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Price Volatility in the European Wheat and Corn Market in the Black Sea Agreement Context

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Abstract: The outbreak of war in Ukraine has severely disrupted global food and agricultural markets and affected commodity prices. The grain agreement, also known as the Black Sea Initiative, was concluded on 22 July 2022 by Ukraine, Russia, Turkey, and the United Nations, to alleviate the global food crisis caused by the conflict. This study aims to ascertain whether the agreement has resulted in the stabilization of cereal markets, examining the evolution of prices of wheat and corn, which are of significant importance in Ukrainian exports, throughout the duration of the agreement, including its signing, implementation, and expiration. The analysis, based on the GARCH model and using daily quotations of corn and wheat futures contracts of the European futures exchange Euronext from December 2021 to May 2024, indicates that prices were characterized by exceptionally high volatility in the period preceding the signing of the agreement, and at the time of its expiration. The uncertainty regarding cereal trade conditions has triggered shocks, with a long-lasting impact on price volatility.

Keywords: price volatility; agricultural prices; Russia–Ukraine war; GARCH model

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1. Introduction

Price volatility, and its fluctuations over time, depend on several key factors. Among them are changes in demand and supply, macroeconomic and political events, speculation, investor actions, and seasonality. In the context of agricultural products, in addition to market, political, and technological aspects, natural and climatic factors are of significant importance. Analysis of agro-climatic conditions in recent years and conditions projected in Europe for the coming decades has shown that agriculture is subject to increasing climate risk [1,2], and therefore, greater variability of yields from year to year [3].

The repercussions of this phenomenon are reflected in agri-food prices, which have exhibited robust growth in recent years, accompanied by heightened volatility [4]. The reasons for this situation, in addition to the above, include the financialization of raw materials markets and related speculative activities, and the increasingly stronger link between agricultural prices and the prices of energy raw materials. The observed changes create a number of challenges for the effective management of the farm, as well as for the stability of the functioning of agricultural markets. Moreover, they lead to the limited ability to meet the basic food needs of the population. This is especially true for poor people and low-income communities [5].

The outbreak of war in Ukraine has posed an additional challenge for global food supply chains, as Ukraine and Russia are among the largest world producers and exporters

of cereals, mainly wheat and corn [6]. These two grains play a pivotal role in the global agri-food trade, underpinning food security, livestock production, and industrial processes. Ukraine itself was the sixth largest producer of corn, with a 4.5% share in the world harvest in 2018–2021, and the seventh largest producer of wheat, with a share of over 4%. Prior to the war, Ukraine and Russia accounted for 30% of global wheat exports and 18% of corn exports. Of this total, Ukraine alone accounted for 12% of corn exports and 9% of foreign trade in wheat. However, while the impact of the war itself on commodity prices has been the subject of many studies [7], few have addressed the effect of the grain agreement, also known as the Black Sea Initiative, on market stabilization.

Consequently, the aim of this study is to present the price volatility of wheat and corn on the European stock exchange—Euronext—during the period of extension of the Black Sea Initiative negotiations. The above enables an assessment of the impact of the uncertainty surrounding the grain agreement on the operation of agricultural markets, and enriches the state of our knowledge concerning mechanisms of functioning of markets in the face of an external shock.

The paper proceeds as follows: the next section constitutes the literature review on price volatility. Then, the data sources and methodology are presented. The subsequent section outlines the circumstances under which the Black Sea Initiative was signed, extended, and expired, and encompasses descriptive statistics and the analysis of the empirical results. The final section concludes the outcomes.

2. Literature Review

Price volatility plays a key role in economic processes and is a common phenomenon in both financial and commodity markets. It is an important subject of research due to its importance for the global economy [8–14], as well as for food security [15,16]. In the literature, we encounter the concept of price volatility, which refers to the scope and speed of price changes in markets over a given period of time. The concept of variability is analyzed in two aspects: variability and volatility. Variability means the range and nature of the movements of observed values. It focuses on the analysis of changes in the level of the value of such data as prices. It describes how dispersed the data is in a given range. On the other hand, price variability in time volatility describes the diversity of changes in time. This is a special type of variability that measures the pace and intensity of changes in data values in a given time [17]. The focus here is on the dynamics of changes, e.g., rapid price jumps in a short period of time.

These fluctuations are associated with risk and uncertainty regarding the value of products, services, or financial instruments over time. The relationship between price volatility and risk refers to phenomena characterized by high randomness of the parameters that describe them, and may be difficult to predict [17]. In the context of commodity markets, e.g., agricultural products, price volatility means fluctuations caused by factors such as demand, supply, geopolitics, or packaging [18–20].

