19 pandemic and the Russia-Ukraine war on these critical markets. Three fundamental agricultural commodity series, namely wheat (w), sunflower oil (sf), and corn (c), are endogenous variables, while the real exchange rate series and the two dummy variables, namely the COVID-19 pandemic and the Russia-Ukraine conflict are exogenous variables. The pandemic's onset and the commencement of the Russia-Ukraine war were precisely marked as January 2020 and February 24, 2022, respectively. To gauge the impacts of these events on the variables of interest, the deliberate creation of dummy variables was undertaken, aligning with their respective dates.

3.2. Econometric approach

The current study examines how the prices of wheat, sunflower, and corn interact against the backdrop of increased uncertainty brought on by the COVID-19 pandemic, the Russia-Ukraine war, and the exchange rate. The consideration of the exchange rate as exogenous in the spill-over linkage to wheat, corn, and sunflower oil is motivated by the large amount of Turkish imports from Russia and Ukraine. The exchange rate is a control variable in both the return and conditional variance equations of three commodity prices to discern their complex relationships. The study applies the multivariate Generalized Autoregressive Conditional Heteroscedasticity (MGARCH) model developed by Baba, Engle, Kraft, and Kroner (BEKK), noted as BEKK-MGARCH herein. This modeling framework depicts how price volatility spreads among the three agricultural commodities.

In the presence of co-integration among staple commodity prices, differences in the natural logarithms of the prices translate into returns and the current study applies the Vector Error Correction Model (VECM) for the mean equation. The approach takes into consideration the cointegration and potential asymmetric impact on the conditional variance of wheat, corn, and sunflower oil prices. Following Rahman and Serletis (2012) and Salisu and Oloko (2015), we assert that negative and positive shocks have different effects on the long-term risks related to wheat, corn, and sunflower oil prices. In the current analysis, the BEKK-MGARCH model was tested against alternatives, including the stacking of vectorized conditional variance matrices (VECH), the constant conditional correlation model (CCC), and the time-varying conditional correlation (DCC) model. The BEKK model is selected because it assimilates asymmetric information flows from multiple data sources (Engle & Kroner, 1995; Rahman & Serletis, 2012; Salisu & Oloko, 2015; Urak & Bilgic, 2023; Urak, Bilgic, Bozma, et al., 2022).

The mean equation of each staple incorporates the square roots of conditional variances (Grier et al., 2004; Rahman & Serletis, 2012). The square roots of conditional variances allow direct measurement of the effect of conditional risks (uncertainties) on fluctuations in commodity prices. The applied methodological approach produces informative results on the dynamics that control commodity prices given the uncertainty caused by the COVID-19 pandemic, the war between Russia and Ukraine, and the exchange rate. Therefore, Equation (1) and Equation (2) respectively, provide the equations for the conditional mean (recording changes in logarithmic pricing) and the conditional variances of the returns for wheat, corn, and sunflower oil. The first equation is expressed in natural logarithm differences in prices:

$$\Delta \text{LnPr}_{i,t} = \mu_i + \sum_{j=1}^p \Phi_{ij} \Delta \text{LnPr}_{i,t-j} + \theta_i \text{R}_{\text{exr},t-1} + \vartheta_i \text{COVID} - 19_{t-1} + \tau_i \text{War}_{t-1} + \sum_{i=1}^3 \Psi_{ii} \sqrt{h_{i,t-1}} + \sum_{k=1}^K \alpha_{ik} z_{k,t-1} + \varepsilon_{i,t-1}, \tag{1}$$

where $i = w, sf, c, j = 1, \dots, p, k = 1, \dots, K$, and $\varepsilon_{i,t-1} = H_{i,t-1}^{1/2} \eta_{i,t-1}$,

In Equation (1), or the conditional mean equation for the returns of agricultural commodities, Δ signifies the first difference, j denotes the lag value, and $\text{LnPr}_{i,t}$ is the natural logarithm of prices for wheat, sunflower oil, and corn. The equation assesses the unitary impact of variations in returns from the real exchange rate ($\text{R}_{\text{exr}, t-1}$), the effects of the pandemic (COVID-19_{t-1}), and the ongoing Russia-Ukraine conflict (War_{t-1}) on logarithmic changes in the prices of the three agricultural commodities in Turkish Lira (TL). Additionally, the influence of the square root of conditional variances ($\sqrt{h_{i,t-1}}$) on the logarithmic changes in commodity prices is captured. The set of explanatory variables empirically probes the assertion that heightened risk in commodity markets leads to reduced market returns. The equation also examines the effects of error correction factors ($z_{k,t-1}$) on the differences in market log prices of wheat, corn, and sunflower oil. The determination of the number of error correction vectors in return equations will be established using Johansen cointegration tests, while the Bayesian Information Criterion (BIC) determines the number of lags in commodity price differences in return equations.

The framework for conditional variances, discerning risk differentials across the three staple commodities, is:

$$H_t = \Upsilon \Upsilon' + A \varepsilon_{t-1} \varepsilon_{t-1}' A + B H_{t-1} B + D \xi_{t-1} \xi_{t-1}' D. \tag{2}$$

The 3×3 matrix H_t in Equation (2) represents the time-varying conditional variance-covariance among wheat, corn, and sunflower oil. Such time-varying variances accurately depict the risk associated with a specific commodity. The H matrix plays a critical role in quantifying market fluctuations, short- and long-term contagion effects on commodity prices, and how these factors jointly affect the market long-term conditional return variance. The H matrix has two primary components. The first encompasses constants, including intrinsic and derived parameters from exchange rate returns, COVID-19 impact, and the Russia-Ukraine conflict (Urak & Bilgic, 2023; Urak, Bilgic, Bozma, et al., 2022; Zhen et al., 2018). The other part pertains to market-driven transient shocks, enduring risks, and asymmetric effects. All factors manifest the dynamic equilibrium between the market supply and demand. Consequently, the constant within the time-varying conditional variance equation (H_t) is $\Upsilon = C + \Gamma * \text{Excr}_{t-1} + \Omega * \text{COVID-19}_{t-1} + \Pi * \text{War}_{t-1}$. The constant term, Υ , is introduced to reflect the influence of exchange rate series (Excr_t), the pandemic (COVID-19), and the Russia-Ukraine conflict (War) on the time-dependent conditional variance-covariance inherent to the considered agricultural commodities. The parameters C, Γ, Ω , and Π show as a 3×3 upper triangular matrix. The inclusion of binary variables representing the COVID-19 and wartime periods serves to empirically show the alterations in risk levels across the three agricultural commodities during the COVID-19 pandemic and since the beginning of the Russia-Ukraine conflict.

Incorporating the exchange rate return ($\text{R}_{\text{exr},t-1}$) within each mean equation enables the measurement of how changes in commodity prices respond to fluctuations in the exchange rate return. Conversely, the exchange rate (Excr_t) in the conditional variance equations establishes how changes in the exchange rate series (Excr_{t-1}) impact the commodity risk (such as conditional variance). The latter part of the H matrix includes short-term shocks ($\varepsilon_{t-1} \varepsilon_{t-1}'$), long-term uncertainty (H_{t-1}), and short-term asymmetric effects ($\xi_{t-1} \xi_{t-1}'$). Corresponding parameter matrices, A (3×3), B (3×3), and D (3×3), respectively account for each of those effects. While the series for short-term shocks and

asymmetric information stems from the aforementioned mean return equations, the time-varying conditional variance series is also constructed using those two information variables, gradually updated until the parameter value converges with the log-likelihood function.

The rationale behind selecting the BEKK-MGARCH model stems from considerations such as the manageable number of commodities and its capability to capture cross-product spillovers, while incorporating asymmetric relationships. The estimation of the VECM-BEKK-MGARCH model employs the Quasi-Maximum Likelihood (QML). This approach assumes a conditional distribution characterized by a joint Gaussian log-likelihood function with a normal distribution, applied to observations at time t and the relevant time series components. Additionally, the evaluation of parameters involves the application of the Student t -distribution (Bollerslev, 1987) through an iterative loop procedure. The Student distribution aids estimating the distribution of conditional residuals, accommodating their leptokurtic nature, and effectively addressing concerns related to non-normal distribution properties.

