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Hedging Strategies Involving Agricultural Commodities: A Systematic Review of Literature

The volatility of agricultural commodity prices, elevated by the COVID-19 pandemic and geopolitical conflicts, has reinforced the importance of hedging strategies for producers, investors, and policymakers. This article presents a systematic review of literature of sixty-six articles published between 2015 and 2024, identified through PRISMA procedures and organized with a structured classification framework.

The evidence shows that futures contracts, especially for grains such as soybeans and corn, are the predominant hedging instruments, with GARCH-type models most frequently employed to capture volatility and estimate hedge ratios. VAR and VEC models also play an important role in examining dynamic interactions and long-run linkages between spot and futures markets.

A major finding is the near absence of machine learning and artificial intelligence methods, despite their potential to capture nonlinearities and enhance forecasting performance. Additional research gaps include the poor study of frontier markets, the need for locally adapted derivatives in emerging economies, the influence of logistics and fuel costs, and the marginal use of cross-hedging and alternative assets.

By consolidating fragmented evidence, this study not only clarifies the intellectual structure of the field but also contributes by outlining research priorities that can advance hedge effectiveness in agricultural commodity markets.

Keywords: Agricultural commodities; futures; hedge effectiveness;systematic review.

Authors:

MARCIO YUKIO SHIMADA

ELI HADAD JUNIOR

MARCELO NEVES GONÇALVES

LEONRADO CRUZ BASSO

DANIELA PASCHOAL NEVES

1. Introduction

The inherent risk in global grain price volatility attracts attention from academics, farmers, investors, agricultural retailers, and grain companies alike. In the last ten years, grain prices have suffered extreme fluctuations due to the COVID-19 pandemic from 2020 to 2022, the Russian-Ukrainian conflict since 2022, and the tariff war in early 2025(Huidan Xue, 2024)

Hedging is vital to managing price and income risk in agriculture, and future contracts allow all market participants to protect themselves from adverse price movements by transferring price risk to other market participants, providing a path to minimize market price risk and stabilize income (Penone et al., 2021). The pursuit of hedge efficiency by companies for value creation and preservation, especially on a highly volatile basis, demands the development of effective strategies for mitigating market risk (Nardino and Figueiredo, 2022).

The hedge in agricultural commodities has traditionally considered the derivative as the most optimal proxy for the producer's inventory price; rational hedging depends on the derivative contract to reduce the variability of the producer's position (Ouzan & Six, 2024)The search for variability reduction led to the development of the first techniques, such as the minimum-variance hedge ratio; however, this approach penalizes both upside and downside deviations from the mean equally. Sequential approaches explored the time and horizon effects in the hedge ratio, leading to the extensive use of econometrics models to enhance hedge effectiveness models.(Sadefo Kamdem & Moumouni, 2020).

Although the Law of One Price drives to a parallel behavior of cash and derivative prices, converging to a standard price at maturity, many factors, ranging from futures contracts mismatches to logistic issues, may cause the absence of tandem movements and even the non-convergence of cash prices at the expiry derivative date (Goswami et al., 2023).

Moreover, the myriad combinations of hedge instruments, ranging from exchange futures to over-the-counter options and swaps, along with cross-hedge or spot/market, are available. Attached to different quantitative hedge ratios and various calculation methods, all these combinations demand a multidimensional approach to evaluate their impact on market risk management. This complexity necessitates a thorough examination of existing literature to identify best practices and innovative strategies that can enhance hedging effectiveness in the agricultural market.

Despite the undeniable contributions that pricing and hedging models have made to modern financial theory, a scarcity of synthesized knowledge remains regarding the components and intellectual boundaries of pricing and risk management theories(Gairola & Dey, 2023).

To address this need, we propose a systematic review of the literature to clarify the intellectual structure, research trends, and directions for future research associated with hedge effectiveness in volatile agricultural markets. Besides, our purpose is to pave the way for future empirical studies, opening avenues of knowledge in the theme, presenting as contribution research priorities that can enhance hedging strategies involving agricultural commodities.

RQ1. What forecasting models are commonly applied to estimate the hedge effectiveness on agricultural commodities in hedging strategies?

RQ2. What methodological market approaches are most frequently used to operate hedging in the context of agricultural commodities?

RQ3. What are the notable gaps or under-researched areas regarding hedging involving agricultural commodities?

The remainder of the article is organized as follows. Section 2 presents a literature review of hedging derivatives in the agricultural commodities market. Section 3 introduces our methodology. Section 4 presents systematic literature review results and discussion, and Section 5 concludes with limitations, gaps, and future research directions.

2. Literature review

The theoretical framework for hedging derivatives in agricultural markets provides the foundation for Modern Portfolio Theory (hereafter MPT), specifically in the application of futures as hedging instruments within the Law of One Price (hereafter LOP).

The LOP suggests that identical goods should sell for the same price when expressed in a common currency, considering transportation and logistical costs. However, empirical evidence often shows deviations from this law due to various factors such as transaction costs, tariffs, and market imperfections (Hazelkorn et al., 2023).

In the context of futures and spot markets, convergence is typically observed as the futures contract approaches maturity, driven by arbitrage activities that exploit price discrepancies. This is supported by the cost of carrying models, which propose that the futures price of a stock index should equal the spot price plus carrying costs, adjusted for dividends (in the case of stocks). Such imperfections in the market can create arbitrage opportunities (Mandal & Agarwal, 2014).

Violations of the LOP may also arise due to intermediation costs and liquidity issues, particularly those related to demand pressures on equity index pricing. Although the study by Hazelkorn et al. (2023) focuses on the stock market, it claims that violations of the LOP also occur across other asset classes. Deviations from the LOP can be commodity-specific and caused by factors such as exchange rates and local market conditions (Protopapadakis & Stoll, 1983).