According to the definition of the Food and Agriculture Organization of the United Nations (FAO), price volatility in agriculture is defined as "the frequency and intensity of price fluctuations above or below their average level over a given period" [21]. In economics, short-term and long-term price volatility is analyzed. Short-term price volatility results from seasonal fluctuations, and sudden changes in supply, demand, or market speculation, while long-term price volatility is related to long-term structural changes, e.g., changes in trade policy, inventions, implementation of innovations, or climate change [22].

The price volatility of agricultural products is the result of many external and internal factors. Stabilizing prices requires integrated political, economic, and technological actions at local and global levels. Contemporary challenges such as climate change and global-

ization further emphasize the importance of monitoring and managing price volatility. The price volatility of agricultural products is a natural phenomenon resulting from the seasonality of production and changing weather conditions. According to Zegar [23], the prices of agricultural products are subject to strong fluctuations. Seasonality in agriculture, resulting from the vegetation cycles of plants and harvest periods, is a key reason for price volatility. An example is the prices of fruit and vegetables, which are lower in season and higher out of season, due to limited supply [23]. The supply of raw materials and, as a result, their prices, are influenced by weather conditions, especially extreme weather phenomena such as droughts, floods, or frosts. They have a huge impact on agricultural production and the availability of raw materials. Drought in the main growing regions can drastically reduce the supply of grains, which leads to a sharp increase in their prices [24].

Price volatility plays an important role in the decision-making processes of both producers and consumers, as it affects their ability to forecast future expenditures and revenues, but it also affects the decisions of investors and politicians [25–27].

The increase in the prices of energy, fertilizers, and plant protection products directly affects the costs of agricultural production. In turn, transport costs determine the prices of agricultural products in markets distant from their place of production [28]. In turn, consumers can also influence price volatility through their preferences. Fluctuations in demand resulting from consumer preferences, changes in income, and dietary trends also affect price volatility. For example, the rise in popularity of organic products has increased their prices compared to conventional products [29]. This variability can lead to difficulties in long-term planning for farmers.

Fluctuations in the value of goods, services, or assets over a given period of time may result from both endogenous and exogenous causes. In the context of commodity markets and agricultural products, the causes of price volatility include the following: supply and demand factors, market speculation, exchange rate fluctuations, geopolitical factors, climatic conditions, global market linkages, and financialization of markets [17,30–32].

Globalization means that local markets are closely linked to the situation in world markets. Changes in trade policy, such as the introduction of tariffs or embargoes, can disrupt the flow of goods, affecting their prices. The war in Ukraine has shown how geopolitical conflicts can destabilize agricultural markets, especially in the context of grain exports [33]. Global agricultural commodity markets are also susceptible to currency fluctuations, which affect local prices. In international markets, currency changes can significantly affect agricultural prices. Sharp fluctuations in the U.S. dollar, the dominant currency in commodity trade, affect import and export costs [34]. Price fluctuations, e.g., of grains and oilseeds, create situations, particularly in developing countries, where they affect food security.

Another aspect that stabilizes prices in markets is support for agriculture through grants and subsidies. According to the FAO [24], the development of support systems for agricultural producers is crucial in limiting the risk related to prices, and their absence often leads to stronger price fluctuations. Price volatility creates a great risk for farmers who have to make production decisions in advance. Sudden price drops can lead to financial losses, while a sharp increase in prices can bring unexpected profits [28] The introduction of intervention purchases of agricultural products is one of the tools to limit price volatility [31]. However, stabilizing agricultural prices is a challenge that requires integrated international action. The globalization of agricultural trade further highlights the need to monitor price volatility. Analysis of historical data shows that price stability in agriculture depends on effective market policy and technological support.

The recent extreme volatility of agricultural prices is causing serious repercussions for different stakeholders and levels in the food value chain, i.e., producers, interme-

diaries, and customers, at the micro-, meso- and macro-economic management levels, respectively. The persistent high/low level of agricultural prices leads to unsustainable production/consumption patterns, thus constituting an obstacle to achieving the goal of responsible consumption and production [35]. These goals were set by the United Nations as part of Agenda 2030. Sustainable development goal 2 (SDG 2) 'Zero hunger' is to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture [36]. Price volatility is a fundamental characteristic of the agricultural market and a major source of risk in international trade in agricultural products, which may affect the level of food security, especially in developing countries [37]. Ukraine plays a key role in terms of production and exports worldwide. The war taking place in Ukraine has significantly affected the market in the country, in Europe, and also worldwide. Among agricultural raw materials, wheat and corn are the most important in terms of food security [38]. As a result of the escalation of the war, their prices exceeded the level of prices of the last global food price crises of 2012 and 2008, and wheat prices were growing the most dynamically [39]. The priority, related to the implementation of the SDG 2 (zero hunger), is state intervention in agriculture, focused on supporting structural transformations that will ensure an increase in its competitiveness, food quality, and safety, and the country's food security in terms of environmental requirements. The key action is the implementation of innovative solutions in agriculture and agri-food processing through instruments supporting the high-quality food sector.

