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Connections between gold, main agricultural commodities, and Turkish stock markets[☆]

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ABSTRACT

This study investigates the relationship between gold prices, agricultural commodity prices (rice, flour, bean, chickpea, lentil, and sugar), and Turkish stock markets. Using the Fourier Toda-Yamamoto causality test and wavelet coherency approach, we find that gold prices significantly influence agricultural commodity prices, emphasizing gold's pivotal role in agricultural market dynamics. Portfolio diversification incorporating gold and agricultural commodities mitigates risks, enhancing portfolio resilience. The BIST100 index and agricultural spot commodity prices exhibit differential impacts depending on specific products. Wavelet coherence analysis reveals time-varying dependencies, suggesting investors leverage their investments in BIST100 and gold for diversification with agricultural commodities. Our findings present agricultural commodities as alternative investment instruments, subject to favorable market conditions. The portfolio analysis uncovers nuanced relationships between commodities and indices, guiding investors in diversification and real asset investments. This research contributes novel perspectives, emphasizing the viability of agricultural commodities in diversified portfolios.

1. Introduction

The development of financial markets, influenced by technological advancements over the last 25 years, the diversification of investment instruments, and the crises experienced has made it compulsory for investors to make financial decisions with more variable choices. Gold, as the most traditional investment instrument, and the stock market stand out as the two investment options most affected by the crises. The relationship between the stock market and gold has been the subject of many studies due to the safe-haven characteristics of gold (Fung & Hsieh, 1999; Bildirici & Sonustun, 2021; Drake, 2022). However, the stock market's collapse due to the bubble, especially in the early 2000s, paved the way for investors to turn to pursuits other than gold, particularly commodity markets (Ding et al., 2021). Commodity markets have been shaped by various factors throughout history. Measures to limit

these movements have sometimes been discussed (Phillips, 1981; CFTC, 2009) due to speculative price movements and other adverse effects (Abbott et al., 2008, 2011; Schnepf, 2008). Many researchers have offered a different perspective by arguing that the price movements in commodities are caused by other factors that impact commodity markets rather than bubbles in their internal markets (Headey & Fan, 2008; Irwin & Good, 2009). Within these discussions and developments, especially in the last twenty-five years, there has been a large flow of funds into commodity markets and their index funds (Falkowski, 2011; ESCAP, 2011; Hamilton & Wu, 2015; Salem, 2017; Just & Łuczak, 2020; Saishree & Padhi, 2022). The commodity financialization wave is the most important reason for this flow (Cheng & Xiong, 2014). The commodity financialization process may be divided into the financialization process in the energy markets (Zhang & Ji, 2019) and other commodity markets (Cheng & Xiong, 2014). Various types of commodities are

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integrated into the global financial system, and this integration continues to strengthen. In particular, commodity futures markets have long performed important functions for commodity producers in hedging commodity price risks (Cootner, 1960; Hirshleifer, 1988; Larson, Varangis, & Yabuki, 1998). Recently, it has taken on a critical role in risk sharing and portfolio diversification (Dana, 2005; Daskalaki & Skiadopoulos, 2011; Hammoudeh et al., 2014; Lean et al., 2021), in addition to its price protection function.

At this point, creating a suitable environment for agricultural commodities to be used as financial instruments is imperative. More support is needed for individual investors to hold these agricultural commodities as a financial instrument. For this reason, agricultural products should be transformed into alternative investment instruments through financialization (securitization), and an investment instrument for this purpose should be created. The most basic way to do this is to develop agricultural exchanges and prepare a platform for Electronic Warehouse Receipts to be traded on various exchanges.

This study aims to unveil the relationship between agricultural commodity prices and key investment instruments, assessing their viability as portfolio diversification tools. The analysis focuses on the correlation between agricultural commodity prices, the stock market, and gold. Understanding this interdependence is crucial for investors engaged in portfolio diversification wherein commodities have emerged as significant components. In portfolio diversification, investors use investment instruments such as gold and foreign exchange on the one hand and stock market investment instruments on the other hand, both as alternatives to each other and for co-investment. Emerging commodity markets have now become an important instrument in this diversification.

This paper contributes to the existing literature on different fronts. First, it examines the relationship between agricultural commodity prices, gold prices, and the stock market index within the Turkish context, providing valuable insights into the dynamics of these interconnected markets. The choice of Türkiye as the geographic focus of this study is driven by several factors. Firstly, Türkiye's agricultural sector plays a crucial role in the country's economy, contributing significantly to employment, GDP, and food security. Analyzing the dynamics of agricultural commodity prices within the Turkish context offers insights into the sector's unique challenges and opportunities.

Furthermore, Türkiye's strategic location at the crossroads of Europe and Asia, and its diverse agricultural landscape make it an interesting case study for understanding commodity market dynamics within emerging market economies. By focusing on the specific dynamics of the Turkish agricultural sector and its integration with global financial markets, this study offers a nuanced understanding of how external factors, such as gold prices, influence domestic agricultural commodity prices and stock market performance. Through empirical analysis, this research sheds light on the complex interplay between traditional investment instruments like gold, emerging agricultural commodity markets, and established stock market indices, thereby enhancing our understanding of portfolio diversification strategies in the Turkish financial landscape.

Examining causal relationships and volatility dynamics among agricultural commodities, gold, and the stock market index advances scholarly understanding and provides practical implications for investors, policymakers, and market participants. Moreover, by addressing the limitations and challenges faced by the Turkish agricultural sector in leveraging financialization processes, this paper contributes to discussions on market efficiency, risk management, and the development of robust financial infrastructure. Through comprehensive analysis and empirical evidence, this study aims to inform decision-making processes at both micro and macroeconomic levels, guiding stakeholders in formulating effective policies, investment strategies, and risk management frameworks tailored to the unique characteristics of the Turkish financial markets.

Our results reveal significant insights into the interrelationship

among agricultural commodity prices, gold prices, and the BIST100 index. Specifically, we find compelling evidence of the impact of gold prices on agricultural commodity prices, highlighting the importance of gold as a determinant of agricultural market dynamics in Türkiye. Moreover, our analysis uncovers nuanced causality relationships between gold prices and specific agricultural commodities, offering valuable guidance for investors seeking to diversify their portfolios in the Turkish market. Additionally, our study identifies the partial influence of the BIST100 index on agricultural commodity prices, underscoring the complex interplay between stock market performance and agricultural market dynamics. These findings contribute to academic discourse and provide actionable insights for investors, policymakers, and market participants navigating the intricacies of the Turkish financial landscape.

While agricultural commodity markets are still evolving, spot and futures transactions in these markets have been carried out in parallel with the development of the stock exchange system. However, in the case of Türkiye, there are still many areas in need of improvement. With the completion of these missing areas and varieties, agricultural commodity markets can perform their expected functions. At this point, addressing the interaction between commodity and traditional markets will be necessary for investor decisions. In this study in the case of Türkiye, the relationship between some important basic food commodity prices, gold, and the stock market is analyzed.

The remainder of this paper is organized as follows. Section 2 reviews the previous studies. Section 3 discusses the methodology and presents the data and descriptive statistics. Section 4 presents the empirical results. Finally, Section 5 concludes the paper.

2. Literature review

The most important issue that needs to be emphasized before examining the literature is the transformation of agricultural products into financial instruments as alternative investment instruments. At this point, transforming agricultural products into alternative investment instruments through financialization (securitization) and creating an instrument that can be invested in this context has not been easy, at least in Türkiye. In the 1990s, including agricultural products among the underlying assets for futures transactions of the Istanbul Stock Exchange (ISB-IMKB) was only possible for cotton, which has international standards and can be standardized regarding contract characteristics. Apart from this, many wheat varieties, different from world standards, were a barrier to standardization until 2014, when the first wheat Electronic Warehouse Receipt (EWR-Turkish: ELÜS) was traded (MKK, 2014). For example, in wheat, the summer and winter groups traded spot in international markets and used as the basis for futures contracts include white hard, white soft, red hard, red soft, durum wheat, Australian wheat or Canadian wheat (CME, 2023), while in Türkiye there are Anatolian durum, Anatolian red hard, Anatolian white hard, Red semi-hard, White semi-hard, other red and other white wheat (TMEX, 2023). The main difference is that under these wheat grades traded in Türkiye, different varieties with different characteristics and qualities are subject to different prices. In other words, when an investor makes a futures or spot investment in winter white hard wheat, the product standards are clear, and prices move within the framework of these standards. For example, for an investor who has made a futures investment in red hard bread wheat in Türkiye, which of the 36 varieties (TMEX, 2023) listed in the wheat benchmark will they take as a reference and maintain their investment? Among the red hard bread wheat varieties, Esperia wheat indicates a higher quality, i.e., a better price, while the Adelaide variety indicates a mediocre quality and price. Therefore, based on the wheat example, an agricultural commodity that can be standardized may be more easily financialized and may attract investors' interest within the scope of alternative investment. Istanbul Stock Exchange (IMKB) cash-settled contracts with agricultural commodity underlying assets are not accepted by investors. Similarly, the