MPT (Markowitz, 1952) can indeed be adapted to the characteristics of the agricultural commodity markets' hedging process through some considerations. If farmers (hedgers) are infinitely risk-averse, and the expected value and variance are the factors that would drive their choice, the minimization of the standard deviation of the hedge portfolio would be analogous to the maximization of the farmer's (producer) expected utility (Penone et al., 2021).

Although not the central objective of this study, the pursuit of an optimal return–variance trade-off, as advocated by MPT, provides a robust theoretical underpinning for hedging strategies. Simultaneously, the use of futures contracts emerges as a crucial instrument for achieving hedge effectiveness, owing to their solid theoretical foundation in the LOP and the liquidity of derivative markets.

LOP and MPT support the pricing and risk-return driving commodity prices through no arbitrage principles; nevertheless, the test of theory propels the development of economic models of empirical phenomena (Hendry & Doornik, 2014) . Specifically, there is a tremendous amount of empirical evidence on futures hedging in commodity markets(Białkowski et al., 2023a).

Hedging effectiveness in commodity markets using futures assumes a protagonist position and shall be measured by quantitative tools and econometrics artefacts proving their accuracy. In tandem with this spirit, forecasting models for the relationship between futures and spot prices of agricultural commodities play a crucial role in hedging activities, as they help determine the optimal hedge ratio and assess hedging effectiveness. The Ordinary Least Squares (hereafter OLS) regression model is commonly used to estimate the optimal hedge ratio by analyzing the covariance and variance of spot and futures returns, which is essential for minimizing the variance of the hedged portfolio(Białkowski et al., 2023; Huang & Xiong, 2024; Penone et al., 2021).

Ordinary Least Squares (OLS) models are more susceptible to endogeneity issues, which can be mitigated by employing multivariate models such as Vector Autoregressive (hereafter VAR) and Vector Error Correction (hereafter VEC) models. VAR and VEC models are system-based approaches that can analyze the relationship between multiple time-series variables, such as cash and future prices of commodities(Spencer et al., 2018).

Cointegration is formally interpreted as the existence of a stationary linear combination among nonstationary variables, implying a long-run equilibrium relationship (Mandal & Agarwal, 2014). When such a relation is detected between futures and spot prices, it indicates convergence in the sense that deviations from the equilibrium are mean-reverting, thereby constraining persistent arbitrage opportunities and supporting the presence of a stable long-run linkage between the two markets (Roll et al., 2007).

However, the OLS model assumes constant risk over time, which may not always be realistic. To address this, more sophisticated models, such as the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model and its variants, including multivariate GARCH models, are employed to capture variance and correlations between spot and futures prices on a time-varying basis (Vollmer & Von Cramon-Taubadel, 2020; Zuppiroli & Revoredo-Giha, 2016). These late approaches led the way for dynamic hedge techniques.

Among the econometric techniques employed are the BEKK-GARCH and DCC-GARCH models, both of which provide a dynamic, time-varying framework for modeling the variance and covariance of the series. Each model is specifically designed to capture evolving volatility structures over time (Diego Pitta de Jesus et al., 2021; Izadi & Hassan, 2018). Although copulas functions such as Gumbel or Franck, for cultures like wheat, surpassed DCC-GARCH models in a range of 11% to 29%(Louhichi & Rais, 2019).

Another approach is the quantile regression, which can analyze how hedge ratios vary across the distribution(quantiles) of spot returns, revealing that for agricultural commodities, the quantile hedge ratio displays an inverted U-shape, being smaller at the extreme tails of the spot return distribution (Lien et al., 2016).

The diversity of results derived from the econometric models is vast, although some basic premises from economic theory, like LOP, underpin the no-arbitrage properties of pricing spot and derivatives markets. This relationship is usually revealed near expiry dates. The dynamic relationship between a financial derivative and the spot market is influenced by numerous factors throughout its existence, such as the type of asset, time period, and logistics aspects.

3. Methodology

The literature review underpins the theory of scientific academic research by synthesizing existing knowledge within a specific field. Over the past decade, reviews based on systematic investigations with a quantitative nature and free from selection bias have gained prominence (Donthu et al., 2021).

The use of quantitative techniques not only eliminates subjectivity and personal bias in the selection of relevant articles but also enables the handling of vast amounts of data. This paper adopts the procedures used by Jabbour (2013) and his five steps:

1) Identify the most significant articles that focus on hedging using futures in agricultural commodities.
2) Develop a classification and coding framework
3) Search for study trends on deviation detection by using the coding framework
4) Analyze and discuss the strengths and limitations of the existing literature on environmental training
5) Propose a future research agenda and conceptual framework to address the significant gaps in current knowledge related to hedging using futures in agricultural commodities.

3.1. Identification of literature for inclusion and exclusion

The selected databases were Web of Science (hereafter referred to as WoS) and Scopus. The search process was carefully documented to ensure the absence of subjectivity in the search procedures and to allow replication by other researchers (Linnenluecke et al., 2020). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) in Figure 1 was applied to ensure transparency.

The definition of search terms was based on Research Questions; however, keeping a broad scope of capture, using the following keywords for data extraction from the databases: (I) commod* and its variants, AND (II) hedg* and its variants, AND (III) future* and its variants. This closed set ((I) AND (II) AND (III)) was restrictively combined via AND with an additive set composed of the keywords (IV) ratio OR (V) basis, resulting in the following search query:

(commod* AND hedg* AND future*) AND (ratio OR basis)

The search on the WoS and Scopus databases was conducted on February 11, 2025. A total of 276 records were retrieved from WoS and 217 from Scopus. The initial filtering process used the native tools of each database. Only journal articles were considered, and just publications from the years 2015 to 2024 were retained. This timespan was chosen as it encompasses the major crises in soy and corn crops in Brazil, which, as a major producer, affected global prices: 2017 Brazil´s truck drivers' strike, 2018/2022 presidential election, and 2020/2021 COVID-19 pandemic. Subsequently, only specific subject categories were included: for WoS, the categories *Business Finance*, *Economics*, *Management*, or *Business*; and for Scopus, the categories *Economics, Econometrics and Finance*, *Business*, *Management*, and *Accounting* were selected.