The log-likelihood function incorporating the t -distribution takes the subsequent form:

$$L_t = \ln \left[\frac{\Gamma\left(\frac{\nu+n}{2}\right) \nu^{\frac{n}{2}}}{(vn)^{\frac{n}{2}} \Gamma\left(\frac{\nu}{2}\right) (\nu-n)^{\frac{n}{2}}} \right] - \frac{1}{2} \ln |H_t| - \frac{1}{2} (\nu+n) \ln \left(1 + \frac{\varepsilon_t' H_t^{-1} \varepsilon_t}{\nu-2} \right), \tag{3}$$

where n is the number of equations and signifies the residuals stemming from the n mean equations. Additionally, ν and $\Gamma(\cdot)$ respectively, denote the degree of freedom ($\nu > 2$) and the gamma function (Urak, Bilgic, Bozma, et al., 2022).³ The parameter values are derived by maximizing the log-likelihood function using the Broyden-Fletcher-Goldfarb-Shanno (BFGS) iterative algorithm.

4. Results

4.1. Examining the data series

The shared movements within the logarithmic series show the influences of both market-related factors and non-market challenges on price over time (Fig. 1). The prices of wheat, sunflower oil, and corn exhibited relative stability between 2010 and 2020. However, in the aftermath of COVID-19, the prices rapidly increased. The increase was exacerbated by the Russia-Ukraine war. The initial surge has been attributed to supply chain disruptions and labor shortages that created an imbalance between supply and demand, driving prices upward (Baffes & Wu, 2020; IFPRI, 2020). The pandemic led to a substantial increase in household demand for staple goods, e.g., cereals, accentuating the upward price pressure. However, the pandemic-induced uncertainty influenced commodity prices (Vijlder, 2020) and aggravated food insecurity in regions already struggling with access to food (Sokhanvar & Bouri, 2023). Global response to the COVID-19 pandemic, including lockdowns, impacted food supply chains, agriculture, and food retailing. Travel and hospitality restrictions further affected trade and income. However, Türkiye has experienced substantial gains thanks

³ The log-likelihood function value obtained under the t -distribution was juxtaposed with the log-likelihood function value derived under the assumption of normal distribution to identify the model best fitting dataset.

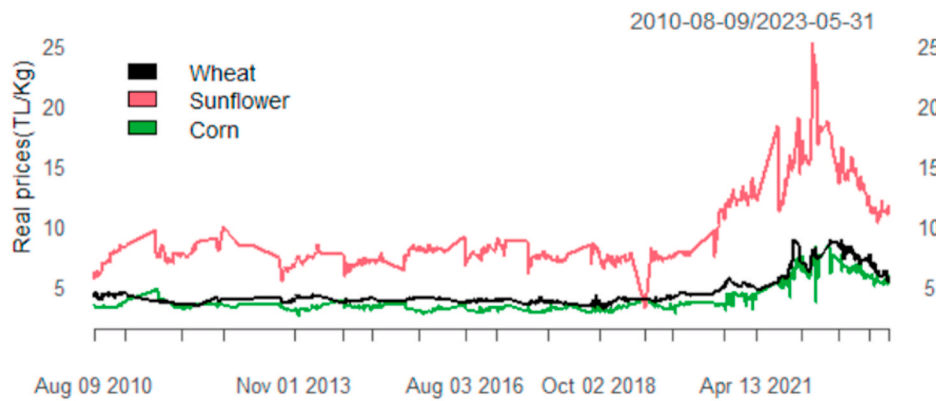


Fig. 1. Co-movement of log prices of three agricultural commodities.

Table 1

Descriptive statistics of three staples and the exchange rate series, in logs.

Statistics	Wheat	Sunflower oil	Corn	Exchange Rate
Mean	1.513	2.180	1.340	2.742
Standard deviation	0.233	0.290	0.250	0.235
Skewness	1.410	1.314	1.469	0.170
Kurtosis	0.810	1.086	0.963	-1.180
Jarque-Bera	405.022 (0.000)	380.548 (0.000)	449.879 (0.000)	71.028 (0.000)
Q(10)	10837.649 (0.000)	10444.673 (0.000)	10371.248 (0.000)	10969.692 (0.000)
LM-ARCH(10)	7450.006 (0.000)	3886.903 (0.000)	2337.744 (0.000)	14685.547 (0.000)
ADF	-2.653	-3.177	-3.524**	-3.924**
KPSS	10.368***	7.318***	10.755***	1.006***

Notes: Q represents the statistics of Ljung-Box, used to test the null hypothesis of the absence of autocorrelation within a series. Furthermore, the LM-statistic assesses all series for the presence of multivariate ARCH effects. Moreover, the symbols *, **, and *** denote statistical significance levels at 10%, 5%, and 1%, respectively.

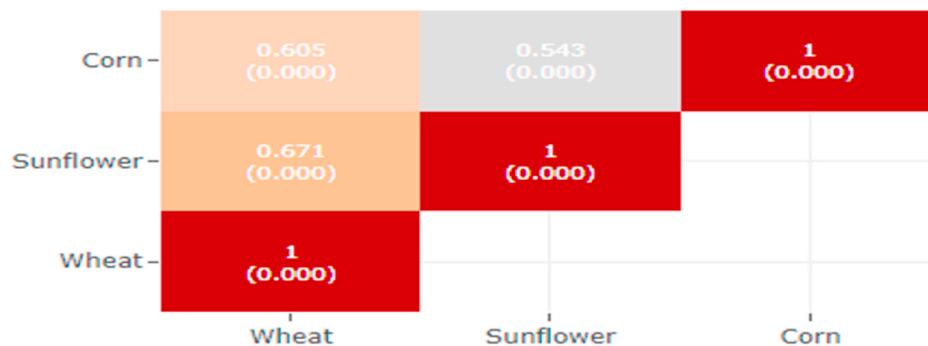


Fig. 2. Real price correlations between three agricultural commodities.

to its intervention in facilitating the establishment of the grain corridor between Russia and Ukraine. Concurrently, the promotion of state-backed seed support among Turkish farmers cultivating sunflowers and corn has resulted in increased domestic supply affecting price dynamics.

Table 1 shows descriptive statistics and the Autoregressive Conditional Heteroscedasticity (ARCH) effects. The sunflower oil market exhibits a distinct level of uncertainty, as the difference between past and present prices (expressed logarithmically) shows the extent of price fluctuations. This observation is supported by the considerable variance of the logarithmic price data of sunflower oil and contrasts with the other considered commodities. The real exchange rate mean value is large and indicates a degree of volatility. Fig. 2 shows that the cross-

correlations among agricultural commodities signify the interdependence of their price dynamics but also suggests a degree of uncertainty transmission.⁴ There appears to be a strong positive relationship between wheat and sunflower oil prices (0.671). The correlations between wheat and corn (0.605) and sunflower oil and corn (0.543) further illustrate the close interaction of their markets. The positive nature of those three relationships indicates that any uncertainties in one market transmit to other markets, inducing the same directional change. Such high correlation coefficients between the logarithmic series provide an a priori indication of significant pass-through between the conditional variances of the considered series.

Further insights are gained from the skewness and kurtosis coefficients, which reveal departure from normal distribution for certain

⁴ Given the non-normal distribution of the series, the Spearman method was employed to show the correlation relationships among these series.