As part of SDG 12 'Responsible consumption and production', it is necessary to ensure, first and foremost, sustainable consumption and production patterns. As the country develops and society becomes more affluent, the level of consumption also increases. It is therefore necessary to develop sustainable consumption and production patterns consistent with the circular model. Maintaining environmental balance requires an appropriate approach to managing environmental resources. This includes planning in accordance with the laws of nature and the principles of sustainable development [39].

According to the definition of the FAO, food security means a state in which the aggregate supply of food is sufficient to feed the population in a way that ensures an active and healthy life. The FAO defines food security using several dozen indicators divided into four areas, including stability (dependence on imports, political system, production, and price variability). Connections in international markets are obvious and common phenomena. Nevertheless, in the case of goods such as agricultural raw materials, which constitute the basis for feeding the population in many countries around the world, these connections may be reflected in the level of stability of the functioning of a given country [32].

Price volatility is natural and related to the operation of the market mechanism. Not every price change indicates a risky situation, which undermines the point of assessing uncertainty directly on the basis of raw time series. Most market participants are aware of seasonal fluctuations, and therefore this type of volatility should not be taken into account when assessing price risk. Long-term price changes related to multi-year trends should also not be treated as a symptom of a crisis or risky situation. This is because market participants have time to adapt to such changes, known as technological trends. Therefore, only part of price volatility can be considered a source of price risk [40]. The situation is different when there is an armed attack on one of the largest producers and exporters of goods, such as wheat and corn. On 24 February 2022, the Russian Federation committed military aggression on the territory of Ukraine, which is the main exporter of grain for countries such as Egypt, Lebanon, Libya, Sudan, Tanzania, Nigeria, Bangladesh, and Pakistan [41]. Considering the threat of famine in the MENA region (Middle East and North Africa), the

United Nations, with the support of Turkey, initiated action to counteract potential famine in the countries of the region.

Geopolitical events are a significant factor influencing volatility. In areas affected by armed conflicts, there is growing economic and political instability. This also affects investment in agriculture. In the context of the war in Ukraine, the armed conflict in this region has caused significant disruptions in food supplies, which has contributed to the increase in grain prices worldwide. This has a profound impact on global markets, including the food sector, as Ukraine plays a significant role in international agricultural trade, as one of the largest grain exporters [42]. As noted by [29], the war in Ukraine has also caused an energy crisis, which affects the costs of food production and transport [39]. Sanctions imposed on Russia have additionally affected the fertilizer market, which has limited agricultural production possibilities. Geopolitical conflicts also have a direct impact on food security in importing countries, especially in North Africa and the Middle East. According to [34], the war in Ukraine has highlighted the need to build more resilient food supply chains. The literature emphasizes that geopolitical events require international action to minimize their effects on global food systems. Zhou et al. [43] indicate that the international organizations WTO, FAO, and WFP should cooperate with each other. Individual countries should strive to cooperate and strengthen food governance, while they should limit protectionism in food trade. The outbreak of war also had an impact on price volatility. Carter and Steinbach found out that wheat futures prices rose by 35% above the counterfactual level until the European Union Solidarity Lanes were announced, more than corn futures prices, which were up 16% [44]. They added that this relative price response cannot be explained by herding behavior and that there is no statistical evidence of abnormal speculative pressure in the market around the time of the invasion. In turn, Just and Echaust analyzed the transmission of price volatility between agricultural and energy markets, proving that after the outbreak of war, wheat became by far the largest transmitter of volatility shocks, transmitting medium volatility to other markets and, to a lesser extent, corn [45]. Budzyńska and Kowalczyk examined agricultural markets in war conditions, stating that the impact of armed conflicts is much greater in relation to products that are the basis for food and ensuring food security (significantly greater in the case of wheat than sugar) [46]. Additionally, armed conflict weakens long-term relations in favor of ad hoc, unstable contacts. An important work when it comes to the volatility of food prices, is the publication of Rice et al. [47], titled: "The Russia-Ukraine war is exacerbating international food price volatility". The authors warned that rising price volatility poses a distinct threat, as it induces greater market uncertainty, which affects production decisions, and can spur speculative behavior. Both would fan further food price inflation. Bullock et al. proved that the escalation in volatility in both futures and basis has resulted in many opportunities for trading firms with increased profits, albeit prospectively lower volumes [48]. Aliu et al. indicate that corn prices are an integral part of price changes in wheat, barley, and sunflower oil. Wheat prices are also essential, but with a weaker influence than that of corn. From a policy perspective, the findings provide reliable signals for countries exposed to food insecurities and inflationary risk [49].