Regarding language criteria, only articles written in English and Portuguese were selected. Brazilian cases play a prominent role in the global agricultural commodities market, maintaining a strong connection with hedging structures involving futures and spot markets for agribusiness assets. Thus, in the WoS database, two articles in Portuguese were retained. In the Scopus database, one article in Spanish and another in German were excluded.

3.1. Removal of duplicates

The data cleaning process began with the elimination of duplicate records identified in both databases. To address overlapping results between WoS and Scopus, the R-Studio environment was employed. This step reduced the initial dataset from a total of 227 articles (130 from WoS and 97 from Scopus) to a unified set of 154 unique articles.

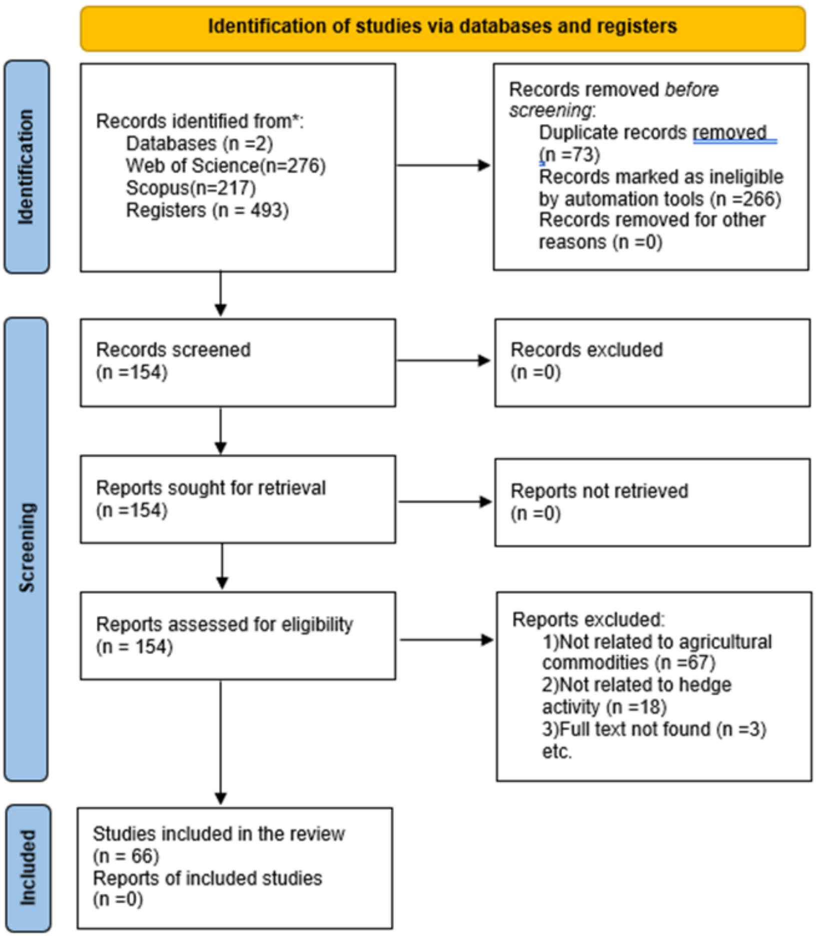

Figure 1- PRISMA Flow

Source: author

3.2. Deletion of Articles Not Related to Agricultural Commodities (Criterion I)

In Stage 3.2, a filtering process was conducted to retain only those articles that involved the agricultural commodities market. For this purpose, *Criterion I* was established, which consisted of reviewing the titles, abstracts, and keywords of all 154 articles to verify the use of quantitative data related to at least one agricultural commodity.

When necessary, a partial or complete reading of the article was carried out (this was the case for 28 articles) to accurately assess whether an agricultural commodity was indeed the underlying asset addressed in the study.

As a result of applying *Criterion I*, 67 articles were excluded from the initial set of 154, leaving 87 articles directly related to agricultural commodities. The excluded articles dealt exclusively with non-agricultural commodities, including 10 articles on precious and base metals (such as copper, aluminum, zinc, lead, and tin), 10 articles on oil and its derivatives (including natural gas and heating oil), and nine articles focused solely on crude oil. Other exclusions included five articles on stocks and metals, four articles that addressed stocks, oil, and metals together, three articles on stocks alone, three articles on stocks and oil, and three articles on the real estate market.

3.3. Deletion of Articles Related to Agricultural Commodities but Unrelated to Hedging (Criterion II):

To ensure the quality and alignment of the selected articles with the research questions, *Criterion II* was established. Following a second round of reading, focusing on abstracts, titles, and in some cases, partial content of the articles, those that did not present hedging as their objective (i.e., protection against price fluctuations of underlying assets inherent to primary operational activities) were excluded.

This second criterion reinforces the methodological rigor in filtering out articles that, although involving agricultural commodities in their datasets, were not connected to the topic of hedging. Given that Scopus encompasses a diverse range of journals with varying levels of quality, this dual-layer filtering approach was deemed prudent (Anas et al., 2024).

The articles excluded by *Criterion II*, after already having passed *Criterion I*, were classified according to their primary focus within the agricultural commodity market. This classification is presented in Table 1, which summarizes the quantity and thematic orientation of the excluded articles.

Table 1. Criterion II applied after Criterion I

Purpose of Relation to Agricultural Commodities	**Number of Articles Removed by Criterion 2**
Inflation forecasting	1
Hedge fund performance	2
Performance-oriented forecasting	14
HME in the commodity market	1
Total articles removed	18

Excluding 18 articles, the dataset resulting from *Criterion II* totaled 69 articles. Three articles could not be physically obtained and were therefore also removed from the sample, resulting in a final total of 66 articles.