Futures and Options Exchange (Turkish: “Vadeli İşlem ve Opsiyon Borsası”, “VOB” for short) was established in 2005 under the leadership of the “Union of Chambers and Commodity Exchanges of Türkiye” (Turkish: “Türkiye Odalar ve Borsalar Birliği”, “TOBB” for short) in İzmir, a province known for its cotton crop (Ersoy, 2011). From 2005 until 2013, when it was merged with Borsa İstanbul (BİST, 2023), cash-settled contracts based on instruments other than agricultural commodities were traded more intensively. The fact that traders or companies that are exposed to different risks at various levels, especially in the agricultural commodity-based industry sector in Türkiye, conduct their risks in this context through agricultural futures contracts traded in Chicago or similar international exchanges is important in terms of pointing out that something is going wrong or incomplete in Türkiye regarding agricultural commodities (Ulusoy, 2016). No Futures and Options Exchange element can make agricultural commodity contracts attractive for investors. There are insufficient arbitrage opportunities and hedging mechanisms, especially in agriculture, where the land structure is fragmented, and agriculture is focused on subsistence rather than industrial production. The lack of an instrument that can manage the price fluctuations arising from the seasonal characteristics of agricultural products, existing commercial customs and practices, and the tendencies of traders and producers are barriers to developing spot or forward contracts based on agricultural products (Dönmez, 2011). Türkiye has not achieved the desired transformation in the World Bank-funded project dated 22.10.1998 (World Bank, 1998) for the transformation of 7 commodity exchanges in Türkiye (Konya, Adana, Şanlıurfa, Eskişehir, İzmir, Edirne, and Polatlı) into specialized exchanges for grain and cotton. It is assessed that the relevant commodity exchanges allocate the relevant funds to areas other than their intended purposes. In 2005, the Law on Licensed Warehousing entered into force with an adaptation specific to Türkiye by analyzing world examples. The relevant law is important for the country’s economy because it necessitates agricultural production and storage standardization and transformation to specialized stock exchanges. It is the basis for introducing Licensed Warehousing practices in Türkiye as an alternative instrument and method since the beginning of the 1900s in the United States of America and since the beginning of the 1990s in many countries such as Canada. With these developments, Türkiye has combined its traditional commercial understanding in the agricultural sector with modern trade understanding in the same pot. It has developed beyond the foreseen with the licensed warehousing and product-specialized stock exchange system (Yücel, 2011). Following the law on licensed warehousing, the first licensed warehouse was built and put into operation with the initiatives of TOBB and the Turkish Grain Board (Turkish: “Toprak Mahsulleri Ofisi”, “TMO” for short) as an example for private sector companies and traders. Some stock exchanges, notably the Konya Commodity Exchange, are granted permission to establish and operate platforms for electronic platforms where agricultural products can be traded in licensed warehouses through an electronic certificate that can be securitized and sold (İTGM, 2016). When the volume of transactions carried out on the electronic trading platforms of the commodity exchanges started to deepen like a baby in an incubator, the Ministry of Trade authorized the establishment of the “Turkish Commodity Exchange.” Transactions started to be traded on the platforms of the commodity exchanges from 2014 until July 2019 and on the Turkish Commodity Exchange (Turkish: “Türkiye Ürün İhtisas Borsası”, “TÜRİB” for short) as of July 2019 (TÜRİB, 2023a). As of July 2023, the Turkish Commodity Exchange (TÜRİB) provides services in 43 provinces of Türkiye with a licensed capacity of 9.348 million tons, an establishment capacity of 20.4 million tons, and a total of 210 licensed warehousing companies with the headquarters and branches of 178 companies (İTGM, 2023). From 2015 to June 2023, the total transaction volume is approximately USD 4.9 billion (Takasbank, 2023). Transactions will continue with a market structure in which the Central Registry Agency serves as the custodian as the Electronic Registry Agency, clearing, and Takasbank carries out settlement transactions. Transactions are carried out in the

BIST matching engine, primarily without intermediaries within “TÜRİB” in the current situation and with an intermediated market structure through Product Market Intermediary Institutions in the future. As the architect of agricultural transformation in Türkiye, there is a single market as the EWR (ELÜS) market within TÜRİB, and services are provided with various order types (TMO order, Contracted order, Normal order, etc.) (TÜRİB, 2023c). With the Tawarruq market and futures, TÜRİB aims to reach a sustainable depth in arbitrage and risk management and to make institutional investors actors in the system. At the point of offering EWR and EWR underlying futures to investors as an alternative instrument, TÜRİB started to publish wheat, barley, corn, and cereals indices (8 indices) as of April 2021. The first financial product on the TÜRİB Bread Wheat Price Index was issued on 23.06.2023 with the ISIN code TRPPSH392321 (TÜRİB, 2023d). Thus, the question of what the investor will invest in agricultural commodities with reference has been answered. This process, which started with wheat in the beginning, will be possible for Cotton, Olives, Raisins, Hazelnuts, Dried Apricots, Pistachios, Barley, Sunflower Seeds, Beans, Triticale, Rye, Paddy, Lentils, Corn, Chickpeas, Soya Beans, and Oats, which are or may be traded in TÜRİB (TÜRİB, 2023b). In line with these developments, it will be possible for granulated sugar, discussed in this study, to be stored and traded on stock exchanges within this scope. Therefore, agricultural commodities may be traded and used as financial instruments in both spot and futures exchanges with this infrastructure. Moreover, due to the biological nature of production processes, agricultural commodities are highly sensitive to supply shocks and, therefore, have high price volatility. The development of storage systems can potentially reduce these risks (Sanches et al., 2021). Therefore, developing licensed warehousing activities and the associated financialization of agricultural commodity prices can benefit the economy synergistically.

The literature provides robust theoretical support for the interconnectedness between gold, agricultural commodities, and stock markets, emphasizing the roles of financialization, volatility spillovers, and hedging strategies.

Créti et al. (2013) investigate the dynamic correlations between commodity and stock markets, highlighting the significant role of the financial crisis in emphasizing these links. The authors underscore the financialization of commodity markets, with gold acting as a safe haven during periods of market turmoil. According to Reboredo et al. (2021), stock markets transmit significant spillovers to commodity markets, including agricultural commodities and precious metals like gold. This interconnectedness is crucial for international investors in terms of diversification, risk management, and asset portfolio hedging. Aumeboonsuke (2020) demonstrate that changes in the prices of energy, agricultural raw materials, and gold significantly influence the Thai stock market. Both long-term and short-term impacts are observed, indicating that past price changes in these commodities are important predictors of stock market developments. The paper by Coronado et al. (2015) explore the bidirectional causality between crude oil, gold, and stock markets in the US. The findings suggest that changes in stock market returns can be monitored by observing the returns of these commodities, which is vital for designing investment strategies. Morema and Bonga-Bonga (2020) assess the impact of gold and oil price fluctuations on the South African stock market. Significant volatility spillovers are found, emphasizing the importance of these commodities in portfolio management and hedging strategies, especially during financial crises. Zapata et al. (2012) examine the historical cyclical relationship between stock and commodity markets, noting a high negative correlation over the past 140 years. The authors highlight the recent price dominance of agricultural commodities and supports the inclusion of agribusiness indexes in investment portfolios for risk-averse investors. The study by Bekiros et al. (2017) provides evidence that gold acts as a hedge and a safe haven for equity markets, particularly during crises. This is especially relevant for emerging markets like the BRICS, which are vulnerable to external shocks, including commodity price

fluctuations. According to Ali et al. (2020), specific commodities, especially precious metals like gold, offer valuable hedge and safe haven roles for international stock markets. The study suggests that combining stock market indices with their best commodity matches can yield significant diversification benefits. Baldi et al. (2016) highlight the increased volatility spillover from stock markets to agricultural commodity markets after the 2008 financial crisis. This indicates a rising interconnection between financial and agricultural commodity markets, emphasizing the impact of stock market shocks on commodity price volatility. Natanelov et al. (2011) underpin that co-movement of agricultural commodity futures prices and crude oil is a dynamic concept, with biofuel policy buffering the co-movement until crude oil prices surpass a certain threshold. MacDonald et al. (2015) emphasize that agricultural trade impacts global food security and resource sustainability, with traded animal products having disproportionate influence and affecting cropland allocation.

After this general assessment, studies on commodity markets in the literature are then reviewed. In some studies on the price formation character of commodity markets, it has been suggested that irrational behaviors characterize them and that prices are formed due to these behaviors (herd behavior psychology) (Pindyck & Rotemberg, 1990). Pindyck and Rotemberg (1990) have argued that the prices of seven seemingly unrelated goods tend to move together in ways that cannot possibly be explained by variables (inflation, change in demand, etc.) that are economically related. While some subsequent studies could not find evidence to support this theory (Palaskas & Varangis, 1991; Leybourne et al., 1994; Deb et al., 1996; McDermott et al., 1999), some studies have found results (Ai et al., 2006; Le Pen & Sévi, 2010; Lescaroux, 2009; Weiner, 2006) to support this phenomenon of price movement (herd psychology, etc.). However, in most studies with evidence of co-activation, the association usually disappears when various factors are removed. Accordingly, the prevailing perception in the literature is that the change in commodity prices is due to the price movements of other economic and financial variables in the market and the relationship between commodity prices and those variables rather than the herd behavior within the commodity group (Demirer et al., 2015; Steen & Gjolberg, 2013).

Many variables that cause changes in commodity prices have been discussed in the literature. The important ones are briefly summarized below.

One of the most important topics in these studies is the effect of exchange rates on commodity prices, and many studies have addressed this issue. In these studies, topics such as the effect of exchange rates on the production and trade of agricultural products (Cho et al., 2002; Orden, 2002; Raflesia et al., 2021; Schuh, 1974; Wang et al., 2012, pp. 451–458) and the effect of exchange rates on agricultural exports (Buguk et al., 2003; Fidan, 2006; Huchet-Bourdon & Korinek, 2011; Mao, 2019; Shane et al., 2008) have been mainly addressed. The relationship between exchange rates and commodity prices is significant in the literature. In many of these studies, oil prices are included in the evaluation along with exchange rates (Ahmid, 2020; Baek & Koo, 2010; Burakov, 2016; Harri et al., 2009; Kadanali, 2021; Kanyam, 2014; Karacan, 2022; Nazlioglu & Soytas, 2012). Studies on the relationship between oil and petroleum products and agricultural commodity prices without exchange rates also occupy a significant place in the literature (Bentivoglio, 2016; Chiou-Wei et al., 2019; Mokni & Youssef, 2020).