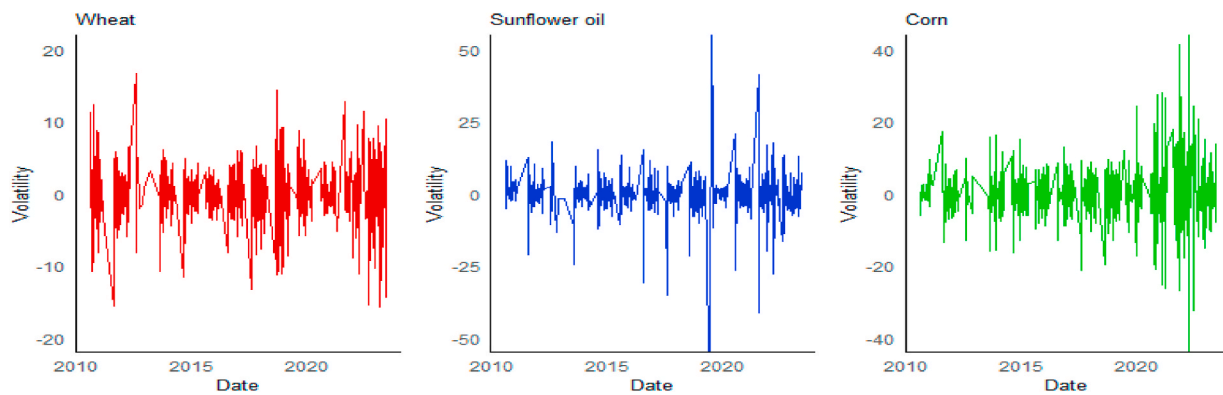


Fig. 3. Time-varying unconditional return series of three agricultural commodities.

Table 2
Parameters of conditional mean equations.

Estimate	Wheat	Sunflower oil	Corn
Cointegration Equations			
$P_t^w + 0.413P_t^s - 1.394P_t^c - 0.533$ and $P_t^s - 1.401P_t^w + 0.238P_t^c - 0.381$			
Constant (μ)	0.005 (0.001)	0.004*** (0.001)	-0.005 (0.006)
$\Phi_{ww,1}$	-0.457*** (0.027)	-0.005 (0.025)	-0.012 (0.026)
$\Phi_{ws,2}$	-0.190*** (0.027)	0.029 (0.023)	0.022 (0.036)
$\Phi_{wc,3}$	-0.024 (0.023)	0.030 (0.024)	0.056** (0.027)
$\Phi_{sw,1}$	0.015 (0.010)	-0.367*** (0.020)	-0.039** (0.019)
$\Phi_{ss,2}$	0.025*** (0.008)	-0.060** (0.023)	0.043* (0.026)
$\Phi_{sc,3}$	0.048*** (0.008)	-0.004 (0.021)	0.020 (0.016)
$\Phi_{cw,1}$	-0.007 (0.014)	-0.030 (0.019)	-0.619*** (0.023)
$\Phi_{cs,2}$	-0.022 (0.014)	-0.051** (0.019)	-0.312*** (0.029)
$\Phi_{cc,3}$	-0.006 (0.011)	-0.042*** (0.015)	-0.143*** (0.026)
θ	0.0008** (0.0003)	0.0007 (0.0005)	-0.0003 (0.0006)
β	0.006*** (0.001)	0.010*** (0.001)	-0.010* (0.005)
τ	0.004 (0.005)	-0.015*** (0.004)	0.013*** (0.005)
Ψ_{ww}	-0.094 (0.099)	-0.070 (0.052)	-0.142 (0.103)
Ψ_{ss}	0.023* (0.014)	0.177*** (0.054)	-0.245** (0.095)
Ψ_{cc}	-0.123** (0.030)	-0.181*** (0.058)	0.448** (0.224)
α_{1i}	-0.0003 (0.0005)	-0.0005 (0.0007)	0.003*** (0.0008)
α_{2i}	0.001*** (0.0006)	0.002*** (0.0007)	-0.002** (0.0008)

Note: *, ** and ***, indicate statistical significance at 10%, 5%, and 1%, respectively.

series (Table 1). The Jarque-Bera test supports the observation. Additionally, the Ljung-Box Q statistic underscores the presence of autocorrelation within the logarithmic series.

4.2. Antecedent statistics on the use of series

The patterns of return values show an increase in returns after initial upturns, and the aggregation of returns (Fig. 3). The results of the ARCH-Lagrange Multiplier (LM) test (Engle, 1982) confirm the presence of the ARCH effect and volatility clustering within the return series across the three log price series. The increasing returns will trigger further increasing returns and a similar pattern is associated with decreasing returns. In such cases, multivariate GARCH models can effectively manage volatility transmission among the three logarithmic series. Furthermore, the series conversion into first differences (I(1)) to assure stationarity is suggested by the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root test results. The co-integrated relationship between the series is tested using the Johansen test (Johansen, 1995). The BIC test value determines the optimal lag length as a three-lag structure. The three-lag Johansen co-integration test indicates the presence of two co-integrating vectors.

The comparison of the data with the t-distribution was verified. The Wald (W) statistic value ($W = 590.911$ and $p < 0.000$) underscores the superior explanatory power of parameters derived under the t-distribution, capturing both mean and time-varying conditional

heteroscedasticity. The distribution reveals the presence of a leptokurtic non-normal distribution of conditional residuals. The robust standard errors are employed to calculate parameter statistics. The discussion that follows refers to the t-distribution of the maximum likelihood function and the statistically significant parameters.

4.3. Results and discussion

This study examines logarithmic price differences ($\Delta \ln Pr$) as a robust measure of commodity returns. The return analysis shows the presence of two co-integrating vectors (see Table 2). The mean equations effectively align with the Vector Error Correction Model (VECM). Both co-integration equations show the complex interaction between sunflower oil and corn price fluctuations and their effects on wheat prices. Specifically, in Türkiye, for each 1% ascent (or descent) in sunflower oil and corn prices, wheat prices decrease by 0.413% (increase) and increase by 1.394% (decrease), respectively. Moreover, the co-integration equations reveal that a 1% increase in wheat prices triggers a proportional 1.401% upswing in sunflower prices. Conversely, a 1% increase in corn prices correlates with a 0.238% reduction in sunflower oil prices. The findings stress the significant pass-through between commodity prices and the practical relevance of the present analysis.

The noticeable variations in the long-term effects of sunflower oil and corn returns on wheat are attributed to complex determinants. The substantial difference in corn and sunflower oil production in Türkiye plays a crucial role because the corn volume is relatively larger than that of sunflower oil. Additionally, competing use as animal feed between corn and wheat contributes to the divergent effects. Thus, this study provides a novel interpretation of wheat, sunflower oil, and corn price relationships, improves commodity market understanding, and clarifies the underlying mechanisms governing their interconnected behavior.

The VEC model scrutinizes the effects of three-period lag values of log prices for each considered commodity in response to the COVID-19 pandemic, the Russia-Ukraine war, and the exchange rate. The model accounts for the square roots of conditional variances and error correction factors on the log price differences of wheat, corn, and sunflower oil. The direction and magnitude of the effects on each commodity vary with the lag length (Table 2). The one-time feedback variable, the COVID-19 pandemic, demonstrates a positive impact on returns in the wheat and sunflower oil markets in Türkiye, whereas the Russia-Ukraine war bolsters corn returns. The findings suggest that both the pandemic and the war triggered an increase in the returns of wheat, corn, and sunflower oil. The one-period lagged exchange rate significantly affects wheat market returns, a staple vital to Türkiye's food sector and highly susceptible to the pandemic's effects.

The pandemic and the war initially adversely affected the energy sector, with the effects gradually spreading to other sectors in Türkiye, resulting in inflation, particularly in food prices. While low-income

Table 3
Parameters of conditional variance equations.