3.3) Classification and coding

The classification framework is composed of 6 classification categories, numbered from 1 to 6, each category subdivided into letter subcategories (A, B, C, D, and so on) to detail research trends in the hedge of agricultural commodities. The categories and subcategories were chosen to describe best the trends regarding methods, data sources, and geographic locations inherent in the hedging process of involving agricultural commodities. Such aspects were initially addressed by reading a 20% random sample of the original sixty-six articles. If any category was not aligned with the articles, we adjusted the classification framework and restarted the process. All papers were analyzed, and each may have been assigned more than one subcategory.

Category 1 regards the economic context of the country or countries involved in the research. Using the Morgan Stanley Capital International (MSCI) market classification framework (emerging, frontier, developed), we classified the site where the analysis or study was being conducted.

The effectiveness of hedging across different portfolios, including those involving commodities and stock indices from G7 countries, underscores the impact of regional economic conditions and asset availability on hedging strategies. Hedging effectiveness is calculated to assess the risk reduction achieved by adding a second asset, indicating that local market conditions and asset correlations are crucial in determining the optimal hedge strategy (Izadi & Hassan, 2018).

The category two database location indicates the geographic region or continent from which the database used in research was extracted. Let us consider the liquidity of an agricultural market as a key factor in determining the effectiveness of a hedge. One important category is to segregate the articles by the continent of origin of the database. In developed markets, the so-called financialization of commodities is stronger, treating them as alternative asset types that help in risk-return relationships within portfolios, with a focus on the financial aspects rather than the demand and supply issues faced by producers or raw material buyers (Zuppiroli & Revoredo-Giha, 2016).

Identifying each type of commodity market is essential, given the diverse range of products, including metals, energy, agriculture, strategic metals, and real estate. Moreover, the impact of each one of them on portfolio investment, as a mean-variance optimizing investor, could utilize commodities in a diversified portfolio alongside stocks and fixed income to achieve higher returns, regardless of the portfolio (Olson et al., 2017). The commodity types per market type were created to cover this aspect of the study. The subcategories are 3A-Energy, 3B-Metals, 3C-Agricultural Grains, 3D-Agricultural Proteins, 3E-Equities or Stocks, and 3F-Fixed Income and Currencies.

It is essential to determine the type of derivative used, in addition to the underlying commodity. Participants in the agricultural commodity market may opt for forward contracts instead of futures to achieve greater flexibility in contract specifications (Vollmer & Von

Cramon-Taubadel, 2020). Forwards are mainly over-the-counter (OTC) contracts. The need for subdivision by kind of market became necessary, forming category 4- Database source type and its subcategories: 4A-OTC, 4 B-Exchange, and 4C-Index. Although an index can be traded in an exchange or OTC, this kind of hedge using benchmarks has to be isolated in response to the necessary adjustments in the classification framework, during the creation process (Cardillo & Basso, 2025).

Our study features derivatives markets as a hedging instrument for the risk exposure of an underlying asset classified as, or related to, an agricultural commodity. In this context, the hedge portfolio comprises both the underlying asset and its corresponding futures contract, through which the hedger aims to maximize the utility of their wealth (Sadefo Kamdem & Moumouni, 2020). However, only the profit margin hedge is essential for a grain producer. So, a spot crop and future sales are necessary; given these two approaches, category five was created. Category 5 has below its hood three subcategories: 5A-Spot x future, also known as direct hedge, 5 B-Portfolio Hedge, and when involving pair hedges of different markets, subcategory 5C – cross hedge. Categories 4 and 5 are essential to address RQ2, as they will provide the most adopted operational strategy.

Table 2- Classification and Coding Framework

Category Code	Category Description	Subcategory Code	Subcategory Description
1	Economic context of the research country	1A	Emergent
		1B	Developed
		1C	Frontier
2	Database location (exchange/OTC)	2A	Asia
		2B	Africa
		2C	Europe
		2D	Latin America
		2E	North American
		2F	Oceania
3	Commodity or Market type	3A	Energy
		3B	Metal
		3C	Agricultural grains
		3D	Agricultural protein
		3E	Equities
		3G	FICC
4	Database source type	4A	OTC
		4B	Exchange
		4C	Index
		5A	Spot x Future(Forward)

5	Type of Hedge	5B	Portfolio Hedge
		5C	Cross Hedge
6	Quantitative/Statistical/Econometric Model	6A	BASIS
		6B	Coupula
		6C	DCC-GARCH
		6D	LSTM
		6E	MACHINE LEARNING
		6F	OLS
		6G	VAR
		6H	VAR-BEKK

Beyond answering RQ2, the category 6 Quantitative/Statistical/Econometric Model is essential for providing the methods used to calculate hedge ratios and hedge effectiveness empirically. It guarantees the hedge works as well as it can, reducing the swing of profit and losses (P&L) from market participants.

A myriad of models, including OLS (Ordinary Least Squares), GARCH, copula-GARCH, and MGARCH, demonstrate different levels of effectiveness in estimating hedge ratios and hedge effectiveness. Copula-GARCH models can refine hedge ratios effectively for direct hedging (Louhichi & Rais, 2019). Intuitively, the prevalence of dynamic strategies using GARCH and MGARCH over OLS models should be a consensus, but depending on the asset analyzed, divergences arise. Spencer et al. (2018) indicate that using bivariate models attached to MGARCH models may only achieve a maximum improvement of 0.27%.

The categories and subcategories are displayed in Table 2: Classification and Coding Framework.

4. Results and discussion

Following the classification system by (Jabbour, 2013). After applying the codification system to each paper, we conducted a frequency count of each category to identify research gaps and the main characteristics and features of hedging activities involving agricultural commodities. The classification aims to facilitate a comprehensible examination of the knowledge and techniques employed in the selected papers (Pinto & Sobreiro, 2022).

The papers that did not have information compatible with the category were labeled as “NA” (not available). They were not included in the frequency sum for their category but were retained in the database. The result is summarized in Table 3.