Apart from foreign exchange, there are some other studies on the relationship between energy market factors and agricultural product prices (Coronado et al., 2018; Demirer et al., 2015; Du et al., 2022; Mokni & Ben-Salha, 2020; Nazlioglu, 2011; Tiwari et al., 2018; Vu et al., 2019).

One of the variables to be considered in this study is gold, and there are also studies in the literature on the relationship between other precious metals and agricultural commodity prices, with a particular focus on gold. The number of these studies is fewer than the other studies mentioned above. Some of these studies are as follows:

Based on their missing economic linkages, Pindyck and Rotemberg (1990) analyzed the prices of seven theoretically unique commodities (wheat, gold, cocoa, oil, timber, copper, and cotton). Surprisingly, the study results revealed, that the model's residuals are highly correlated after controlling for some economic factors.

Kang et al. (2017) used the multivariate DECO-GARCH model and the spillover index to explore the return and volatility spillover impacts of six commodities futures (gold, silver, West Texas Intermediate crude oil, maize, wheat, and rice). Their findings suggest a positive correlation between commodity futures market returns and another factor, with these returns increasing dramatically during crises. The spillover effects between the metrics studied during the latest financial crises are more prominent than previously observed.

Mensi et al. (2017) employed variational mode decomposition and copula functions to analyze the dependence between crude oil prices and major regional stock markets during various market phases and investment horizons. Their study identifies tail dependence between oil and stock markets, with the short-term horizons of these markets showing average dependence, except for the S&P500. The study also finds asymmetric risk spillovers from oil to stock markets and vice versa across short- and long-term horizons, with asymmetry varying over time and investment horizons.

Kumar et al. (2020) investigated the relationships between 13 main commodity markets (three energy commodities, six agricultural commodities, and four precious metal prices). The study discovered that the interdependence of these commodities changes depending on the financial situation.

Using the World Bank commodity database, Shahzad et al. (2021) examined the correlations between three commodity indices: energy, agriculture, and precious metals. The precious metals commodity index includes gold, silver, palladium, and platinum prices. The results show time-varying causal relationships between index returns and the volatility of energy, agriculture, and precious metals.

Studies in the literature of the causal relationship between stock indexes and commodity prices are important. Most studies in this area have focused on examining the relationship between stock returns and commodity future returns. Driesprong et al. (2008), Thuraishamy et al. (2013), Nguyen et al. (2015), Li et al. (2021), among others, are studies that can be given as examples. Another group includes studies on the relationship between oil prices and stock returns. Studies in this group generally reveal the effects of oil prices on firm returns (Narayan & Sharma, 2011). While some of these studies have found that oil price has a statistically insignificant effect on market returns (Chen et al., 1986), others have found that it has a negative effect (Jones & Kaul, 1996). Some studies have found different results for different countries (Driesprong et al., 2008). Studies on the effect of gold on the stock market are crucial in the literature. In these studies, it has been revealed that gold volatility, like oil, affects stock market volatility (Kazak, 2023; Thuraishamy et al., 2013). Whether gold is a safe haven has been addressed in many studies (Baur & Lucey, 2010). In these studies, the relationship between stocks and gold was evaluated. It was found that gold has a safe-haven feature in some studies (Baur & Lucey, 2010; Baur & McDermott, 2016). Gold particularly shows this feature when market conditions change, such as crisis periods (Areal et al., 2015). However, it sometimes loses this feature during certain crisis periods (Akhtaruzzaman et al., 2021; Miyazaki & Hamori, 2013). The relationship between the stock market and the market prices of commodities other than precious metals and energy market products, such as oil (especially the prices of agricultural products), is relatively rare in the literature. In these studies, it has been revealed that the relationship between commodity markets and the stock market exhibits a time-varying movement pattern (Bekiros et al., 2016; Gorton & Rouwenhorst, 2006).

Atik et al. (2023) examine the effects of global crises on market dependence analysis, introducing the tail-restricted integrated regression function for a more nuanced approach to tail-mean dependence.

Their study of the US and Turkish agricultural markets from 2016 to 2022 reveals asymmetric risk spillovers from the US to Türkiye. The authors suggest that launching an agricultural commodity futures market in Türkiye would enhance market completeness and integration. Similarly, Uddin et al. (2024) investigate quantile coherency across bonds, commodities, currencies, and equities using a novel approach to examine asset return dependence at various frequencies. Their analysis of sixty-seven asset return series across four asset classes reveals stronger low-frequency dependence in the bond, foreign exchange, and equity markets. The findings, which highlight significant dependencies between specific markets such as German and French bonds and various currencies and commodities, have critical implications for portfolio allocation and investment strategies. Atik et al. (2023) and Uddin et al. (2023) employ a nonlinear quantile approach to investigate the links between different financial instruments. This approach has an advantage over the standard conditional mean approach, as it provides a comprehensive view of the relationship between dependent and explanatory variables and allows analysis at any point in the distribution. However, the authors should justify using causality and coherency analyses, which do not illustrate relationships across different quantiles, given that relationships between financial variables can vary significantly at lower and higher quantiles.

The relationship between many types of commodities and market variables has been revealed in various studies. This study will analyze the relationship between spot market prices of some agricultural commodities, spot gold prices, and the stock market index, within Turkish markets, as opposed to futures markets. The study makes an important contribution to the literature and financial markets by examining certain causality relationships, which have yet to be examined in the Turkish case, and evaluating causality with an analysis method, enriched with Fourier functions.

3. Data and methodology

3.1. Data

This study analyzes the causal relationship between spot prices of selected major agricultural products (rice, wheat flour, beans, chickpeas, lentils, and sugar) and two essential investment instruments, the spot gold price and the BIST100 index. These agricultural commodities represent staple food items in Türkiye's domestic market and are critical indicators of the country's agricultural sector performance. Including gold prices and the BIST100 index allows for an assessment of how external factors and broader market trends influence agricultural

commodity prices.

The selected period for analysis spans from January 2005 to February 2023, encompassing nearly 19 years of monthly spot price data. This duration provides a substantial dataset for conducting time series analysis and allows identifying long-term trends, seasonal patterns, and potential structural breaks within the data. Additionally, focusing on monthly data offers a balance between capturing meaningful fluctuations in commodity prices while minimizing noise inherent in higher-frequency data.

The data sources utilized in this study are carefully selected to ensure reliability and consistency. Agricultural product prices are obtained from the Turkish Statistical Institute (TÜİK) database, the primary source for official statistics in Türkiye. Sourced from the Central Bank of the Republic of Türkiye data center, gold prices providing accurate and up-to-date information on precious metal prices. BIST100 values are retrieved from the reputable financial website "<https://tr.investing.com>", offering comprehensive coverage of stock market indices and financial data. Fig. 1 shows the standardized price time series of agricultural commodities.

Natural logarithms of the data are employed to facilitate robust statistical analysis. Log-transforming the variables helps stabilize variance and reduce the influence of outliers, enabling more accurate modeling of the relationships between agricultural commodity prices, gold prices, and the BIST100 index.

Table 1 presents the descriptive statistics for all analyzed series. The series are non-normally distributed, as indicated by the strong rejection of the Jarque-Bera statistic at the 1% significance level for six variables and at the 5% significance level for two variables. Five series are skewed to the right, and all variables are skewed. The mean series reveals the variables' average values, with BEAN having the highest mean at 1.925. Meanwhile, the risk series, measured by standard deviations, indicates the variability of each variable, with BEAN having the highest standard deviation of 0.598.

At this stage, we present the correlation matrix for the variables analyzed (Table 2).

It is clear from Table 2 that all correlation coefficients between pairs of variables are statistically significant and positive. There is a high positive correlation between all variables. This high correlation is a preliminary indicator of the causality tests to be conducted going forward. The FLOUR-SUGAR correlation has the highest average value ($r = 0.988$). Table 3 shows that all correlation coefficients between pairs of variables are statistically significant and positive. All variables have a high positive correlation when considering the whole time series without fragmentation. The BEAN-RICE correlation has the highest

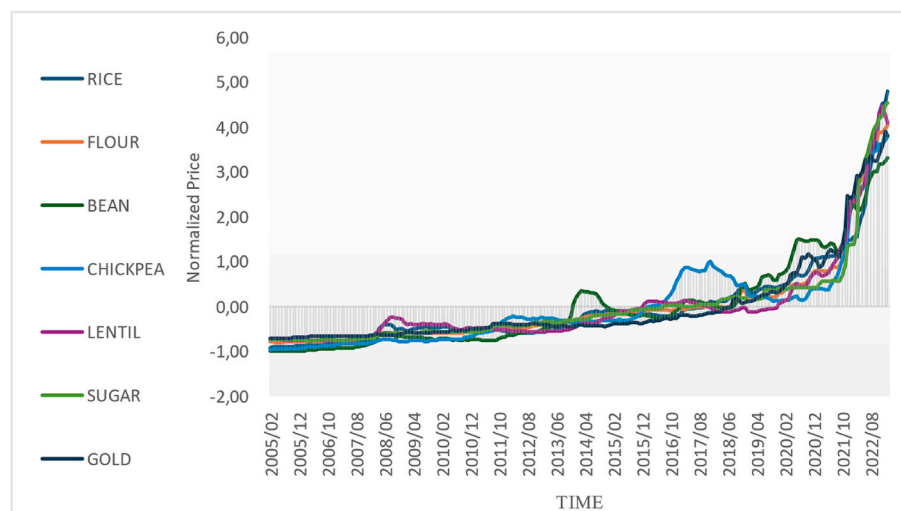


Fig. 1. Standardized price time series of agricultural commodities.