Parameters	Wheat (i = 1)	Sunflower oil (i = 2)	Corn (i = 3)
Constants in $\Upsilon\Upsilon'$:			
<i>Pure constant parameters(C):</i>			
c_{1i}	0.003*** (0.001)	–	–
c_{2i}	–0.007*** (0.004)	0.011*** (0.002)	–
c_{3i}	–0.009 (0.002)	–0.007 (0.005)	0.015*** (0.004)
<i>Parameters associated with exchange rate (Exr_{t-1}):</i>			
Γ_{1i}	–0.002*** (0.000)	–	–
Γ_{2i}	–0.004*** (0.001)	–0.005*** (0.001)	–
Γ_{3i}	–0.0009 (0.002)	–0.004*** (0.001)	–0.00009 (0.0009)
<i>Parameters associated with selected agricultural commodities price return in the COVID-19 period (COVID – 19_{t-1}):</i>			
Ω_{1i}	–0.006*** (0.001)	–	–
Ω_{2i}	–0.006 (0.006)	–0.018*** (0.005)	–
Ω_{3i}	0.038*** (0.011)	–0.022* (0.013)	–0.016 (0.027)
<i>Parameters associated with selected agricultural commodities price return in the war period (War_{t-1}):</i>			
Π_{1i}	0.014*** (0.002)	–	–
Π_{2i}	0.029** (0.011)	0.038*** (0.011)	–
Π_{3i}	–0.035** (0.016)	0.034*** (0.012)	0.035 (0.031)
ARCH parameters:			
a_{1i}	–0.229*** (0.052)	–0.108*** (0.040)	0.222*** (0.067)
a_{2i}	0.031*** (0.011)	0.556*** (0.068)	–0.181** (0.075)
a_{3i}	–0.013 (0.015)	0.110*** (0.036)	0.216*** (0.140)
GARCH parameters:			
b_{1i}	0.955*** (0.014)	0.045 (0.050)	0.089*** (0.028)
b_{2i}	–0.015 (0.024)	0.631*** (0.065)	0.018 (0.014)
b_{3i}	0.026** (0.012)	0.019 (0.063)	0.662*** (0.098)
GARCH asymmetric parameters:			
d_{1i}	–0.024 (0.110)	–0.180 (0.202)	–0.398*** (0.138)
d_{2i}	–0.022 (0.027)	0.423** (0.193)	0.195 (0.114)
d_{3i}	0.018 (0.020)	–0.110 (0.087)	0.522*** (0.095)
Shape(t degrees)	3.977*** (0.163)		

Note: *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

families bore the brunt of food inflation, farmers’ revenues from selling their crops increased. The increased uncertainty in the corn market adversely affects returns in the wheat market ($\Psi_{cc} = -0.123$) according to the results, while long-term risks in the sunflower oil market positively influence its returns ($\Psi_{ss} = 0.177$). The transmission of uncertainty from the corn market dampens the market return of sunflower oil ($\Psi_{cc} = -0.181$). Similarly, uncertainty in sunflower oil diminishes returns in the corn market ($\Psi_{ss} = -0.245$). The varying effects of uncertainty across the markets suggest that an increase in uncertainty in one market is, to some extent, reduced by a decrease in uncertainty in another market. Furthermore, the two error corrections ($\alpha_j, j = 1,2$) derived from the co-integration analysis reveal diverse effects on the returns of the three staples. The wheat market returns realign with the long-term relationships, while the sunflower oil market deviates from the long-term equilibrium. The return of the corn market reverts to the long-term equilibrium.

Table 3 shows the parameters characterizing the variance equation within the VECM-BEKK-MGARCH model. The short-term uncertainty stemming from the wheat market refers to the ARCH effect ($a_{11} = -0.229$). The short-term fluctuations are statistically significant. The dampening effect of short-term shocks stemming from the wheat market—in response to both positive and negative news—on the uncertainty surrounding wheat yields in Türkiye holds significant implications, especially for commodity traders. Knowledge of the effects could prompt immediate responses from traders, calming the market. Moreover, the short-term momentary movements alleviating long-term

uncertainties in the wheat market may be attributed to market actors facing an uninterrupted supply as well as a consistently high trading volume. McKnight et al. (2022) emphasized that the wheat price volatility is generally influenced by short-term shocks rather than volatility spillovers from competing markets such as corn or barley.

Simultaneously, the short-term risk spillover from the wheat market significantly affects the long-term uncertainties associated with corn and sunflower oil ($a_{12} = -0.108$ and $a_{13} = 0.222$). While the short-term risk spillover reduces the long-term uncertainty in the corn market, it makes the uncertainty in the sunflower oil market permanent. The result implies that short-term shocks originating from the wheat market exhibit a parallel transmission, affecting both its own market and the corn market in the same direction, but the uncertainty transmission in the opposite direction in the sunflower oil market. Furthermore, transient market-driven events, which often dominate the sunflower oil market, lead to an escalation of long-term risks not only within its own market ($a_{22} = 0.556$) but also, albeit to a lesser extent, within the corn market ($a_{23} = -0.181$). Similarly, the short-term economic and non-economic dynamics in the corn market contribute to an increase in long-term risks both within its own market ($a_{33} = 0.216$) and the sunflower oil market ($a_{32} = 0.110$). Such a differential impact can be attributed to the varying importance of those commodities in the Turkish market. The pronounced impact of short-term shocks on corn’s long-term risks is particularly relevant given the importance of corn. The result supports earlier studies by Hamadi et al. (2017), McKnight et al. (2021), Tiwari et al. (2022), and McKnight et al. (2022) who underscored the complex relationship between short-term shocks and long-term uncertainties in commodity markets.

GARCH effects characterize long-term uncertainty spillovers. The effects intensify uncertainties within their respective markets ($b_{11} = 0.955$ for wheat, $b_{22} = 0.631$ for sunflower oil, and $b_{33} = 0.662$ for corn). The result clarifies the critical role of past volatility in shaping future volatility. Importantly, the result stresses that the corn and sunflower oil markets exhibit heightened sensitivity to both short-term shocks and long-term risks, whereas wheat is especially responsive to long-term fluctuations. The wheat returns, marked by broader and persisting fluctuations, carry greater risk for investors compared to the other two commodities. Moreover, the uncertainty in the corn market likely influences the wheat market ($b_{31} = 0.026$), and concurrently, the persisting long-term uncertainties in the wheat market also affect the corn market ($b_{13} = 0.089$). The results underscore the notion that long-term risk spillovers in price formation, driven by supply-demand dynamics, resonate across various markets. Earlier, Hamadi et al. (2017) confirmed bidirectional volatility spillovers, particularly transmissions from soybean and soybean oil markets to corn and wheat markets.

When reviewing the dynamics of short-term asymmetric information spillover in the context of long-term uncertainties, it is apparent that negative news originating from the sunflower oil market ($d_{22} = 0.423$) and the corn market ($d_{33} = 0.522$) clearly diverge from positive news, culminating in the persistence of risk within their respective markets. The negative news shape price formation in the sunflower oil and corn markets, thereby accentuating market risk. Short-term asymmetric information stemming from domestic sunflower oil and corn markets perpetuate uncertainties within their own markets. Since the negative information tends to have a greater effect than positive news, disruptions in the supply chain specific to the particulate markets, global geopolitical events such as wars or pandemics, and market-specific speculation are more likely to affect the market. Given the relevance of negative events to the market, the listed factors more likely prolong the market risks presence. Positive news is often short-lived, and the effects are less pronounced. While asymmetric information does not significantly affect the wheat market, it tempers the transmission of long-term volatility in the corn market ($d_{13} = -0.398$). The observed reduction of long-term uncertainties in the corn market due to negative news originating from the wheat market suggests that actors in the corn market reacted to negative news from the wheat market where they may