Table 3. Categorized papers based on Table 2 criteria

Selected papers	1	2	3	4	5	6
Badshah I, 2019, Energy Econ	1B	2F	3A3B3C3D3E	4C	5C	6A
Olson E, 2017, Res Int Bus Financ	1B	2E	3A3B3C3D3E	4C	5B	6A
Cui J, 2023, Int Rev Financ Anal	1A	2E	3A3B3C	4A4B	5C	6A
Demiralay S, 2022, Energy Econ	1A1B	2A2C2E	3A3B3C3D3E3F	4C	5B	6A
Hucher N, 2016, Res Int Bus Financ	1B	2E	3C3E	4A	5A	6A6H
Ouzan S, 2025, Eur J Oper Res	1A1B	2E	3A3B3C	4A	5A	6H
Penone C, 2021, Risks	1B	2C2E	3C	4A4B	5A	6A6E
Huang H, 2023, J Futures Mark	1A	2A	3A3B3C	4B	5A	6B6E
Bialkowski J, 2018, J Futures Mark	1B	2E2F	3D	4A4B	5A	6E
Chalid D, 2022, Journal Of Economic Studies	1A	2E	3A3B3C3E3F	4A4B4C	5B	6A
Watugala S, 2019, J Futures Mark	1B	2E	3A3B3C	4A4B	5A	6A
Ozcelebi O, 2024, N Am Econ Financ	1A	2C2E	3A3B3C3E3F	4A4B	5B	6A6C
Pandey V, 2023, Investm Manage Financ Innov	1A	2A	3A3B3C	4B4C	5B	6G
Nienhaus R, 2023, J Co-Op Organ Manag	1B	2C	3C	NA	NA	6H
Chen S, 2016, Can J Agric Econ-Rev Can Agroecon	1A1B	2C	3C	4A4B	5A	6B
Drugova T, 2019, J Agric Resour Econ	1B	2E	3C	4A4B	5A5C	6C
Ahmad N, 2018, Manag Account Review	1B	2C	3C	4B	5A	6A
Spencer S, 2018, J Commod Mark	1A	2E	3C	4A4B	5A	6C
Karmakar M, 2020, Appl Econ	1A	2A2E	3A3B3C3E3F	4A4B4C	5A	6A

Zhao Y, 2025, Comput Econ	1A	2A	3C	4A4B	5A	6A6F
Fuertes A, 2023, J Commod Mark	1B	2E	3A3B3C3D	4A4B	5B	6B
Nardino F, 2022, Rev Econ Sociol Rural	1A	2D	3C	4A4B	5A	6G
Hachicha N, 2022, Int Rev Financ Anal	1A	2E	3A3B3C3D3E3F	4C	5B	6C
Zivkov D, 2021, Agric Econ	1C	2E	3B3C	4A4B	5B	6A
Conlon T, 2016, Eur J Financ	1B	2E	3A3C	4A4B	5A	6G
Louhichi W, 2019, J Asset Manage	1B	2E	3A3B3C3E3F	4B4C	5A	6A6B
Olson E, 2019, Glob Financ J	1B	2E	3A3B3C3D	4C	5C	6A6E
Singh J, 2019, Resour Policy	1A1B	2E	3A3B3C3D3F	4C	5B	6A6B
Goswami A, 2023, J Commod Mark	1B	2E	3C	4B	5A	6H
Barbi M, 2016, Appl Econ	1B	2E	3A3B3C3E	4B4C	5B	6H
De J D, 2021, Rev Evidenciacao Contab Financ	1A	2D	3C3D	4A4B	5A	6A
Mirza N, 2020, J Quant Econ	1B	2F	3D	4A4B	5A5C	6A6E
Jia S, 2023, J Futures Mark	1A	2E	3A3B3C3E	4B4C	5C	6A
Kang S, 2017, Energy Econ	1A1B	2E	3A3B3C	4B	5B	6A
Ewald C, 2017, Mar Resour Econ	1B	2C	3D	4A4B	5A	6H
Goswami A, 2022, J Agric Appl Econ	1B	2E	3C	4B	5A5D	6A6C
Kamdem W;Kamdem D;Fono ;Louis A L	1A	2B2C	3C	4A4B	5A	6H
Nekhili R, 2022, Borsa Istanb Rev	1C	2E	3A3B3C3D3E3F	4A4B	5A	6A6B
Palazzi R, 2024, J Futures Mark	1A	2D2E	3A3C	4A4B	5A	6C
Rad H, 2020, J Empir Financ	1B	2E	3A3B3C3D	4A4B	5A	6E6H
Bialkowski J, 2023, J Commod Mark	1A1B	NA	3A3B3C3D	NA		6A6E
Lu R, 2023, Econ Anal Policy	1A1B	2A2D	3A3B3C3E	4B4C	5B	6C
Nakagawa K, 2024, Int Rev Financ Anal	1B	2E	3A3B3C3D	4B	5B	6H
Magalhaes L, 2022, J Futures Mark	1A	2D	3A3C3D	4B	5A	6E
Clement N, 2022, Ann Financ	1A	NA	NA	NA	NA	6H