It can be posited that the impact of the Black Sea Initiative on grain prices remains an area of niche interest. Thus, in the research process, the following hypotheses were formulated:

H1. *The outbreak of war in Ukraine significantly increased the volatility of wheat and corn prices in the European market.*

H2. *The Black Sea Initiative helped stabilize grain prices in the initial stages of its implementation, but its expiration contributed to increased price volatility in the markets.*

3. Materials and Methods

In order to estimate the impact of the war in Ukraine on the volatility of agricultural commodity prices, in the first stage, the importance of Russia and Ukraine in the global agricultural commodity market was determined, using data published on the platform AMIS—Agricultural Market Information System (2024) [50] for the 2018/19, 2019/20, and 2020/21 seasons (July of one year–June of the following year). Moreover, the process of concluding the Black Sea Initiative was described. In the next stage, the variability of agricultural raw material prices was analyzed using statistical methods, based on daily price quotations on the stock exchange Euronext. The period covered by the study was from 1 December 2021 to 15 May 2024. It enables the determination of the impact of the outbreak of war and the grain agreement's signing and extension on price volatility. The disruption caused by the pandemic and the subsequent lockdowns influenced the decision not to extend the time series.

The first step was to calculate the logarithmic rates of return:

$$u_i = ln\left(\frac{S_i}{S_{i-1}}\right) i = 1, \ldots, n \quad (1)$$

where

S_i—the price of the underlying asset (in this case, grain prices on the Euronext stock exchange).

Previous research on the volatility of agricultural product prices has shown that it behaves similarly to the volatility of financial instruments, i.e., bonds, shares, and stock exchange indices. It is not constant, but evolves over time and tends to cluster, at first with high values and then with low values [51]. Therefore, it was decided to use the GARCH model (ang. Generalized Autoregressive Conditional Heteroskedasticity), which takes into account conditional variability and allows for a better representation of real data than models that assume constant variance (e.g., ARMA). GARCH models are widely used in time series analysis and are valuable tools for understanding and forecasting price volatility and managing risks. They can also provide insights into how shocks (e.g., policy changes and international trade disputes) propagate through the market. However, agricultural prices are influenced by many other factors (like weather, harvest, and global trade conditions), which are not captured by standard GARCH models. Nevertheless, we believe that they may be useful for the purposes of this analysis.

Before modeling the variance of returns, the series was tested for stationarity and the presence of the ARCH effect. The stationarity of logarithmic rates of return was verified using the Augmented Dickey–Fuller test. In order to check whether a given series is characterized by heteroscedastic variance, i.e., whether the volatility in one sub-period depends on the volatility realized in the previous periods, the Engle test of Lagrange multipliers (test for the occurrence of the ARCH effect) was used.

Then, an autoregressive model with a random component described by the GARCH process was built for each of the studied time series (p,q). It was proposed by Bollerslev as a generalization of the ARCH process introduced by Engle in 1985 [52].

The typical and most common process in empirical research is the GARCH model (p, q) for $p = 1$ i $q = 1$. The adoption of such lag orders allows for the economical conditioning of the conditional variance (h_t) from the entire history of the random component ε_t. The original GARCH process, consistent with Bollerslev's definition (1, 1) has a conditional normal distribution with zero expected value and variance h_t:

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 + \sum_{j=1}^{p} \beta_j h_{t-j} \quad (2)$$

where ε_t denotes a sequence of independent, identically distributed random variables with zero expected value and unit variance,

whereas $\alpha_0 > 0$, $\alpha_i \geq 0$, $\beta_j \geq 0$, for $i = 1, 2, \ldots, q$, $j = 1,2 \ldots, p$.

The general form of the model is as follows:

$$u_t = \gamma_0 + \gamma_1 u_{t-1} + \varepsilon_t \quad (3)$$

where u_i—logarithmic rates of return on wheat or corn prices.

The models were estimated using the maximum likelihood method.

4. Results and Discussion

The summary of the research results is presented in three parts. The first presents a brief description of the importance of Ukraine and Russia in the global agricultural commodity market, the second describes the process of concluding the Black Sea Initiative, and the third presents the results of the price volatility analysis.