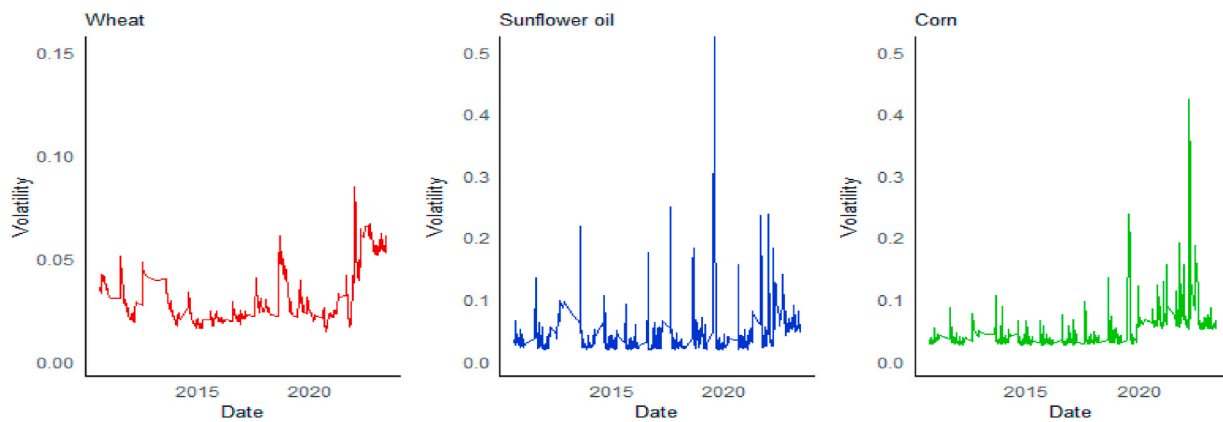


Fig. 4. Time-varying conditional volatility of three agricultural commodities.

have taken positions to increase returns in the corn market. The findings coincide with earlier reports (Chowdhury et al., 2021; Urak & Bilgic, 2023).

The results of the COVID-19 pandemic, the Russia-Ukraine war, and the exchange rate effects on the variance and conditional variance equation show that the exchange rate amplifies the volatility of wheat and sunflower oil returns ($\Gamma_{11} = -0.002$ and $\Gamma_{22} = -0.005$). An increase in the exchange rate indicating the Turkish lira weakening against the US dollar, reinstates volatility in wheat and sunflower oil prices in Türkiye. The increasing exchange rate attracts producers and brokers to commodity markets, offering a hedge against potential risks by switching from the Turkish lira to foreign currency. The result supports the findings of a causal long-term relationship between agricultural product prices and the exchange rate (Burakov, 2016). Askan, Urak, and Bilgic (2020) and Urak, Bilgic, Dağdemir, and Özer (2022) also stress that the exchange rate plays a role in agricultural commodity volatility. The heightened commodity price sensitivity to the exchange rate is attributed to Türkiye’s dependence on imports. Akgunduz, Cilasun, and Tok (2020) shows that the increase of premiums within the agricultural product supply chain erodes the competitive position of commodity producers. Consequently, imported agricultural commodities promptly respond to exchange rate fluctuations (for example, Urak, Bilgic, Bozma, et al., 2022).

The pandemic significantly influences the conditional variances of both wheat and sunflower oil ($\Omega_{11} = -0.006$ and $\Omega_{22} = -0.018$), likely due to Türkiye’s imports from Russia. The import disruptions in the pandemic’s early stages reduced conditional variances in the wheat and sunflower oil markets. The pandemic prompted Türkiye, like many other countries, to restrict agricultural commodity exports through quotas or bans to stabilize domestic prices. Such actions might have increased tax revenues but also increased prices of exported commodities on international markets.

The Russia-Ukraine war positively and significantly effects the conditional variances of wheat ($\Pi_{11} = 0.014$) and sunflower oil ($\Pi_{22} = 0.038$). Additionally, the war positively impacts the relationship between wheat and sunflower oil markets ($\Pi_{21} = 0.029$), implying that the volatility in one market is mirrored in the other, i.e., the war has increased the conditional volatility of agricultural commodity prices. Even in the period preceding the war, spot and futures markets saw surges in the prices of commodities heavily exported by Russia and Ukraine, with sunflower oil prices reaching historic highs. The volatility in commodity returns during 2019 (Fig. 4) threatened low- and middle-income household food security. The outbreak of the war accelerated staple food price increases. Türkiye implemented programs shielding the population from grain price volatility and providing seed subsidies for farmers to mitigate the adverse impacts of the war. Sokhanvar and Bouri (2023) pointed out that the conflict between Russia and Ukraine triggered an increase in wheat and energy prices, particularly associated

Table 4
Some diagnostic and hypothesis tests.

Parameters	Wheat (i = 1)	Sunflower oil (i = 2)	Corn (i = 3)
<i>Panel A: Residual Diagnostic Tests</i>			
<i>Serial Correlation in residuals:</i>			
LB-Q (20)	17.525 (0.618)	14.616 (0.797)	20.122 (0.450)
McLeod-Li (20)	17.181 (0.641)	1.289 (1.000)	13.733 (0.843)
HM-Q (20)	157.902 (0.881)		
<i>ARCH Effects in residual squares:</i>			
ARCH-LM(20)	0.594 (0.918)	0.062 (1.000)	0.653 (0.873)
HM-Q ² (20)	83.902 (1.000)		
<i>Additional Statistics:</i>			
Z	0.404 (0.686)	-0.964 (0.335)	-0.021 (0.983)
z ²	0.897 (0.541)	1.229 (0.409)	1.127 (0.449)
AIC	-13864.369		
SBC	-13331.380		
HQC	-13662.984		
Log FPE	-14076.369		
Log-Likelihood	7038.184		
<i>Panel B: Model Specification Tests</i>			
<i>Granger Causality Tests</i>			
H ₀ : No effects of all other variables in the mean wheat equation, except for the constant and lagged wheat parameters			117.893 (0.000)
H ₀ : No effects of all other variables in the mean sunflower oil equation, except for the constant and lagged sunflower oil parameters			130.493 (0.000)
H ₀ : No effects of all other variables in the mean corn equation, except for the constant and lagged corn parameters			57.999 (0.000)
No GARCH	H ₀ : $a_{ij} = b_{ij} = d_{ij} = 0$ for all $i, j = 1, 2, 3$		86990.901 (0.000)
Diagonal GARCH	H ₀ : All off-diagonal elements of A, B, and D are jointly zero		133.299 (0.000)
No Asymmetry	H ₀ : $d_{ij} = 0$ for all $i, j = 1, 2, 3$		133.080 (0.000)
H ₀ : Off-diagonal exchange rates in the conditional variance equations are jointly zero			25.107 (0.000)
H ₀ : Off-diagonal of COVID-19 in the conditional variance equations are jointly zero			53.918 (0.000)
H ₀ : Off-diagonal of war in the conditional variance equations are jointly zero			30.030 (0.000)

Notes: Q and Q² are Ljung-Box statistics, evaluating the absence of autocorrelation in a series using standardized and standardized squared residuals, respectively. In addition, the HM -Q and HM-Q² statistics are Hosking’s multivariate portmanteau Q-statistics, employed to test the null hypothesis of no autocorrelation across all series, considering a specified number of lags, for both standardized residuals and standardized squared residuals. Furthermore, the LM-statistic tests for multivariate ARCH effects, assuming zero means and no serial correlation, with a fixed covariance matrix for the series under evaluation.

with the appreciation of the Canadian dollar (as a commodity currency) against the euro and yen. While the Canadian economy benefited from the global commodity price increase due to war, the European and Japan

economies experienced rising inflation as wheat and energy prices increased. In Türkiye, following the Russian invasion of Ukraine on March 4, 2022, the Ministry of Trade imposed export restrictions on sunflower seeds, sunflower oil, corn oil, and their derivatives (TSI, 2022a, 2022b). Additionally, the government introduced limitations on the quantities of sunflower oil, sugar, and other select staples available for sale in retail outlets, including Agricultural Credit Cooperative outlets. In hindsight, the government measures at curbing volatility fell short, especially in the wheat and sunflower oil markets. The current study generates knowledge about the evolving wheat, sunflower oil, and corn prices and commodity market dynamics.