Lien D, 2018, J Futures Mark	1A1B	2E	3C	4B4C	5B	6A
Rout B, 2021, Iimb Manag Rev	1A	2A	3C	4B	5A	6A6E
Huang H, 2024, Appl Econ	1A	2A	3D	4A4B	5A	6A6E6G
Bina J, 2022, J Commod Mark	1A	2E	3C3D	4A4B	5C	6E
Wang Q, 2024, J Commod Mark	1B	2E	3A3B3C3D	4A4B	5B	6D
Wu G, 2021, J Asian Financ Econ Bus	1A	2A	3A3B3C3D	4A4B	5B	6F
Bolandifar E, 2020, Omega-Int J Manage Sci	1C	2A	3C	4A	5B	6G
Jitmaneeroj B, 2018, Int Rev Econ Financ	1A	2E	3A3B3C3D	4A4B4C	5B	6A
Lien D, 2016, J Futures Mark	1B	2E	3B3C3F	4B	5A	6E
Bohl M, 2018, J Asian Econ	1B	2A	3C	4B	5A	6A6E
Tonin J, 2020, Agribusiness	1A1B	2D2E	3C	4B	5A	6A6C
Hrabynska I, 2022, Agric Resour Econ: Int Sci E-J	1A1C	2C2E	3C	4B	5A	6E
Impacts Of Changes In Market Fundamentals	1B	2E	3D	4A4B	5A	6E
Jacobs K, 2018, Am J Agr Econ	1B	2E	3C	4A	5A	6E6H
Thenmozhi M, 2020, J Emerg Mark Financ	1A	2A	3C	4B	5A	6A
Boons M, 2019, J Financ	1A	2E	3A3B3C3D	4A4B	5A	6E
Goswami A, 2023, J Commod Mark	1B	2E	3C	4B	5A	6E
Vashishtha A, 2020, Int Rev Econ	1A	NA	NA	NA	NA	6G
Nhung N, 2020, Investm Manange Financ Innov	1A	2A2C2E	3C	4A4B	5A	6C
Vollmer T, 2020, German J Agric Econ	1B	2C	3C	4B	5A	6A6C
Izadi S, 2018, Eurasian Econ Rev	1B	2E	3A3B3C3D	4A4B4C	5A5B	6A

The frequency and statistics of each category were analyzed to extract the knowledge structure and identify gaps. The economic context of the country was studied, including its classification within the MSCI country classification framework, where the research was created and developed. Figure 2 shows that emergent markets account for 46.05% of total category 1, are almost tied with developed countries at 48.86%, and comprise just 5.26% for frontier countries. Additionally, emergent markets also achieved a high participation rate in total crops. Differences can be noted, as markets like India are more vulnerable to oil market volatility due to their high dependency on imports, as denoted by a higher interconnection between the agricultural and energy sectors (Thenmozhi & Maurya, 2020). Fuel can be a research gap for countries with high dependence on oil imports, providing a primary environmental issue for control.

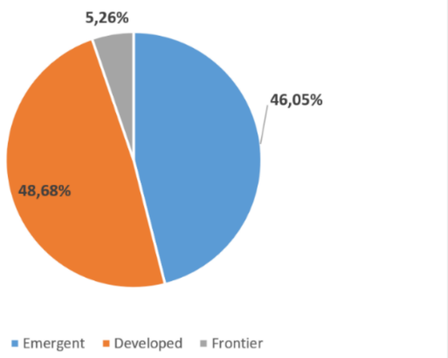

Figure 2-Country Economic Classification

Database location refers to the country's database utilized in each article, covering both spot and derivative markets, for crop hedging purposes. Although primary agricultural commodities, crops (wheat, corn, soy), can be found worldwide. The analysis of category 2 shows concentration in different regions, as shown in Figure 3. North America (the US and Canada) has 55.26% of the articles as market data feeders, Asia is the second, with 17.11%, followed by Europe (14.47%) and Latin America (7.89%).

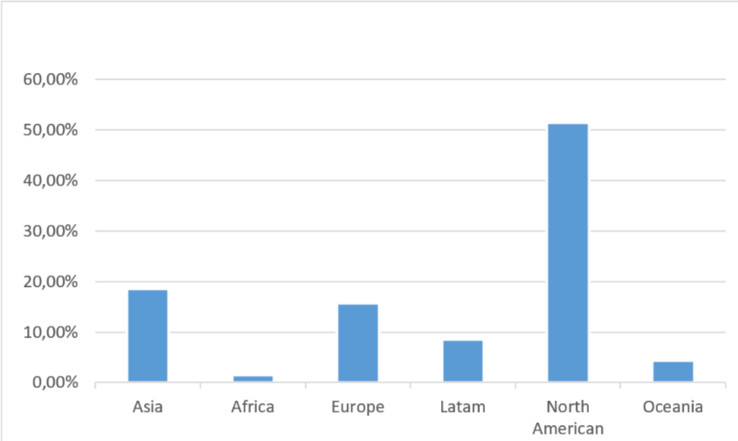

Figure 3-Studied Region

In the spot market, the US benefits from its technological advancements and large-scale agricultural production capabilities, which allow it to maintain a competitive edge in terms of efficiency and output (Palazzi et al., 2024). The U.S. policies to enhance the biofuel market have strengthened the link between agricultural commodities like corn and energy prices, thereby amplifying the U.S.'s role in global market dynamics (Tonin et al., 2020).

To reinforce this aspect, the CBOT is highlighted as the most significant exchange, particularly for agricultural commodities like corn, wheat, and rice, which are traded extensively and have a substantial impact on global pricing due to their high trading volumes and integration with other markets, such as energy futures (Kang et al., 2017).

Studies of India's agricultural commodity futures reveal several pricing inefficiencies impacting their participants, as the cash market drives the future, which is the opposite of how an efficient futures market should function (Rout et al., 2021). Brazil also plays a crucial role, particularly in the production of corn and soybeans. The Brazilian futures exchange (B3) plays a significant role in risk management for local corn producers (Tonin et al., 2020). As the first export item in Brazil's trade balance, soybeans are driven by CBOT (Chicago Board of Trade) soybeans. Additionally, despite its unbalanced investor base, China's futures market is very liquid, particularly in corn futures, which are crucial for the country's food market stability (Huang & Xiong, 2023). All those aspects raise the research gap in how emergent market exchanges can develop products adapted to local realities, providing more effective hedge instruments.

The type of commodity market categorization reveals the central role performed by agricultural grains (Figure 4). The inherent volatility and the ability to absorb shocks in supply and demand make grain commodities effective for risk management. This volatility is often linked to weather conditions, geopolitical events, global supply and demand dynamics, and local logistic issues, which are often distinct from those affecting financial markets, thus providing diversification benefits(Sadefo Kamdem & Moumouni, 2020).