4.1. The Importance of Ukraine and Russia on the Global Grain Market

Ukraine and the Russian Federation are among the world's leading producers of agricultural commodities, especially grains and oilseeds. According to the data presented on the platform AMIS—Agricultural Market Information System [50], in the three seasons preceding the outbreak of the war, i.e., 2018/19, 2019/20, and 2020/21, together accounted for 14% of global wheat production and 4% of corn production. Ukraine itself was the sixth largest producer of corn, with a 4.5% share in the world harvest, and the seventh largest producer of wheat—with a share of over 4%.

These countries were even more important in the global trade in agricultural commodities. Both are net exporters of agricultural products. Their share in the 2018/19, 2019/20, and 2020/21 seasons in global wheat exports was 30%, i.e., almost twice as high as in the 2013/14 season, and in the case of corn—18%. Of this total, Ukraine alone had a 12% share in corn exports and a 9% share in foreign trade in wheat.

The relatively high concentration of both production and trade in key agricultural commodities generally results in increased market vulnerability to shocks [53]. The outbreak of war in Ukraine has severely disrupted global food, fuel, and fertilizer markets. However, as Arndt et al. point out, in contrast to the 2008/09 food crisis, this only affected a few specific commodities, mainly those whose supply chains were linked to Ukraine [54].

According to FAO data [55], in 2022, the year the war in Ukraine broke out, global food prices reached their highest level since 1990, when the survey was introduced. The FAO price index was 143.7 points, i.e., 14% higher year-on-year and almost 9% higher than the record in 2011. Between January 2022 and March 2022 alone, it rose by almost 18% to a record level of 160.2 points. This was due to the dynamic increase in the prices of grains—by 21% compared to January 2022, to 170.1 points—and oils and oil plants—an increase of over 35% to 251.8 points.

In the EU countries, the highest price level of the most basic cereal, food wheat, was recorded in May 2022, when the EU average was EUR 380.8/t, over 34% higher than in January 2022 and almost 72% higher year-on-year [56]. In turn, corn increased in price by almost 34% between January and April 2022 to EUR 346.5/t, i.e., it was almost 58% more expensive year-on-year.

Since the third quarter of 2022, the prices of plant raw materials have been gradually decreasing. Therefore, given the relatively short-term increase in the prices of agricultural raw materials, the focus in the further part of the study was on price volatility.

4.2. Grain Agreement of 22 July 2022

The functioning of global agricultural commodity markets has been changed by the geopolitical situation resulting from the Russian invasion of Ukraine on 24 February 2022. Ukraine, as a key exporter of wheat, corn, and oilseeds (sunflower) occupied by war, additionally faced an export crisis due to the blockade of ports on the Black Sea, mainly in Odessa, Chornomorsk, and Pivdenny. From these ports, Ukraine made about 75% of its domestic agricultural exports. The Russia-induced blockade caused disruption of grain supply chains to countries in the Middle East, Africa, and Asia [57]. In the above markets, Ukrainian grains played a significant role in the structure of imported food. Supplies from Russia, the world's second largest exporter, were also limited to these markets. These events caused a deepening global food crisis.

The export blockade caused an increase in food prices in world markets, which particularly affected developing countries largely dependent on grain imports. This affected the countries of the MENA region, most notably Egypt, Lebanon, Sudan, and Nigeria. The situation of deepening food insecurity became particularly dangerous, which caused the risk of malnutrition in this region and, consequently, social unrest [58].

The Black Sea Initiative was signed on 22 July 2022 by Ukraine, Russia, Turkey, and the United Nations in Istanbul. The aim of the agreement was to enable the safe transportation of grain and other food products from three Ukrainian ports in the Black Sea to global markets, in order to alleviate the global food crisis caused by the conflict in Ukraine [59,60]. The agreement covered three key ports: Odessa, Chornomorsk, and the Pivdenny (Yuzhny) port. These ports were chosen because of their strategic importance for Ukrainian exports. Before the war, approximately 75% of Ukrainian agricultural exports flowed from ports located on the Black Sea. Odessa, as the largest seaport in Ukraine, has key infrastructure for the export of agri-food products and the largest storage capacity. The port of Chornomorsk is the second largest port on the Black Sea in the territory of Ukraine, and the third port covered by the agreement, Pivdenny, has the modern infrastructure necessary to maintain the continuity of exports [53,59,60].

The agreement was intended to alleviate the global food crisis. Ukraine is one of the largest grain exporters in the world, and the blockade of ports has significantly limited deliveries, which has resulted in an increase in food prices in many regions around the world [4]. Additionally, the agreement supported the Ukrainian economy by allowing farmers to continue production and exports, which was crucial to the country's economic stability [53,59,60].