Table 1
Descriptive statistics.

	BEAN	CHICKPEA	FLOUR	LENTIL	RICE	SUGAR	BIST100	GOLD
Mean	1.925	1.819	0.918	1.627	1.798	1.285	6.607	4.661
Median	1.935	1.801	0.881	1.499	1.733	1.210	6.623	4.564
Maximum	3.282	3.385	2.614	3.578	3.462	2.860	8.614	7.068
Minimum	1.038	0.794	0.084	0.609	0.938	0.678	5.463	2.890
Std. Dev.	0.598	0.642	0.608	0.690	0.549	0.485	0.590	1.053
Skewness	0.405	0.373	0.864	0.737	0.725	1.197	0.723	0.438
Kurtosis	2.258	2.551	3.553	3.482	3.421	4.692	4.329	2.563
JB	10.966 ***	6.895 **	29.891 ***	21.857 ***	20.688 ***	78.105 ***	35.029 ***	8.722 **

Note. JB stands for Jarque-Bera. “***” and “**” denote rejection of the null of normality at 5% and 1% significance levels, respectively.

Table 2
Correlation matrix.

	BIST100	GOLD	BEAN	CHICKPEA	FLOUR	LENTIL	RICE	SUGAR
BIST100	1							
t-stat	–							
GOLD	0.929 (***)	1						
t-stat	36.97	–						
BEAN	0.902 (***)	0.957 (***)	1					
t-stat	30.69	48.35	–					
CHICKPEA	0.928 (***)	0.941 (***)	0.913 (***)	1				
t-stat	36.73	40.78	32.84	–				
FLOUR	0.946 (***)	0.974 (***)	0.970 (***)	0.949 (***)	1			
t-stat	42.77	63.58	58.49	44.04	–			
LENTIL	0.874 (***)	0.924 (***)	0.928 (***)	0.900 (***)	0.963 (***)	1		
t-stat	26.45	35.42	36.56	30.39	52.89	–		
RICE	0.918 (***)	0.959 (***)	0.969 (***)	0.911 (***)	0.980 (***)	0.969 (***)	1	
t-stat	34.09	49.78	57.25	32.46	71.91	57.89	–	
SUGAR	0.945 (***)	0.955 (***)	0.944 (***)	0.945 (***)	0.988 (***)	0.950 (***)	0.966 (***)	1
t-stat	42.65	47.08	42.12	42.64	95.94	44.64	55.32	–

Note. “***” indicates 1% significance level.

value ($r = 0.987$).

3.2. Econometric methodology

To examine the causality relationships, we employ the Panel Fourier Toda-Yamamoto (PFTY) causality test, which enhances the traditional Toda-Yamamoto approach by incorporating Fourier functions to account for unknown structural breaks in the data. The Toda-Yamamoto procedure is based on estimating a Vector Autoregression (VAR) model at the levels of the variables, regardless of their integration order, by adding additional lags to the VAR system to account for the maximum order of integration [missing information]. $d_{\max}$ Specifically, we first estimate a $\text{VAR}(p + d_{\max})$ model, where p is the optimal lag length determined by standard information criteria (AIC, BIC), and $d_{\max}$ is the maximum degree of integration. The causality is then tested using a modified Wald statistic that tests the joint significance of the lagged variables. The Fourier function is added to the model to capture structural breaks in a smooth and flexible manner. The Fourier series allows for modeling breaks in both the intercept and the slope without requiring prior knowledge about the timing, size, or shape of the breaks. This is crucial for detecting gradual and persistent changes in the relationships between variables.

To obtain the individual critical values for the causality tests, we apply a bootstrap approach. This method is used because the distribution of the Wald statistic may not follow the standard chi-squared distribution when the data exhibit cross-sectional dependence or when the VAR model includes non-stationary variables. The bootstrap technique involves resampling the residuals from the estimated VAR model to create a large number of simulated samples. For each resampled dataset, the FTY test is re-estimated, and the distribution of the test statistic is derived from the resampled data. The critical values are then determined based on the percentiles of this bootstrap distribution, ensuring a

more accurate inference about the presence of causality, especially in small sample sizes or when structural breaks are present.

First, the stationary and maximum degree of integration ($d_{\max}$) are determined using the flexible Fourier form and Dickey-Fuller type unit root test proposed by (Enders & Lee, 2012). In light of the results obtained from the stationarity tests, the approach (Toda & Yamamoto, 1995) has been analyzed by enriching it with Fourier functions. The Granger (1969) p-lag vector autoregression (VAR) model is given as follows in Eq. (1):

$$y_t = \alpha + \vartheta_1 y_{t-1} + \dots + \vartheta_p y_{t-p} + \varepsilon_t \tag{1}$$

In Eq. (1), the endogenous variables y_t represent a vector of α cut-off terms, while $\vartheta = (\vartheta_1 \dots \vartheta_n)$ parameters and ε_t refer to white noise residuals. To test the null hypothesis of no Granger causality for a specific variable of interest, the p-degrees-of-freedom chi-square Wald statistic is commonly employed. However, in cases where the variables incorporated in the vector autoregressive (VAR) model exhibit integration or cointegration, the Wald statistic deviates from a standard distribution and becomes dependent on certain nuisance parameters (Toda & Yamamoto, 1995). To overcome these challenges, Toda and Yamamoto (1995) propose the estimation of a VAR(d) model using the level of variables, where d represents the maximum degree of integration observed among the relevant variables. $p + dd_{\max}$ This approach effectively addresses the limitations of testing Granger causality by aligning with the power and size properties of unit root and cointegration tests (Zapata & Rambaldi, 1997).

The Toda and Yamamoto (1995) study is still being expanded using new models. Among these methods, the employment of Fourier forms in unit root and causality analysis is most significant. The Fourier series is a periodic function expansion in terms of the infinite sum of sines and cosines $f(x)$. An infinite number of sines and cosines can represent each periodic series $f(x)$ (Tolstov & Silverman, 1976). Using a Fourier series,

Table 3
Rolling window correlation (48-months).

	RICE	FLOUR	BEAN	CHICKPEA	LENTIL	SUGAR	GOLD	BIST100	
5	RICE	0.950	0.987	0.904	0.919	0.914	0.782	0.076	0.96
4		−0.794	−0.720	−0.873	0.856	−0.789	−0.800	−0.330	
3		0.853	0.642	0.175	0.756	0.699	0.410	0.163	
2		0.953	0.898	−0.788	0.545	0.923	0.964	0.436	
1		0.958	0.943	0.935	0.957	0.958	0.925	0.986	
5	0.950	FLOUR	0.978	0.921	0.891	0.896	0.801	0.174	
4	−0.794		0.564	0.933	−0.870	0.886	0.934	0.599	
3	0.853		0.301	0.621	0.972	0.951	0.777	0.122	0.80
2	0.953		0.952	−0.759	0.703	0.879	0.949	0.407	
1	0.958		0.947	0.983	0.984	0.965	0.975	0.958	
5	0.987	0.978	BEAN	0.918	0.917	0.912	0.800	0.089	
4	−0.720	0.564		0.696	−0.496	0.687	0.463	0.112	
3	0.642	0.301		−0.235	0.109	0.073	−0.147	−0.234	
2	0.898	0.952		−0.780	0.762	0.853	0.935	0.403	
1	0.943	0.947		0.899	0.969	0.902	0.971	0.921	
5	0.904	0.921	0.918	CHICKPEA	0.715	0.720	0.920	0.395	0.53
4	−0.873	0.933	0.696		−0.877	0.932	0.941	0.544	
3	0.175	0.621	−0.235		0.678	0.747	0.886	0.000	
2	−0.788	−0.759	−0.780		−0.261	−0.834	−0.816	−0.070	
1	0.935	0.983	0.899		0.957	0.965	0.934	0.947	
5	0.919	0.891	0.917	0.715	LENTIL	0.971	0.577	−0.206	
4	0.856	−0.870	−0.496	−0.877		−0.854	−0.914	−0.709	
3	0.756	0.972	0.109	0.678		0.972	0.856	0.128	
2	0.545	0.703	0.762	−0.261		0.503	0.645	0.479	0.32
1	0.957	0.984	0.969	0.957		0.929	0.985	0.950	
5	0.914	0.896	0.912	0.720	0.971	SUGAR	0.591	−0.178	
4	−0.789	0.886	0.687	0.932	−0.854		0.912	0.574	
3	0.699	0.951	0.073	0.747	0.972		0.878	0.116	
2	0.923	0.879	0.853	−0.834	0.503		0.932	0.345	
1	0.958	0.965	0.902	0.965	0.929		0.910	0.960	
5	0.782	0.801	0.800	0.920	0.577	0.591	GOLD	0.380	
4	−0.800	0.934	0.463	0.941	−0.914	0.912		0.641	0.11
3	0.410	0.777	−0.147	0.886	0.856	0.878		0.042	
2	0.964	0.949	0.935	−0.816	0.645	0.932		0.382	
1	0.925	0.975	0.971	0.934	0.985	0.910		0.915	
5	0.076	0.174	0.089	0.395	−0.206	−0.178	0.380	BIST100	
4	−0.330	0.599	0.112	0.544	−0.709	0.574	0.641		
3	0.163	0.122	−0.234	0.000	0.128	0.116	0.042		
2	0.436	0.407	0.403	−0.070	0.479	0.345	0.382		
1	0.986	0.958	0.921	0.947	0.950	0.960	0.915		

we can decompose an arbitrary periodic function into a sequence of simple terms that can be solved independently and then recombined to yield the original problem's solution at the required degree of precision (Shima & Nakayama, 2010). Enders and Jones (2016) proposed a study adding a Fourier function to the VAR model to examine Granger causality, which has provided an important breakthrough in this context. Instead of estimating the number, shape, and size of breaks, a variant of Gallant's (1981) flexible Fourier form controls for breaks in a VAR.