Agricultural commodities like corn and soybeans are closely linked to fundamental economic activities, such as food production and biofuel generation, which ensures a consistent demand and makes them reliable hedging instruments (Hrabynska et al.,2022). Besides, the financialization of commodity markets has increased their accessibility and liquidity, allowing for more efficient hedging strategies. Other commodities, such as metals and energy, are present due to their high correlation with agricultural markets, which sparks the use of cross and portfolio hedges using copulas and connectedness GARCH strategies. All those market methods and aspects correctly answer RQ2.

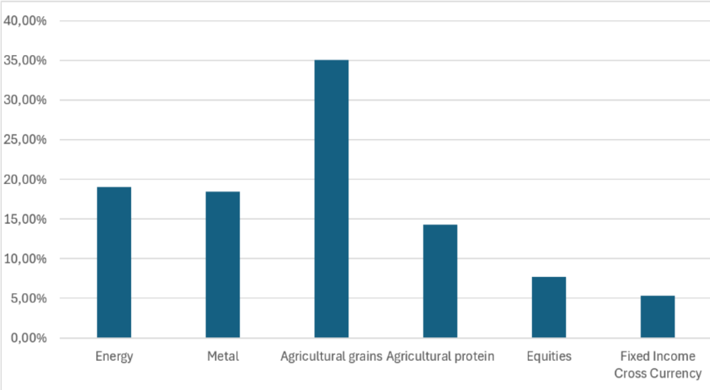

Figure 4 -Type of commodity

Due to several key factors, agricultural commodity derivatives are popular as hedge instruments for other underlying assets. Depending on the market characteristics, the type of derivative may vary. Among the categories of hedging involving agricultural commodities, futures markets are the most used (Figure 5). They offer better credit risk than over-the-counter (hereafter, OTC) and typically higher liquidity. OTC instruments, such as index-based price contracts, offer flexibility and customization, allowing firms to negotiate terms that align closely with their specific risk management needs. These contracts are particularly prevalent in industries dealing with commodities like chemicals and agribusinesses, where they help link transaction prices to input procurement costs, thereby reducing profit volatility (Bolandifar & Chen, 2020).

As exchange products offer higher transparency and credit conditions for execution, the access and conditions of OTC products could be facilitated in order to increase their presence

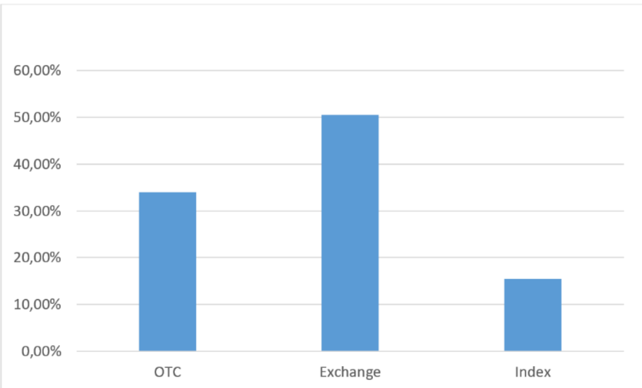

Figure 5 Type of derivative market

in the market, which should be a gap to be explored, the conditions for this enhancement present great complexity, including the risk of turning them into exchange products.

The frequency of subcategories for the type of hedge (3 elements) is described in Figure 6. Futures markets are often used for hedging due to their ability to transfer price risk and facilitate price discovery, making them a preferred choice for traders looking to manage volatility in commodity prices (Zuppiroli & Revoredo-Giha, 2016). The financialization of commodity markets can impact the effectiveness of futures as a hedging tool, as increased speculation may lead to a divergence between futures and spot prices, potentially reducing the effectiveness of hedging. The presence of arbitrage opportunities and the ability to execute cross-hedges depend on the correlation between different commodity prices (Olson et al., 2017)

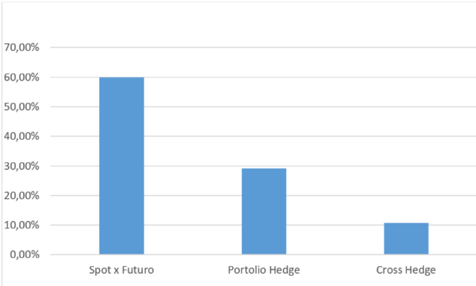

Figure 6-Type of Hedge

and the availability of suitable futures contracts. The agricultural commodity futures market is often used as an instrument for cross-hedging thanks to its high liquidity. However, they are susceptible to volatility spillovers between markets, leading to unpredictable results (Rout et al., 2021). However, the lower frequency of cross-hedge can provide a gap in research. Its 10% presence compared to 60% of spot and future may indicate a market predisposition to trade underlying assets and their future markets, even before analyzing cheaper and more liquid alternatives in the cross-market.

The selection of an appropriate econometric or statistical model is crucial, as it directly influences both its predictive accuracy and the quality of managerial decision-making. A wide range of models is considered and summarized in Figure 7. To address RQ1, category six was created.

In highly volatile markets, the issue of model selection becomes even more critical. Despite its frequent use, the traditional OLS method presents notable limitations, particularly its static treatment of volatility over time, which compromises model precision. Although OLS exhibits the second-highest frequency of application among the reviewed studies, it often serves as a benchmark for more complex approaches, such as VAR/ VEC and GARCH models. VEC model is particularly valuable when cointegration exists between spot and futures prices, as it incorporates an error correction term that captures long-term equilibrium adjustments (Vollmer & Von Cramon-Taubadel, 2020).