The implementation of the contract encountered a number of challenges. Shortly after signing the agreement, the port of Odessa was attacked by Russian missiles, which undermined confidence in the stability and security of the export corridor. Additionally, the need to provide insurance for ships and the high costs of transportation through alternative routes posed significant challenges for the agreement's stakeholders [57,58,61].

The Black Sea Initiative was extended three times:

- First extension: 17 November 2022—The contract was extended for another 120 days, until 19 March 2023;
- Second extension: 18 March 2023—The contract was extended for another 60 days, until 18 May 2023;
- Third extension: 17 May 2023—The contract was extended for another 60 days, until 17 July 2023.

In July 2023, the Black Sea Initiative expired, due to the lack of consent from the Russian Federation to continue it under the current conditions. Russia has repeatedly expressed dissatisfaction, claiming that the agreement did not bring with it the expected benefits [59,60]. Moreover, it used the agreement as a tool to put pressure on the West

to obtain the lifting of sanctions, and in July 2023, it set conditions for the continuation of the Black Sea Initiative, which were not met by the UN and Western countries [59]. It should also be emphasized that attacks on Ukrainian ports that took place during the grain agreement and the tense military situation undermined the security of the agreed export corridors [61].

The primary objective of the agreement was to stabilize global prices and provide Ukraine with the necessary support to strengthen its economy [62]. It was thanks to the income from exports that Ukrainian farmers were able to continue production and ensure stability in the domestic market. The signing of the agreement allowed for the stagnation in deliveries to countries threatened by social unrest due to high prices and shortages of raw materials to be stopped. The resumption of exports allowed for the partial satisfaction of demand in developing countries, mitigating the potential threat of famine.

4.3. Grain Price Volatility

The main aim of the Black Sea Initiative was to stabilize global wheat and corn prices. Thus, a price volatility study was conducted to ascertain the extent to which this goal had been realized. The analysis used logarithmic rates of return for daily wheat and corn price quotations on the Euronext stock exchange. Their stationarity was tested using the Augmented Dickey–Fuller test, obtaining a positive result each time. The ARCH tests confirmed the occurrence of the ARCH effect (variance clustering). The test results are presented in Table 1.

Table 1. Augmented Dickey–Fuller and ARCH LM test statistics.

Augmented Dickey–Fuller Test for Unit Root		
	Test Statistic with Constant	**Test Statistic with Constant and Trend**
corn	−6.241	−6.36362
wheat	−13.6937	−13.7816
ARCH LM Test Summary Statistics		
	Test Statistic	***p*-Value**
corn	51.8765	5.71887×10^{-10}
wheat	92.9688	1.59717×10^{-18}

Source: Own study based on Euronext data.

In the next stage, GARCH (1,1) models were estimated for the analyzed logarithmic returns. Based on the analysis of descriptive statistics, it was determined that the best-fitting GARCH models were those with the Student t-error distribution. The results of Engle's test determined the selection of models with lag 1.

The model estimation results are presented in Table 2.

The sum of parameter estimates ($\alpha + \beta < 1$) was slightly less than one in case of corn, which confirms that the stochastic processes were stationary. In the case of wheat, the sum reached one, which means the model satisfies the Integrated GARCH model. Thus, it is not a covariance stationary process, but it is still a strictly stationary process.

In both cases the shock phenomena had a long-term effect on the variances of the processes studied, whereby for wheat, the current variability has an infinite effect on the prediction of the conditional variance. The β coefficients for wheat and corn were significantly higher than the α coefficients, which in turn suggests large, unexpected variability.

Table 2. Parameters of estimated GARCH models for corn and wheat prices.

Time Series	Parameter	Coefficients	Standard Error	z-Statistic	*p*-Value
corn	const	−0.00103477	0.000484986	−2.134	0.0329 **
	omega	1.44882×10^{-5}	6.44250×10^{-6}	2.249	0.0245 **
	alpha	0.134967	0.0628100	2.149	0.0316 **
	beta	0.832222	0.0570215	14.59	3.03×10^{-48} ***
wheat	const	−0.000740700	0.000552575	−1.340	0.1801
	omega	2.38284×10^{-5}	1.20165×10^{-5}	1.983	0.0474 **
	alpha	0.159252	0.0657006	2.424	0.0154 **
	beta	0.838293	0.0546446	15.34	4.08×10^{-53} ***

** indicates a statistical significance of 5%. *** indicates a statistical significance of 1%. Source: Own study based on Euronext data.