In this study, we employ a causality test incorporating the Fourier function (FFT) into the Toda-Yamamoto approach proposed by Nazlioglu et al. (2016). By expanding the Toda-Yamamoto framework with progressive structural changes via the Fourier technique, the test presents a new and straightforward approach to accounting for breakdowns in Granger causality analysis. This procedure does not require prior knowledge of the number of breaks, their date, and their shape. A single Fourier frequency reflects several breaks in the deterministic components, regardless of the breaks' date, quantity, or form (Becker et al., 2006). In the process, Nazlioglu et al. (2016) employed a single frequency component and defined $\alpha(t)$ as follows:

$$\alpha(t) = \alpha_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \quad (2)$$

Nazlioglu et al. (2016) developed the model shown in Eq. (4) by adding the Fourier equation in Eq. (2) to the VAR model specified in Eq. (3).

$$y_t = \alpha(t) + \vartheta_1 y_{t-1} + \dots + \vartheta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (3)$$

$$y_t = \alpha_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \vartheta_1 y_{t-1} + \dots + \vartheta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (4)$$

The null hypothesis developed for this test is that there is no causality.

For the panel Fourier Toda-Yamamoto causality test, the Fisher test statistic is as follows (Eq. (5)):

$$FTYP = -2 \sum_{i=1}^N \ln(p_i^*) \quad (5)$$

In Eq. (5), p_i^* represents the bootstrapping p values corresponding to the Wald statistic for the i 'th individual slice. The bootstrap technique (Emirmahmutoglu & Kose, 2011) was used to test causality in cross-section-dependent panels because the limit distribution of the Fisher test statistic would not be accurate due to cross-sectional dependence.

In addition to causality analysis, chose to use a wavelet approach. Although the Fourier transform is an important step compared to traditional causality tests, it has some limitations. Wavelet approximation is proposed as an important method to overcome the limitations of the Fourier transform. This is because more accurately localized temporal and frequency information can be obtained using wavelet analysis in studies using the Fourier transform (D. T. Lee & Yamamoto, 1994; Gençay et al., 2001; Gallegati & Semmler, 2014). In light of these explanations, the wavelet approach is preferred in this study as it is a powerful tool for time-frequency analysis.

Within the framework of the Wavelet coherence technique, the terms “long-term” and “short-term” refer to different time horizons over which relationships between variables are analyzed (Aloui & Hkiri, 2014). The long-term in the context of the Wavelet coherence technique typically refers to the analysis of relationships over extended periods that can span several years or even decades, depending on the context of the study. The short-term aspect of the Wavelet coherence technique refers to the analysis of relationships over shorter periods, such as months or a few years. This is often used to capture more immediate or transient interactions between variables.

In this study, the wavelet coherence analysis is conducted by partitioning the original time series using a sliding window function. The window function is designed to divide the time series into smaller, overlapping sections, each of which is assumed to be stationary for the duration of the window. The length of the window is selected based on the nature of the data and the desired frequency resolution, balancing the need to capture both short- and long-term relationships while ensuring local stationarity within each section. By analyzing the local frequency contents within each window, we are able to identify time-varying relationships between the variables over both short and long horizons. While Wavelet coherence analysis avoids the strict assumption of stationarity across the entire time series, as suggested by Gençay et al. (2002), it relies on the concept of local stationarity. As stated by Goswami and Chan (2011): to overcome the stationarity assumption, the original signal is partitioned into smaller segments using a specified window function. Each partitioned section is then assumed to be stationary for the duration of the window. This approach allows us to analyze the local frequency content, thereby capturing the time-varying nature of the relationships between variables while ensuring that the assumption of local stationarity holds within each window.

In this study, we employ both the Toda and Yamamoto (1995) causality test and wavelet coherence analysis to capture different aspects of the relationships between gold, agricultural commodities, and the stock market. The Toda & Yamamoto test is applied to assess Granger causality between variables, providing a robust framework for non-stationary data without requiring pre-testing for cointegration. This method is particularly useful for understanding causality over the entire sample period. In contrast, the Wavelet coherence technique allows us to detect time-varying relationships between the variables, capturing both short-term and long-term dynamics. By analyzing how the coherence between variables changes over time and across frequencies, we can gain insights into the evolving nature of causality across different time horizons. Thus, the combination of these two methods provides a comprehensive picture of both static and dynamic causal relationships.

The continuous wavelet transform (CWT) is a mathematical technique introduced in the early 1980s for analyzing inputs with characteristics that vary at different scales, such as signals or images (Goupillaud et al., 1984; Grossmann & Morlet, 1984). CWT decomposes a signal or a continuous function on a time-frequency basis through a particular class of functions called wavelets (Larnier et al., 2016). Wavelet transform signals, called mother wavelets, are decomposed based on two functions: time position (τ) and frequency. Accordingly, Torrence & Webster (1999) defined the equation of the corrected wavelet coherence coefficient as follows (Eq. (6)):

$$R_n^2(s) = \frac{|S(s^{-1} \underline{W}_n^{(f,\tau)}(s))|^2}{S(s^{-1} |\underline{W}_n^{(f,\tau)}|^2) S(s^{-1} |\underline{W}_n^{(f,\tau)}|^2)} \quad (6)$$

For the Morlet wavelet (MW), it can be represented as time (τ) and frequency (f), respectively, as in Eq. (7) (Yilanci & Pata, 2022):

$$S_\tau(\omega) = (\omega_n(s) * \lambda_1^{-t^2/2s^2}); S_f(\omega) = (\omega_n(s) * \lambda_2 \Pi((0, 6s))) \lambda_1 + \lambda_2 \quad (7)$$

Here, λ_1 and λ_2 are the normalization constants, and Π is the rectangle function. The coefficient 0.6 in the equation is the scale-averaging factor empirically determined by Torrence & Compo (1998). The

significance of the estimated wavelet coherence was determined using Monte Carlo simulations.

Next, the volatility dynamics between variables are analyzed using the Diagonal BEKK model, and optimal portfolio weights are calculated following Kroner and Ng (1998), using Eq. (8).

$$w_{ij,t} = \frac{h_{jj,t} - \zeta_{ij,t}}{h_{ii,t} - 2\zeta_{ij,t} + h_{jj,t}}, \text{ if } 0 \leq w_{ij,t} \leq 1; 0 \text{ if } w_{ij,t} < 0; 1 \text{ if } w_{ij,t} > 1 \quad (8)$$

Using Eq. (9), dynamic long/short hedge ratios between variables are calculated based on Dey and Sampath (2018).

$$\beta_{ij,t} = \frac{\zeta_{ij,t}}{h_{jj,t}} \quad (9)$$

In Eqs. (8) and (9), $h_{ii,t}$ and $h_{jj,t}$ are the conditional variance of the first and second variables and $\zeta_{ij,t}$ is the conditional covariance of these variables.

Finally, the efficiency of the hedging strategy is calculated. This efficiency is measured by the percentage reduction in the variance of the optimal portfolio compared to the unhedged portfolio. Accordingly, we calculate hedging efficiency (HE) by using Eq. (10) and (11) (Yousaf et al., 2023):

$$HE = \left[\frac{h_{unhedged} - h_{hedged}}{h_{unhedged}} \right] \quad (10)$$

$$h_{hedged} = (w_{ij,t})^2 h_{ii,t} + (1 - w_{ij,t})^2 h_{jj,t} + 2w_{ij,t}(1 - w_{ij,t}) \zeta_{ij,t} \quad (11)$$

4. Results

In Granger causality tests based on the VAR model, the main assumption is that the data considered are stationary to accurately show whether there is a cointegration correlation between the variables, to obtain significant correlations between the variables, and to eliminate the spurious regression correlation. The Toda-Yamamoto (1995) causality test is insensitive to the number of unit roots. In other words, the series must not be I(1) stationary at the first difference. However, unit root tests are needed to determine the maximum degree of cointegration (d_{max}). Since the Panel Fourier Toda-Yamamoto (PFTY) test will be used within the scope of the study, Fourier-based tests should also be used for unit root. The flexible Fourier form and Dickey-Fuller type unit root test, recommended by Enders and Lee (2012), are used for this. Given the potential for cross-sectional dependence in panel data, which arises from unobserved common factors or interactions between cross-sectional units, we incorporate tests that address this issue. For the unit root analysis, we use the Cross-sectionally Augmented Dickey-Fuller (CADF) test by Pesaran (2007), which augments the standard ADF test by including cross-sectional averages of lagged levels and first differences of the series. This approach ensures robustness to cross-sectional dependence. Furthermore, the panel Fourier Toda-Yamamoto (PFTY) causality test also addresses cross-sectional dependence by applying a bootstrap technique that adjusts for dependencies across units. This bootstrapping procedure generates critical values based on resampling, which accounts for the cross-sectional dependence between units. To address cross-sectional dependence in the panel Fourier Toda-Yamamoto causality test, we utilize a bootstrap approach. This method resamples from the residuals to create simulated datasets, allowing us to compute critical values that adjust for dependencies across cross-sectional units. This adjustment is crucial for providing accurate inference in the presence of cross-sectional dependence.