4.4. Post-model specification tests

Several diagnostic tests were applied to gauge the model's fit to empirical data, emphasizing the evaluation of standardized errors from post-model estimation. Specifically, the null hypothesis that "individual error terms demonstrate no autocorrelation" was verified by the Ljung-Box statistics using a lag length of 20. The Hosking's multivariate portmanteau Q-statistics corroborated the Ljung-Box test confirming the absence of residual correlation. Another null hypothesis concerned the constancy of error term variances over time and was revised using the ARCH-Lagrange Multiplier (hereafter referred to as ARCH-LM), McLeod-Li statistics, and multivariate ARCH statistics. The results did not reject the null hypothesis and the results of the ARCH-LM tests were consistent with those of the McLeod-Li examination. Overall, the tests confirmed the temporal constancy of standardized error terms emanating from the VECM-BEKK MGARCH model. The error terms are centered around a constant mean and indicate statistically robust estimations within the variance equation.

Next several hypothesis tests helped evaluate the parameters shown in panel B, Table 4. The null hypothesis that "no effects emanate from any other variables, apart from the constant and lagged wheat parameters, in the mean wheat equation" was rejected at a 1% significance level ($\chi^2 = 117.893$ and $p < 0.000$). Specific variables, including sunflower oil and corn log prices, exchange rate returns, the COVID-19 pandemic, the Russia-Ukraine war, product-related uncertainties, and error correction terms, were all identified as salient determinants of wheat market returns. Similar null hypotheses were applied to the prices of sunflower oil ($\chi^2 = 130.493$ and $p < 0.000$) and corn ($\chi^2 = 57.999$ and $p < 0.000$), with each hypothesis firmly rejected. Those results underscore the combined effect of COVID-19 and the war as well as their intrinsic market dynamics on the prices of wheat, sunflower oil, and corn in Türkiye, notably, the global supply chain disruption stemming from the COVID-19 pandemic (Alvi & Gupta, 2020; FAO, 2020) and contraction of international trade (Mbah & Wasum, 2022; Nicas, 2022; OECD, 2022; Saâdaoui et al., 2022). The supply shortages on grain markets affected grain trade, increased prices (Sokhanvar & Bouri, 2023; Yan et al., 2021), and exacerbated food insecurity among low-income households, particularly in countries highly dependent on imports, including Sudan, Lebanon, and Rwanda (OECD, 2022). Those countries, dependent on grain imports from Russia and Ukraine, already struggling with food insecurity, faced further risks (Jagtap et al., 2022; Sokhanvar & Bouri, 2023).

The Wald test application discerned the presence of GARCH, No-GARCH-M, and diagonal GARCH effects within the conditional variance equations of the BEKK MGARCH model (panel B, Table 4). The null hypothesis asserting that "short-term shocks, long-term volatility, and asymmetric effects are unrelated to the conditional variance" was rejected ($\chi^2 = 86,990.901$ and $p < 0.000$). Furthermore, the null hypothesis that "conditional variance exerts no impact on the return series in the mean equation" was also rejected ($\chi^2 = 133.299$ and $p < 0.000$). The results highlight the influence of uncertainty across markets, both intrinsic and extrinsic to commodity markets, on the time-varying conditional variances. For example, the asymmetric impact of short-term shocks on conditional variances indicate the differential effects

stemming from positive and negative shocks ($\chi^2 = 133.080$ and $p < 0.000$). The last set of null hypotheses postulating that "the real exchange rate, the COVID-19 pandemic, and the Russia-Ukraine war have no causal effect on conditional volatility." The results (panel B, Table 4) show that the exchange rate is a key determinant of time-varying fluctuations within the conditional variances of wheat, corn, and sunflower oil ($\chi^2 = 25.107$ and $p < 0.000$). Prior research emphasized the importance of the exchange rate as an exogenous variable in estimating the conditional variance of returns for beef and lamb (Urak & Bilgic, 2023; Urak, Bilgic, Dağdemir, & Özer, 2022). The current study further stresses the importance of the exchange rate for agricultural commodities.

Mitigating exchange rate uncertainty is essential for ameliorating uncertainty in Turkish agricultural commodity pricing. Türkiye's substantial fertilizer and agricultural input imports introduce uncertainty into the domestic food inflation and volatility in agricultural commodity markets. The effect of the exchange rate was exemplified by the rapid rise in the Food Price Index in Türkiye from 993 in January 2022 to 1366 in August 2022 (TSI, 2022a, 2022b), an increase of 37% that closely mirrors a 34% increase in the nominal exchange rate. The inherent inflexibility of short-term agricultural production compels producers to account for potential pricing uncertainties. Akgunduz et al. (2020) suggested that large-scale farmers may employ hedging strategies, such as futures and options contracts to manage exchange rate volatility. Small-scale farmers, including those primarily cultivating for personal consumption, may lack timely access to information resulting in losses due to input cost fluctuations caused by exchange rate volatility. The declining production, even if limited to small farms, curtails overall supply inducing short-term price increases and possibly long-term production losses. Furthermore, the null hypothesis asserting "the COVID-19 pandemic exerts no causal effect on the conditional volatility of commodity returns" was rejected ($\chi^2 = 53.918$ and $p < 0.000$). The finding coincides with a study by Wieser et al. (2020), who conclude that the COVID-19 pandemic not only led to food price increases but also food insecurity.

Lastly, the null hypothesis that "the Russia-Ukraine war has no causal effect on the conditional volatility of commodity returns" was rejected ($\chi^2 = 30.030$ and $p < 0.000$), supporting earlier findings (Behnassi & El Haiba, 2022; Jagtap et al., 2022; Nicas, 2022, Sokhanvar and Bouri, 2023) that food prices substantially increased while food insecurity became conspicuous in the aftermath of Russia's war against Ukraine (Polat et al., 2023; Saâdaoui et al., 2022). Further disruptions in agricultural production are related to EU trade sanctions affecting natural gas imports from Russia which could lead to food insecurity within the EU since Russia is a principal supplier of synthetic fertilizers (WFP, 2022) and interruptions in fertilizer imports could adversely effect agricultural production (EPRS, 2022).

4.5. Effects of pandemic and war on post-model time-dependent conditional variances and correlations

The examination of the distributional relationship centered around the median provides insights regarding variances and correlations in the post-estimations of agricultural commodities, the COVID-19 pandemic, and the Russia-Ukraine war. For instance, while the wheat market remained relatively resilient to the effects of the pandemic, the Russia-Ukraine war resulted in a substantial amplification of volatility. Fig. 4 illustrates the spillover transmission dynamics in the Turkish wheat market. Both the sunflower oil and corn markets exhibited heightened volatility (Fig. 4). The sunflower oil and corn market experienced severe uncertainty during the pandemic, further exacerbated by the war, reflected in an almost threefold increase in market swings. Low-income households immediately suffer from price instability, which also tempers farmer expectations. The relationships between the wheat and sunflower oil market and between the wheat and corn market show similar uncertainty correlation between those markets (Fig. 5). The