The conditional standard deviations for the logarithmic rates of return of corn and wheat are presented in Figure 1. Differences in the calculated variances are particularly visible at the beginning and end of the period under review. In the case of corn, visible peaks are mainly characterized by the second half of February 2022 (the beginning of Russia's aggression against Ukraine) and the end of July 2022, i.e., the period before the signing of the Black Sea Initiative. However, the values obtained on the basis of the GARCH model are clearly underestimated in these periods, which indicates the strength of the shock. Subsequent extensions of the agreement did not increase the level of volatility of corn prices, only its expiry on 17 July 2023 caused a slight increase in the conditional variance.

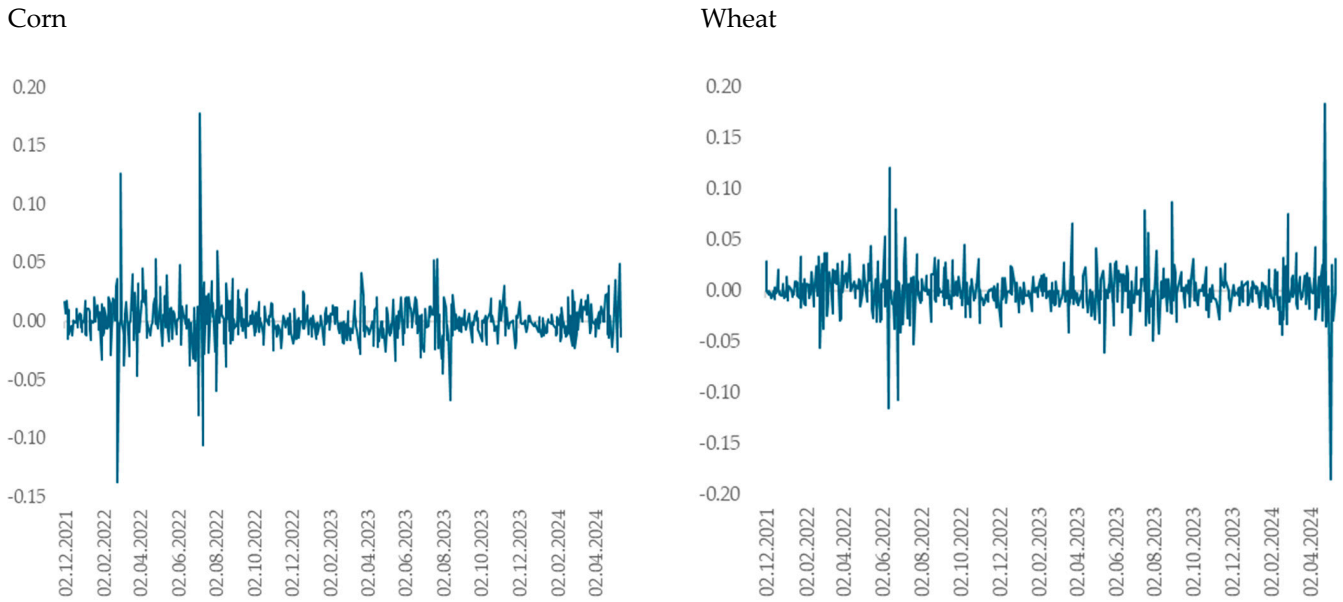

Figure 1. Conditional variance of corn and wheat prices. Source: Own study based on Euronext data.

In the case of wheat, the outbreak of war resulted in only a small increase in price volatility. Only the uncertainty related to signing the agreement contributed to their stronger fluctuations. As the period under review drew to a close, the conditional volatility of wheat began to exceed that of corn. However, the cause of these changes was not related to the war. On 13 May 2024, there was a sharp increase in wheat prices, which was likely due to revisions to wheat harvest forecasts in Russia resulting from persistent cold weather. This led to increased market anxiety about crop losses caused by adverse weather

conditions. However, as of 14 May, wheat prices weakened markedly, largely in response to the latest weather forecasts, which somewhat eased concerns about wheat yield losses and encouraged investors to make profits.

The objective of the present analysis was to enhance comprehension of price volatility. The research carried out indicates that the source of volatility in grain prices is, to a large extent, the uncertainty prevailing in the market. This uncertainty stemmed from two primary drivers: the outbreak of war and the governments' attempts to stabilize the market through the signing of the Black Sea Initiative. The research results indicate that these two factors exerted a greater influence on the volatility of corn prices, which is consistent with Ukraine's higher share in the global market for this grain.