We employ the Fourier Toda & Yamamoto causality test due to its flexibility in dealing with non-stationary time series, without requiring the series to be pre-tested for cointegration. This approach is particularly advantageous given the potential structural breaks in our dataset, which are accounted for by the Fourier function. The Toda & Yamamoto method tests causality in the levels of the variables, thereby avoiding the

introduction of pretest bias that may arise from prior cointegration testing, as is required in VECM. This allows us to directly assess the causality between gold, agricultural commodities, and the stock market, even in the presence of structural breaks.

As can be seen in Table 4, while all variables are not stationary at the level (contain unit root, H0 hypothesis is accepted), all variables become stationary at the 1% level at their first difference (do not contain unit root, H0 hypothesis is rejected, H1 hypothesis is accepted). Accordingly, the maximum degree of integration was determined as 1. ($d_{max} = 1$)

At this stage of the study, the causality test and the relationship between the variables are evaluated. The results of the analysis, carried out using the causality test developed by Enders and Lee (2012), which enriches the Toda-Yamamoto procedure with the Fourier function (FTY), are shown below (Table 5).

Evaluation of the table reveals a Granger causality relationship at the 1% significance level, indicating that changes in the spot gold price lead to changes in agricultural commodity prices. Among these variables, only the BEAN variable is seen to affect gold prices at the 5% significance level, and therefore, there is a causality from BEAN to gold. In this case, there is a bidirectional causality relationship between GOLD and BEAN. Unilateral causality runs from GOLD to agricultural products for all the variables representing other agricultural commodity prices. In line with this determination, it is clear that for an investor GOLD, no benefit can be obtained from portfolio diversification by simultaneously investing in the agricultural products mentioned. Another significant result is that gold prices play an important role in determining the prices of these agricultural products. In a society like Türkiye, where increases in GOLD prices far exceed inflation, this causality in primary food products poses significant challenges for low-income citizens. This effect, detected in a society like Türkiye that can produce such agricultural products, is remarkable. Analysis results support the work done by Pindyck and Rotemberg (1990) and Kang et al. (2017). Causality has been revealed in the studies by Kumar et al. (2020) and Shahzad et al. (2021), which also discuss causality relationships that change over time. The study makes a significant contribution by confirming the literature findings through the example of Türkiye, revealing that the direction of the relationship is from gold to agricultural products, although it is double-sided in one product.

The second investment instrument discussed in this study is the relationship between the Borsa Istanbul 100 Index (BIST100) and the prices of selected agricultural commodities. In this analysis, no causal relationship was found between three related agricultural products (RICE, BEAN, and LENTIL) and the BIST100 index. A unilateral causality relationship was found between the BIST100 index and two variables representing other agricultural products (CHICKPEA and SUGAR). In one variable (FLOUR), a unidirectional causality was found from BIST100 to the variable, indicating that changes in BIST100 cause changes in FLOUR. When these data are evaluated, the critical causal relationship between agricultural products and GOLD, is not considered equally important in BIST100.

In contrast, three of the related agricultural products (RICE, BEAN, and LENTIL) are affected by GOLD prices (BEAN, which is bilaterally

causal), and the same agricultural products are not affected by the BIST100 index and do not affect the index. Therefore, for those investing in the BIST100 index, investing in these commodity groups will contribute positively to portfolio risk diversification. Another important finding is that while SUGAR and CHICKPEA prices are affected by GOLD prices, SUGAR and CHICKPEA prices affect the BIST100 index. This is an important finding. Since SUGAR is considered an investment tool in the Turkish market, it has an unusual effect on the market. Flour, which draws attention as an essential export product, is affected by the BIST100 index and gold prices. In the literature, studies such as those by Gorton and Rouwenhorst (2006) and Bekiros et al. (2016) state that agricultural products and stock prices have changing relationships over time. This study shows that some agricultural products affect or are affected by the BIST100 index, whereas some agricultural products have no causal relationship with it.

In the next stage, Wavelet coherence (WTC) analysis was performed. The partitioning of the time series using the window function allows us to examine time-varying relationships between the variables under the assumption of local stationarity. The choice of window length plays a critical role in capturing both short-term and long-term dynamics. Our analysis shows that the relationships between agricultural commodities, gold prices, and the stock market vary significantly over different time scales, as revealed by the coherence patterns within the partitioned sections of the series.

The results of the Toda & Yamamoto causality test indicate significant time-invariant causality between gold prices and agricultural commodity prices, suggesting that gold plays a pivotal role in driving agricultural market dynamics over the entire sample period. However, to capture the evolving nature of these relationships, we also conducted wavelet coherence analysis, which reveals time-varying causal patterns. The wavelet analysis shows that the strength and direction of causality between gold and agricultural commodities fluctuates over time, particularly during periods of market stress or economic shocks. These time-varying causal relationships are not captured by the Toda & Yamamoto test, underscoring the value of using both methods, to provide a fuller understanding of the dynamic interconnections between the variables.

According to the WTC analysis results, the left axis shows the frequency density between 0 and 64. On the right axis, values between 0.0 and -0.8 represent the intensity of the relationship. The colors in Fig. 2, i.e., red, yellow, green, and blue, represent lower coherence. The areas shown with black lines in the figures indicate the presence of a significant relationship. The horizontal axis in the figures shows the years between 2005 and 2023. Finally, the direction of the arrows inside the islets, where a significant relationship is found in the figures, shows the correlation. Arrows pointing down and to the left indicate a negative correlation, while arrows pointing up and to the right indicate a positive correlation. Based on this information, the relationship between RICE, FLOUR, BEAN, CHICKPEA, LENTIL, SUGAR commodities, and GOLD and BIST 100 variables is analyzed.

While Wavelet coherence analysis provides valuable insights into time-varying causality, the Toda and Yamamoto test offers important

Table 4
Panel unit root test results.

	Variables	Level			The first difference			
		ADF-stat	Freq.	Chos. Lags	ADF-stat	Freq.	Chos. Lags	
SELECTED FOOD PRODUCTS	RICE	1.586	4	1	-9.268	4	0	***
	FLOUR	2.486	5	1	-12.183	5	0	***
	BEAN	0.689	3	1	-8.045	4	1	***
	CHICKPEA	-0.066	3	1	-8.270	3	0	***
	LENTIL	0.764	3	1	-7.402	3	0	***
	SUGAR	2.860	5	1	-10.262	5	0	***
INVESTMENT TOOLS	GOLD	0.150	1	1	-10.833	1	1	***
	BIST100	0.744	3	0	-14.105	3	0	***

Note. "****" represents significance at 1% level. The model was evaluated as a break in level, and lag lengths were determined by the Akaike Information Criteria.

Table 5

FTY causality test results.

Variable	H0: Variable $\nrightarrow$ GOLD				H0: GOLD $\nrightarrow$ Variable				Causality		
	F	p	Lag	Freq.	F	p	Lag	Freq.			
RICE	4.150	0.130	2	1	12.625***	0.006	2	1	VRB	$\leftarrow$	GOLD
FLOUR	0.549	0.738	2	2	9.662**	0.010	2	2	VRB	$\leftarrow$	GOLD
BEAN	10.579**	0.027	4	3	19.459***	0.001	4	3	VRB	$\leftrightarrow$	GOLD
CHICKPEA	6.208	0.167	4	3	19.739***	0.003	4	3	VRB	$\leftarrow$	GOLD
LENTIL	0.047	0.977	2	3	13.992***	0.002	2	3	VRB	$\leftarrow$	GOLD
SUGAR	5.276	0.516	6	2	31.612***	<0.001	6	2	VRB	$\leftarrow$	GOLD
Variable	H0: Variable $\nrightarrow$ BIST100				H0: BIST100 $\nrightarrow$ Variable				Causality		
	F	p	Lag	Freq.	F	p	Lag	Freq.			
RICE	4.296	0.141	2	3	0.865	0.648	2	3	VRB	$\leftrightarrow$	BIST100
FLOUR	3.239	0.192	2	3	5.875*	0.052	2	3	VRB	$\leftarrow$	BIST100
BEAN	1.367	0.524	2	3	0.385	0.802	2	3	VRB	$\leftrightarrow$	BIST100
CHICKPEA	8.297**	0.023	2	3	0.183	0.906	2	3	VRB	$\rightarrow$	BIST100
LENTIL	6.115	0.118	3	3	3.779	0.293	3	3	VRB	$\leftrightarrow$	BIST100
SUGAR	10.765*	0.070	5	3	7.209	0.246	5	3	VRB	$\rightarrow$	BIST100

Note. $\nrightarrow$ Granger states the H0 hypothesis, which indicates non-causality. “*”, “**”, and “***” denote significance at the 10%, 5%, and 1% levels, respectively. “ $\rightarrow$ ” and “ $\leftarrow$ ” indicate unidirectional causality, “ $\leftrightarrow$ ” indicates bidirectional causality, and “ $\leftrightarrow$ ” indicates that there is no causal link between the variables.

information about time-invariant causal relationships. This is particularly relevant when analyzing long-term investment strategies or policy implications, where understanding consistent, long-term causal relationships between variables is essential. Therefore, using both methods allows us to provide a more holistic analysis, offering insights into both persistent and evolving causal relationships.

The use of a window function to partition the original time series into smaller, locally stationary sections provides a more flexible framework for analyzing the time-varying relationships between agricultural commodities, gold, and stock markets. This approach allows us to capture both short-term fluctuations and long-term trends, while adhering to the assumption of local stationarity within each window. Our findings indicate that these relationships are not constant over time but instead fluctuate depending on market conditions and external factors, as captured by the localized frequency contents of the time series.