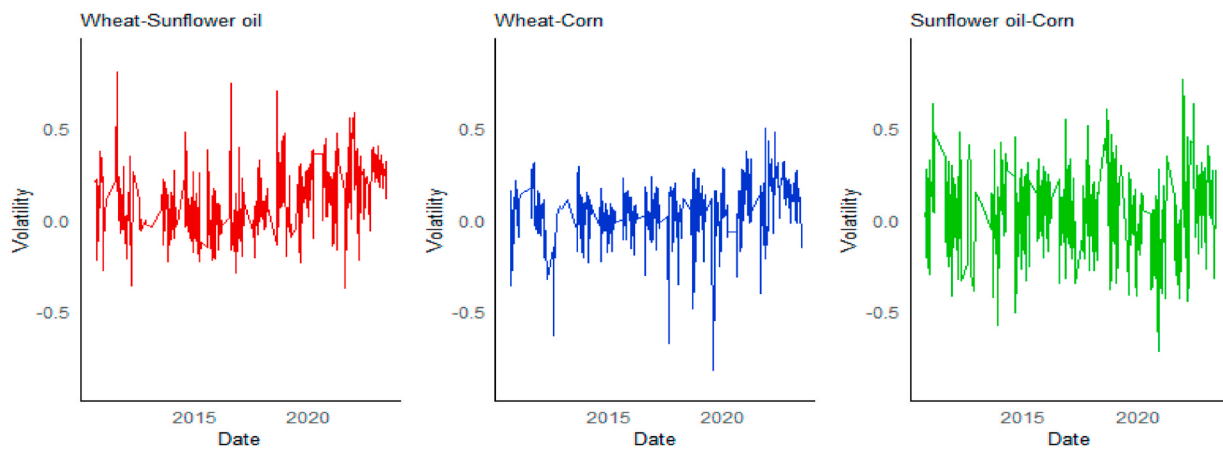


Fig. 5. Time-varying conditional correlations between agricultural commodities.

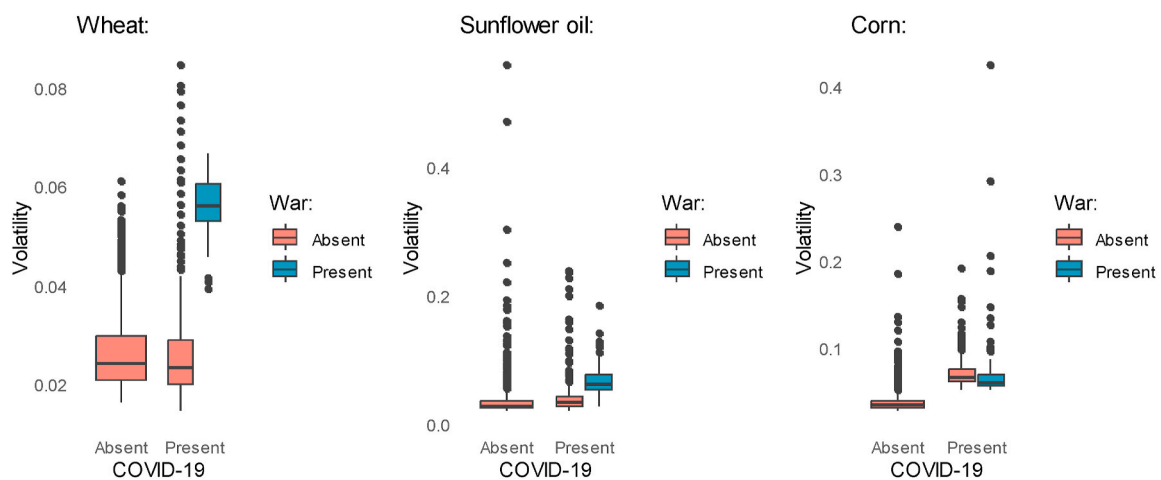


Fig. 6. The time-varying conditional volatility distributions of agricultural commodities within the framework of the COVID-19 pandemic and the Russia-Ukraine war context.

correlation between the sunflower oil and corn markets exhibits a different pattern (Fig. 5).

The uncertainty within the wheat and sunflower oil markets in Türkiye declined during the pandemic in comparison to the non-pandemic period (Fig. 6). The decline is attributed to stringent regulations and measures implemented to mitigate the pandemic effects. However, the outbreak of the Russia-Ukraine war rekindled and intensified uncertainty. The war had a disproportionate impact on the wheat market, in contrast to the relatively more resilient sunflower oil and corn markets. Additionally, government support, especially seed provision to farmers cultivating sunflower and corn, lessened the war effects on uncertainty in the sunflower and corn markets, but not in the wheat market. The differential effect of the pandemic and the war reveals the distinct vulnerabilities of various agricultural commodity markets, especially the wheat market, to geopolitical events. Fig. 7 shows the interconnections within Türkiye’s staple food markets are more pronounced primarily due to the compounding effect of the pandemic and the Russia-Ukraine war. The most notable correlation has been between the wheat and sunflower oil markets and between the wheat and corn markets. The relationships transitioned from a negative correlation to positive between the sunflower oil and corn markets. The correlations between the real prices were 0.556 ($p < 0.000$) between wheat and sunflower oil, 0.463 ($p < 0.000$) between wheat and corn, and 0.383 ($p < 0.000$) between sunflower oil and corn before the war. However, since the war begun those correlations increased to 0.604 ($p < 0.000$), 0.654 ($p < 0.000$), and 0.781 ($p < 0.000$), respectively. Since the start of the

Russia-Ukraine war, the inter-product uncertainty has significantly increased, and between sunflower oil and corn nearly doubled. Türkiye is dependent on imports of those commodities, and the inevitable spread of uncertainty in one market affects uncertainty in the other.

5. Policy repercussions

The COVID-19 and the Russia-Ukraine war inserted themselves into the pre-existing conditions in Turkish food markets. In years prior to the pandemic, fluctuating meat prices characterized periods of shortages in domestic supplies of lamb and beef. The policy response was to import meat and livestock to stabilize domestic prices and lower public resentment (Urak, Bozma, & Bilgiç, 2018). Import policy and its effect on prices sent mixed signals to farmers and interfered with decisions, especially concerning the long cattle production cycle. However, besides meat, Türkiye also has been importing substantial volumes of food, feed grains, and sunflower oil, primarily from Ukraine and Russia before the pandemic.

In Türkiye, the direct policy response to the COVID-19 pandemic was to suspend agricultural exports to assure adequate domestic supply. Efforts brought visible results as the domestic sunflower production reached 2.7 million tons (TSI, 2022a, 2022b). Increased imports of fertilizer and seeds improved farmers’ access to quality inputs. At stake is the implementation of a sustained mechanism that could facilitate such access since the country remains dependent on wheat, sunflower, and corn imports. The current analysis shows positive returns in the wheat

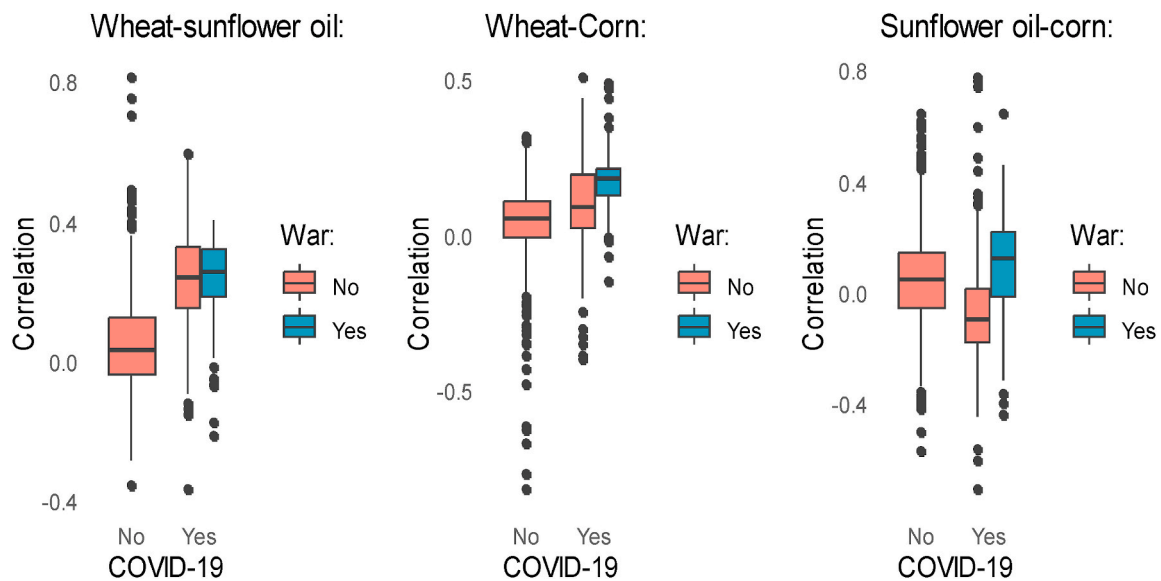


Fig. 7. The time-varying conditional correlation distributions of agricultural commodities within the framework of the COVID-19 pandemic and the Russia-Ukraine war context.

and sunflower markets in Türkiye, while the Russia-Ukraine war bolsters corn returns. However, the varying import policies and intermittent farm support prevent farmers from committing to sustained production of specific crops.