The findings align with studies that emphasize the negative consequences of the Russia–Ukraine war on commodity market volatility [49,63], but additionally highlight the importance of the Black Sea Agreement for price formation. The first hypothesis is thus confirmed. In contrast, the second hypothesis—that the expiration of the Black Sea Initiative led to increased price volatility in the markets—is rejected, particularly in the case of corn. There is no significant price volatility observed following the agreement's termination. This suggests that the uncertainty surrounding its extension had a greater impact on prices than the actual impediments to trading in this grain.

The present study has a number of limitations. Firstly, the GARCH model does not provide an explanation for the causes of volatility, it rather describes the mechanism. The illustration of price changes in the context of signing and extending the Black Sea Initiative suggests the potential impact of this process on grain prices, though without quantification.

Moreover, the method used fails to consider other factors that influence the level and volatility of prices, such as grain stocks, macroeconomic processes, the volatility of other assets or long-term trends resulting from changes in agricultural policy, or technological progress. Consequently, future research could involve incorporating incoming market information into the GARCH model by introducing additional exogenous variables. However, the analysis of grain price volatility is based on daily data, whereas most market and macroeconomic data are published on a monthly or quarterly basis. Consequently, incorporating such information into the model to explain volatility is considerably impeded.

5. Conclusions

In February 2022, one of the leading producers of agricultural commodities attacked another. In previous seasons, the attacked Ukraine was a key exporter of, among others, corn and wheat, i.e., agricultural commodities of strategic importance. Ukraine's high share in the global trade of agricultural commodities, which are the basis of nutrition for many people around the world, meant that the outbreak of this war seriously disrupted global markets for food, fuel, and fertilizers. Concerned about the famine, the UN took action to enable the continued safe export of grain from three key Ukrainian ports. This initiative, supported by Turkey, was called the Black Sea Initiative, which was signed separately by Ukraine and the Russian Federation. Due to the nature of this agreement, reports about its possible conclusion were followed by media around the world from the first rumors on the subject. Television news, websites, newspapers, and industry magazines described progress and negotiations throughout the spring of 2022 until July 22. The Black Sea Initiative was concluded for a fixed term and was extended three times until Russia's withdrawal in July 2023. The conclusion of this agreement itself was associated with a great deal of uncertainty, and the short periods of its validity and therefore the need to extend it were a very media-related topic, a period of speculation, forecasting, and uncertainty. This contributed to the verification of how the aforementioned uncertainty affected the prices of these two strategic grains. Research allowed us to verify that, in the case of wheat, the

outbreak of war resulted only in a small increase in price volatility. Only the uncertainty related to the signing of the agreement contributed to their stronger fluctuations. The outbreak of war itself had a greater impact on the corn market, which is consistent with Ukraine's greater share in the global market for this grain. The research confirmed the first hypothesis, which states that armed conflict in Ukraine significantly increased the volatility of wheat and corn prices in the European market, including through potential disruptions in supply chains and restrictions on exports from the Black Sea region. The second hypothesis about the Black Sea Initiative aiding the stabilization of grain prices in the initial stages of its implementation, but its expiration contributing to increased price volatility in the markets, was partially confirmed, because of it not applying to both grains to the same extent.

The observed volatility shocks following the outbreak of war, coupled with the uncertainty surrounding the validity of the Black Sea Initiative, confirm that forecasting volatility during such a period is significantly more challenging than during peacetime. This poses a major challenge for all participants in the food chain. The authorities of individual countries should monitor price volatility on the strategic grain market and, in the event of an emergency, have tools to mitigate shocks.

It is worth emphasizing the need for further research taking into account other factors when constructing a multidimensional model. The impact of the war in Ukraine on the price volatility of strategic grains and other strategic raw materials and transmission to other sectors is a further topic for research, while this work mainly focused on the Black Sea Initiative and its impact.

6. Recommendations

Our research may have the following policy implications. First of all, agreements such as the Black Sea Initiative should not be concluded for periods as short as 60 days and should not be repeatedly extended for further short periods. Such short periods of validity of agreements on the export of strategic raw materials create uncertainty and risk for consumers, producers, exporters, and importers. Multiple extensions of such a contract increase the volatility of the prices of a given raw material. Thus, it is suggested to conclude contracts for the export of strategic materials for longer periods of time and to prevent the creation of media confusion regarding the extension of a given contract.

In addition, the method of communication regarding such agreements is extremely important. Contradictory messages about extending or not extending generate even greater price volatility through emerging uncertainty about the security of exports or imports of strategic raw materials.

It should be emphasized that wheat and corn are strategic commodities, the safe export or import of which translates into people's food security. There should be no fueling of uncertainty for these types of raw materials. Increased price volatility in the wheat and corn markets raises concerns about the next steps for producers, the exporting country, what's most important for the importing countries, and in the final stage for its citizens.

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