The relationship between RICE and GOLD variables is observed at different frequencies, and low intensities, in different years. The relationship with a frequency intensity of 4–16 between 2005–2010 and 2017–2023 is also observed, towards the end of the analysis period. The downward direction of the arrows indicates that the correlation of this low frequency, but significant relationship is negative.

When the relationship between FLOUR and GOLD variables is analyzed, no significant relationship is observed in the first 5 years at the beginning of the analysis period. Between 2008 and 2014, and between 2018 and 2023 towards the end of the analysis period, a significant relationship with above-average frequency density is observed. The direction of the arrows implies that the correlation in this significant relationship is positive.

When the relationship between BEAN and GOLD variables is analyzed, a relationship is observed at a frequency intensity of 64, which is the high-frequency level throughout the analysis period. This relationship is significant, and the direction of the correlation is negative.

At the beginning of the analysis period, there is a medium frequency and a negative relationship between the CHICKPEA and GOLD variables. However, towards the end of the analysis period, the intensity of frequency increases, especially after 2019. Apart from the frequency intensity change, the correlation's direction in the relationship also changes from negative to positive.

The LENTIL and GOLD variables have a similar relationship to the one between CHICKPEA and GOLD. While there is a significant relationship between low frequency and negative correlation in 2007–2008, a relationship is observed towards the end of the analysis period, especially after 2018, at a frequency density between 16 and 32, considered above the average frequency density. When the direction of the

correlation in this relationship is analyzed, a positive correlation is observed.

The last relationship between GOLD and agricultural commodities pertains to SUGAR. The analysis of the relationship between sugar and gold variables reveals a weaker and lower relationship compared to the relationship with other commodities. The limited relationship between these two variables is more intense towards the end of the analysis period in 2020 and beyond. The direction of the correlation of this limited relationship is negative with a moderate intensity.

While analyzing the relationship between BIST100 and agricultural commodities, the first analysis involves the RICE and BIST100 variables. The relationship between RICE and BIST100 variables is significant in the 0–32 frequency range, between 2005 and 2009, at the beginning of the analysis period. In this relationship's correlation direction, there is a positive relationship at low frequencies but a negative relationship at above-average frequency density.

The relationship between FLOUR and BIST100 variables is similar to that between RICE and BIST100. At the beginning of the analysis period, a positive correlation exists at frequencies below the average frequency density. In contrast, in regions above the average frequency, the direction of the correlation becomes negative. Towards the end of the analysis period, there is a minimal but significant relationship with the rice variable.

When the relationship between the BEAN and BIST100 variables is analyzed, there is a more significant and intense correlation than that between the FLOUR and RICE variables. While there was a negative correlation at the beginning of the analysis period, it is seen that the negative relationship continues in low-frequency data in the middle of the analysis period. Still, between 2014 and 2022, the frequency intensity of the relationship increased; the direction of the correlation turned from negative to positive with this increase.

When the relationship between CHICKPEA and BIST100 variables is analyzed, there is no significant relationship at the beginning and end of the analysis period. In the middle of the analysis period, a relationship is observed between the years 2013–2019, characterized by a frequency density that is below the average yet significant, and the direction of the correlation is positive.

LENTIL and BIST100 variables are the most intense and significant relationship between agricultural commodities other than BEAN and BIST100. At the beginning of the analysis period, there was a high-frequency and long-lasting correlation between 2005 and 2014, characterized by a negatively directed correlation. Especially after 2014, there has been a decrease in the frequency of the relationship, but the direction of the correlation has turned from negative to positive.

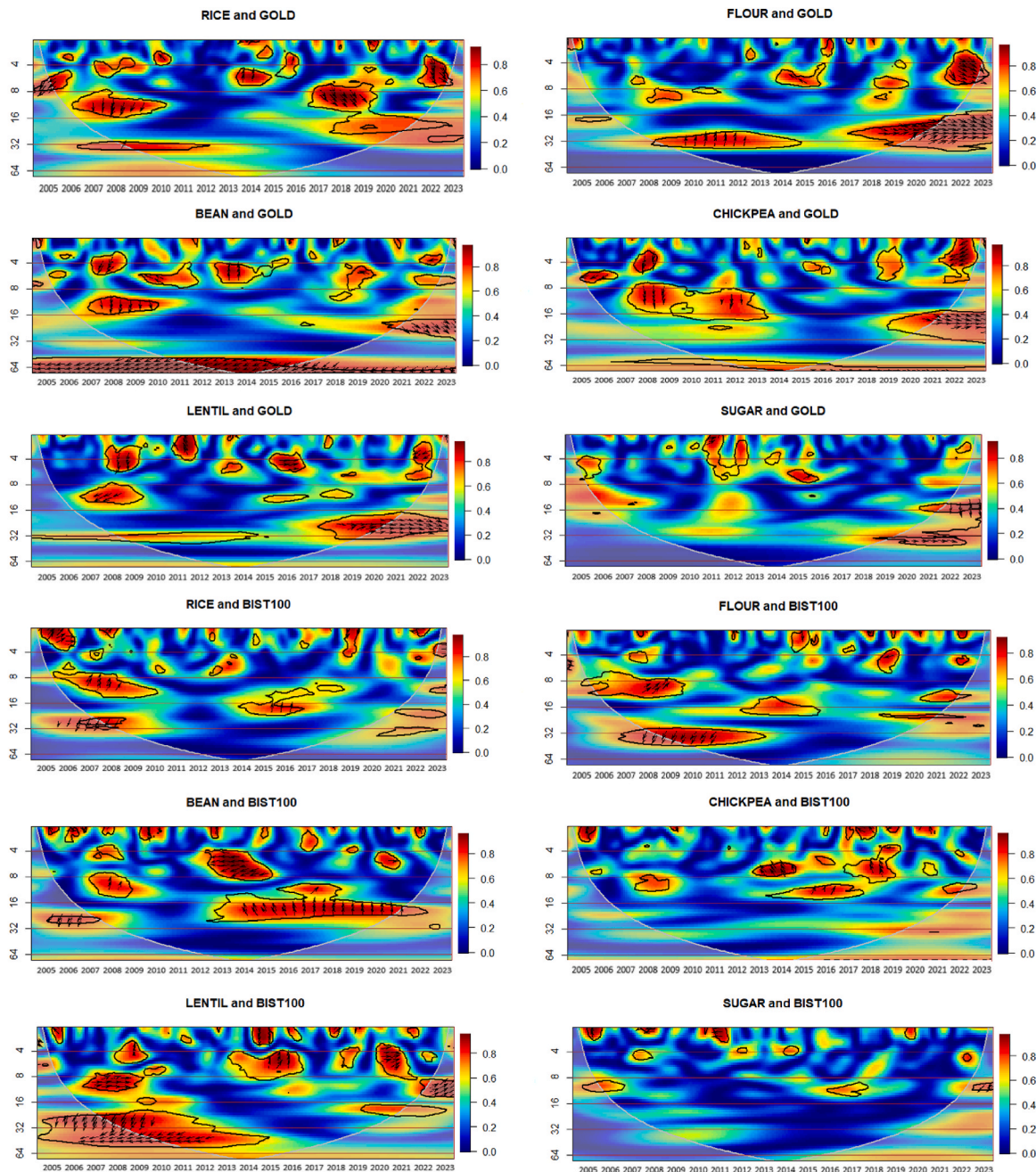


Fig. 2. Results of the WTC analysis.

The correlation between SUGAR and BIST100 is the least significant among the relationships between various agricultural commodities and BIST100. There is low-frequency density, and low significance level correlations. However, this level of correlation does not even allow for a precise determination of the direction of the correlation. At the end of the analysis period, 2023, there is a negative correlation between low-frequency intensity and another variable, though the level of statistical significance is relatively low. Similar situations with very low-frequency intensity can be mentioned similar situations with very low-frequency intensity for 2005, 2008, and 2011.

When all these analyses are considered together, a unilateral causal relationship from gold to agricultural products has changed over time for all of the variables representing commodity prices. This change is observed for RICE with a negative correlation between 2005–2010 and 2017–2023; for FLOUR with a positive correlation between 2008–2014 and 2018–2023; for BEAN in almost all periods for CHICKPEA with

negative correlation in the first periods between 2005 and 2013 and after 2019, with a positive correlation in the following periods; for LENTIL with positive correlation between 2007 and 2008 and after 2018; for SUGAR, especially in 2020 and afterward, in negative correlation. Although the results of neutrality suggest that an investor who invests in gold cannot benefit from investing in these agricultural products at the same time in terms of reducing risk, the results of the WTC analysis show that gold and commodity investments can be used for portfolio diversification, depending on time.

In terms of the BIST100, causality analyses reveal no causality relationship between three agricultural products (RICE, BEAN, and LENTIL) and the BIST100 index. However, there is a unilateral causality relationship from two variables, representing other agricultural products (CHICKPEA and SUGAR), the BIST100 index, and a unilateral causality relationship from the BIST100 to the variable (FLOUR). When the results of the wavelet coherence analysis (WTC) are evaluated, it is

seen that the causality relationship changes over time. Accordingly, for RICE, there is a positive relationship between 2005 and 2009, at low frequencies, but a negative relationship at frequency intensity above the average. FLOUR has a relationship similar to rice. For BEAN, the frequency relationship is more significant and intense than with the FLOUR and RICE variables. While there is a negative correlation at the beginning of the analysis period, this negative relationship continues in low-frequency relationships in the middle of the analysis period. Still, between 2014 and 2022, the strength of the relationship has increased. The direction of the correlation turns from negative to positive with this increase. There is very little correlation for CHICKPEA compared to other agricultural commodities in the middle of the analysis period, resulting in a positive correlation. For LENTIL, there is a high-frequency relationship at the beginning of the analysis period and a long-lasting negative correlation between 2005 and 2014. After 2014, the frequency intensity of the relationship decreases, and the direction of the correlation turns from negative to positive. Finally, the least significant relationship exists for SUGAR. The results of the WPC analysis show that time-dependent BIST100 and agricultural commodity investments can be used for portfolio diversification. Especially sugar and chickpea stand out here. While there is a causality with BIST100 in causality analyses, WPC analysis reveals that this relationship is weak and valid for a limited period. Again, WTC analysis showed that for RICE, where a causality relationship could not be detected, periodic relationships occur; while for BEAN and LENTIL, periodic but more intense relationships could be observed. For FLOUR, WTC analysis showed that periodic relationships could be observed for which a unilateral causality relationship was detected from BIST100 to FLOUR. Taken together, the results of the WTC analysis suggest that BIST100 and agricultural commodity investments can be used for portfolio diversification over time.