The Russia-Ukraine war re-ignited commodity market volatility as the effects of the pandemic subsided. The dependence on Russia and Ukraine exports of wheat and sunflower seeds was immediately at risk. Türkiye negotiated a “grain corridor” allowing grain exports from the countries engaged in war to continue, which has been recently renegotiated. Although wheat and corn showed a return to long-term equilibrium, this was not so in the case of sunflower oil. Policymakers need to be advised on developing a strategy to alleviate the uncertainty in the sunflower oil and, possibly, other vegetable oil markets. The analysis results suggest uncertainty spread among agricultural commodity markets after the war, shaping interdependence between commodity markets and signaling rising costs. When forming crucial decisions about short-, medium-, and long-term strategies to alleviate market tensions, it is essential to prioritize production planning for the short-, medium-, and long-term outcomes.

Rising wheat and sunflower oil prices primarily affect food security of low-income families. To provide short-term relief, the government opened retail stores selling rationed amounts of staples below market prices. The approach offers a short-term solution but leaves the need for a coherent medium- and long-term policy for a sustained domestic supply response. For example, the efficient use of irrigation water poses a continuous challenge as evidenced by low yields. The rising corn prices increase grower returns, but livestock farmers face increased feed costs. In addition to the corn price increase, the depreciation of the Turkish Lira against foreign currencies, coupled with increases in energy prices, constrains livestock and dairy farmers. The rising meat and milk prices exacerbate risks to household food security.

The study shows that past volatility shapes future volatility in agricultural commodity markets in Türkiye. The confirmed persistent volatility creates risks discouraging investment. Farmers may boost domestic grain supply if they can lower production costs. Access to improved seed, ample fertilizer, and the judicious use of fungicides and herbicides will increase yields and generate substantial revenues even at relatively low market prices. On-farm storage would enable farmers to manage sales of wheat or corn between harvests, creating a revenue stream between seasons. The establishment of the Turkish Commodity Exchange permits electronic trading of agricultural commodities,

matching buyers and sellers. Price and timing prioritize trade execution, with daily transactions facilitated through matching and supported by licensed warehousing. Recognizing that the increasing number of licensed warehouses will lead to a growth in the daily trading volume, decision-makers should incentivize producers to use the exchange for marketing their crops. Developing farmer education programs can broaden the use of the commodity exchange and reduce the number of intermediaries between producers and end-buyers, improving market management skills.

The results of the current study show that the effects of the pandemic and the Russia-Ukraine war have been amplified by exchange rate fluctuations. The weakening of the Turkish lira against the US dollar contributes to wheat and sunflower oil volatility returns. Unstable exchange rates alter the expectations of all stakeholders and encourage market intermediaries and commodity brokers to seek ways to lower risk. To remedy this situation requires major institutional adjustments including autonomous control of the exchange rate and its links to monetary policy. A change would realign market signals sent to farmers and others along the supply chain. Agriculture’s susceptibility to fluctuations in exchange rates due to imported inputs rises with the depreciation of the Turkish lira, increasing domestic production costs. The depreciation of the Turkish lira may enhance agricultural product exports, thereby influencing the overall trade balance of the country. This depreciation can also affect the international prices of agricultural products, leading to fluctuations in selling prices and affecting local farmer income. The depreciating currency continues to generate inflationary pressure, while the country has already experienced a 70–80 percent inflation rate. To reduce inflation, interest rates increased raising credit costs to the agricultural sector reliant on credit. Finally, inflationary pressure resulting in price instability negatively impacts future investment projects and may delay agricultural production modernization.

Lasting improvements require sustained stability of exchange rates, import regulations that diversify suppliers, application of farm production support such as access to improved seed and other variable inputs, and vigorous extension efforts in transferring knowledge and teaching skills in technology use, managing irrigation water, and market risks. The suggested policies pose implementation challenges because they differ in their scope and amount of time necessary to observe actual effects. However, it is clear that ad hoc policy decisions create temporary winners, like government benefiting from increased tax revenues

and farmers gaining from price increases, but fail to address the core issues and assure lasting food security for low-income families.

6. Conclusion and recommendations

Price volatility and uncertainty in staple food commodities represent a formidable challenge to global food security. Sudden and unforeseen events in commodity markets can trigger rapid price increases, jeopardizing household access to staple foodstuffs. This study examines the repercussions of two international events—the COVID-19 pandemic and the Russian-Ukrainian war—on the conditional volatilities of three staple agricultural commodities: wheat, sunflower oil, and corn. We employ the VECM-BEKK MGARCH model to explore long-term relationships among commodities, the effects of short-term shocks on long-term equilibrium, the interplay between conditional variances and returns, and the asymmetric impact of positive or negative news on conditional variance. Rigorous tests affirm the model's suitability for the applied dataset.

The current study establishes the long-term co-integration of the commodity series. Over time, short-term deviations gravitate towards long-term equilibrium. Moreover, the presence of reciprocal causality among wheat, corn, and sunflower oil prices underscores their mutual influence. While the conditional variance of wheat seems not to exert a statistically significant influence on sunflower oil returns or its own, the conditional variance of corn yields a statistically significant effect on the two other commodities. The COVID-19 pandemic, specified as a binary variable, significantly increased the returns of wheat and sunflower oil. Similarly, the Russian-Ukrainian war left a lasting mark on wheat returns in Türkiye. The government export ban and seed distribution program maintained relative stability in the sunflower oil and corn supply and partially mitigated the war's impact. Meanwhile, the current analysis of volatility pass-through between wheat, sunflower oil, and corn shows volatility is transmitted across these commodities, but the transmission is asymmetric. Positive and negative news originating in one market have varied effects on return volatility in another. Paradoxically, long-term uncertainty emanating from external markets can, at times, act as a corrective force, ultimately restoring prices to their long-term equilibrium.

The COVID-19 pandemic, the Russia-Ukraine war, and the exchange rate significantly influence returns volatility. The findings underscore the pandemic's adverse effects on staple prices but also reveal certain risk-mitigating dynamics in select agricultural markets. In stark contrast, the Russia-Ukraine war exacerbated the preexisting risks within commodity markets. This, coupled with the energy crisis, resulted in substantial food inflation in Türkiye and placed an additional burden on consumers. To alleviate these difficulties, government-backed initiatives such as Agricultural Credit Cooperatives provided food products at below market prices by selling volumes larger than super-market chains.

While the current study is centered on Türkiye, its implications extend to countries dependent on agricultural commodity imports. The empirical results show that in times of heightened uncertainty, returns experience substantial volatility and spread across agricultural commodity markets, reinforcing the existing connection. The observed volatility can be reduced by domestic production expansion through comprehensive policies enhancing rural area development, assuring farmers access to inputs, and implementing market risk mitigating measures. Furthermore, monitoring price collusion among major food suppliers, digitizing price monitoring systems, and expanding storage facilities can significantly enhance market stability.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Information about funding sources

None.

CRedit authorship contribution statement

Faruk Urak: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Abdulkali Bilgic:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Wojciech J. Florkowski:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Gürkan Bozma:** Conceptualization, Data curation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing.

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