Next, the volatility dynamics between variables are analyzed using the Diagonal BEKK model, and optimal portfolio weights are calculated following Kroner and Ng (1998). For this purpose, the study determines that it has a problem of varying variance, which is eliminated with the Diagonal BEKK model. As shown in Table 3, while all variables are non-stationary at their level, they become stationary at the 1% level in their first differences. When our study data is evaluated, using the Diagonal BEKK model is deemed appropriate since it considers time-varying volatility and correlation and satisfies the positivity condition. The Diagonal BEKK model has fewer parameters and therefore has more appropriate degrees of freedom and has been used in many studies in the literature (Brik et al., 2022; Katsiampa, 2019; Mezghani et al., 2021; Riaz et al., 2023).

The optimal portfolio weights following Kroner and Ng (1998), the dynamic long/short hedge ratios between variables based on Dey and Sampath (2018), and finally, the effectiveness of the hedging strategy are presented in Table 6.

Table 6
Portfolio analysis.

Group	Variables	Portfolio Weights	Hedge Ratio.	Hedging Effectiveness
GOLD	RICE/GOLD	0.54	−0.08	0.19
	FLOUR/GOLD	0.28	−0.09	0.43
	BEAN/GOLD	0.38	−0.02	0.46
	CHICKPEA/GOLD	0.37	0.05	0.42
	LENTIL/GOLD	0.23	−0.01	0.38
	SUGAR/GOLD	0.60	0.12	−0.22
BIST100	RICE/BIST100	0.64	0.26	−0.39
	FLOUR/BIST100	0.31	0.14	0.27
	BEAN/BIST100	0.45	0.03	0.4
	CHICKPEA/BIST100	0.44	−0.12	0.45
	LENTIL/BIST100	0.24	0.07	0.35
	SUGAR/BIST100	0.64	−0.03	−0.78

Table 6 shows that the average weight of the CHICKPEA/GOLD portfolio is 0.37, indicating for a 1-unit portfolio, 0.37 units should be invested in the CHICKPEA commodity and 0.63 units in the GOLD asset. Similarly, the average weights of the RICE/GOLD, FLOUR/GOLD, and BEAN/GOLD portfolios are 0.54, 0.28, and 0.38, respectively. The average weights of other variables with the presence of GOLD, are also shown in the table. The portfolio weights of the BIST100 variable and other agricultural commodity instruments show that the average weight of the FLOUR/BIST100 portfolio is 0.31, which means that for a 1-unit portfolio, 0.31 units should be invested in the FLOUR commodity and 0.69 units in the BIST100 index. Table 6 shows the average weights of the other variables, together with the BIST100 index. When the Hedge Ratio values are analyzed, it is evident that the values are negative for all agricultural commodities except CHICKPEA and SUGAR when invested with the GOLD asset. The value is positive for all agricultural commodities, except CHICKPEA and SUGAR, which are co-invested with the BIST100 index. This shows that hedging in bilateral investments with negative hedge ratio values does not require taking short positions in each asset. When hedging effectiveness values are evaluated, agricultural commodities' hedging effectiveness is negative for SUGAR in the GOLD group and RICE, and SUGAR in the BIST100 group. This shows that all investment dichotomies can help reduce portfolio risk, except for dichotomous investment instruments with negative outcomes.

5. Conclusion

This study examines the relationship between the spot prices of some primary food products (BEAN, CHICKPEA, FLOUR, LENTIL, RICE, SUGAR) and the spot GOLD price and Borsa Istanbul 100 (BIST100) index from January 2005 to February 2023 in Türkiye. The main purpose of the study is to reveal the relationship between agricultural commodity prices, spot GOLD prices, and the BIST100 index. On the other hand, it aims to evaluate the potential of agricultural products as an alternative investment tool. It is thought that the future results to be revealed will be an essential guide for investors' portfolio diversification decisions. Additionally, the study provides important data regarding policymakers' evaluation of the factors affecting the price mechanisms of agricultural products. The most important limitation of the study is that it was conducted only on the Turkish sample. In addition, only the relationship between the variables considered in the study was evaluated, and other factors and relationships were excluded. Therefore, other variables may have possible effects. In addition, various economic crises and fluctuations are experienced during this period, and possible changes in these abnormal periods are also outside the scope of this study. Addressing these limitations in future studies and different country samples is essential for improving the study results, and we recommend this approach.

By combining the Toda & Yamamoto causality test with Wavelet coherence analysis, we offer a comprehensive approach to understanding the relationships between gold, agricultural commodities, and the stock market. The Toda & Yamamoto test captures stable, time-invariant causality, while wavelet analysis allows us to explore the dynamic, time-varying relationships between variables. This dual approach enriches the analysis, providing insights into both the long-term and short-term interactions that are critical for investors and policymakers alike.

The empirical results presented in this study provide strong evidence for the impact of gold prices on agricultural commodity prices. The results of the study support the literature revealing the effect of GOLD prices on agricultural commodity prices (Pindyck and Rotemberg (1990), Kang et al. (2017), Kumar et al. (2020), and Shahzad et al. (2021)). This study highlights an important finding in terms of the direction of causality. Gold affects the commodity prices discussed in this study. There is a bilateral causality relationship only between GOLD and BEAN. For other commodities (chickpea, flour, lentil, rice, sugar), there is a unilateral causality relationship toward food products evaluated in terms of their value relative to gold. This result is crucial in identifying

the critical role of gold prices in determining the prices of agricultural products. It is critical for policymakers trying to manage economic development processes to consider this effect of GOLD, in terms of ensuring that low-income citizens have access to agricultural products. The results of the causality analysis also reveal that investing in the agricultural products considered in the analysis would not have a risk mitigation function in portfolio diversification for an investor who invests in gold. However, this result is not valid for all periods. The wavelet coherence analysis (WTC) results reveal that gold and agricultural commodity prices may have a risk mitigation function in terms of portfolio diversification over time.

Another significant result revealed in the study is that the Borsa Istanbul 100 (BIST100) index partially affects agricultural commodity prices, unlike the stronger influence of gold on these prices. The analyses found no causal relationship between three agricultural products (RICE, BEAN, and LENTIL) and the BIST100 index. This result shows that these three agricultural products can be used for risk reduction and portfolio diversification with the BIST100 index for investors. A unilateral causal relationship was found between other agricultural products (CHICKPEA, SUGAR, and FLOUR) and the BIST100 index. Another important finding is that while SUGAR and CHICKPEA prices are affected by GOLD prices, they affect the BIST100 index. This finding is critical. Especially since SUGAR is considered an investment tool in the Turkish market, it has a significant impact on the market. Investors who have already evaluated the relationship between GOLD and SUGAR in the current commodity markets, in Türkiye, consider SUGAR to be a security or cash. This effect may partially explain its influence on BIST100. Flour, which is an important agricultural export, is affected by the gold prices and the BIST100 index. It is critical for policymakers in Türkiye, a vital flour exporter, to consider this feature of FLOUR. Similar to the results for GOLD, the wavelet coherence analysis (WTC), results reveal that BIST100 and agricultural commodity prices may exhibit a risk mitigation function for portfolio diversification over time.

Additionally, the portfolio analysis underscores the intricate dynamics of asset allocation and hedging strategies. The weights and hedge ratios illuminate the nuanced relationships between commodities and indices. While some combinations show promising hedging effectiveness, others reveal challenges, highlighting the complexity inherent in portfolio management and risk mitigation.

Our results suggest that designing integrated strategic plans for the money markets, capital markets, and the agricultural sectors is crucial for country governments. The study also provides essential portfolio diversification and risk mitigation results for investors. The study results provide significant findings, especially for public authorities and policymakers. In line with these results, it is necessary to strengthen the country's commodity exchanges, make the internet infrastructure suitable, and improve the electronic commodity representation documents used in these markets. It is also essential that these efforts are appropriately communicated to the public and investors through appropriate measures. In addition, agricultural commodities are essential because they serve as basic foodstuffs. Commodity stocks held as investment instruments in times of war and famine will strengthen the country against difficult periods. Although this situation is undesirable, it also has the potential to generate additional returns for investors. In future studies, it would be appropriate to examine the periodic changes in causality (especially during crisis periods) by focusing on the Turkish case. In addition, comparing the results obtained in the Turkish case with those in other countries, will significantly contribute to the literature and stakeholders.

Author contribution statement

Title of the manuscript: Connections between gold, main agricultural commodities, and Turkish stock markets.

Hasan Kazak, Abdullah Kilicarslan, and Ahmet Tayfur Akcan have contributed jointly to the conceptualization, data collection, analysis,

and interpretation; Hasan Kazak, Walid Mensi, Mehmet Akif Gunduz, and Ahmet Tayfur Akcan have contributed jointly to the research design and composition of this study.

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