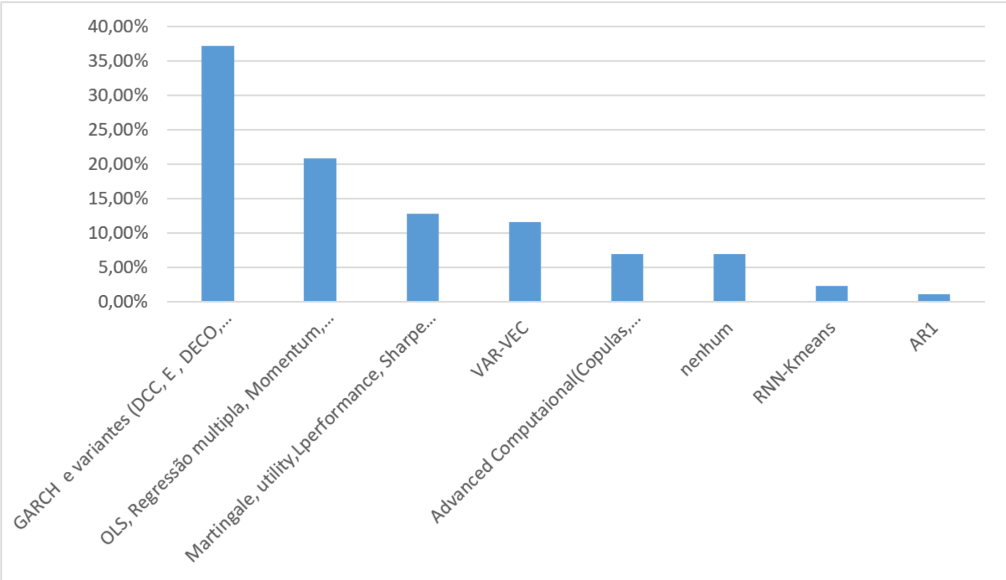

Figure 7- Quantitative Model

GARCH models represent the sample's most frequently employed class of econometric models, accounting for 38% of the total. These models are particularly effective in addressing heteroskedasticity, as they allow the conditional variance to evolve, an essential feature for capturing volatility clustering, which is a well-documented characteristic of financial markets (Olson et al., 2017). Fig. 7 illustrates that various GARCH extensions are applied, including the Dynamic Conditional Correlation (DCC) and Asymmetric DCC (ADCC) models. These variants introduce time-varying correlation structures, a promising feature for improving hedge accuracy in highly volatile environments (Louhichi & Rais, 2019).

Vector Autoregressive (VAR) and Vector Error Correction (VEC) models are the third most frequently adopted approaches in the econometric model category. Their prevalence reinforces the significance of multivariate modeling within our systematic review. These models are particularly effective in forecasting returns and generating residuals, which can be modeled using GARCH-type frameworks to capture time-varying volatility dynamics.

Our sample's near absence of neural network and machine learning models, accounting for only 3.57% of the model categorization, reveals a significant research gap. This underrepresentation is significant, as machine learning models can capture nonlinear interactions between spot, futures, and exogenous variables, possessing superior predictive performance, which highlights the need to explore these approaches further. While machine learning and deep learning models have been increasingly adopted in recent empirical studies to capture cross-market interdependencies and enhance portfolio analysis, they remain largely unexplored within the core literature analyzed (Demiralay et al., 2022).

The frequency of the subcategories is an important source of information that can evidence abnormalities and develop and improve the functional aspect of making decisions about them (Pinto & Sobreiro, 2022). Each category and subcategory's classification and frequency are summarized in Figure 8. Using the five steps of Jabbour (2013) and the six categories and their subcategories, we were able to identify the following candidates to research gaps:

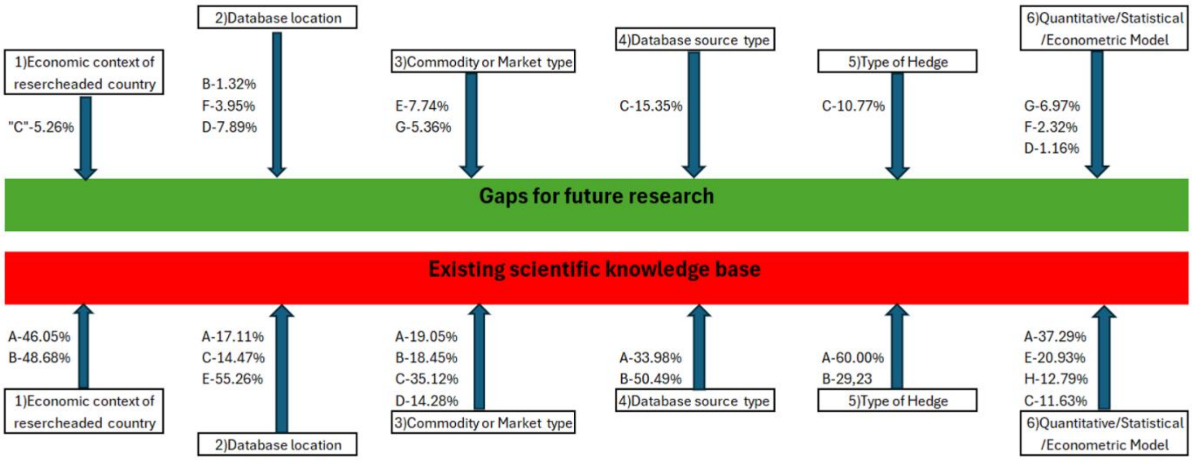

Figure 8-Summary of Subcategory frequency

1) Frontier countries had a lower frequency, and their representativeness is very small in World agricultural production. However, the lack of liquidity and access to foreign investment can be a research gap for in-depth study in specific agricultural products like coffee in Vietnam and spices in India.

2) Emergent and frontier countries usually face logistics issues, such as a poor transport network. These issues represent questions of fuel volatility influencing commodity prices and should, therefore, be used as a research gap. The impact of fuel consumption on price hedge and its environmental impacts is a relevant concern.

3) Although important agricultural commodities producers, emerging markets like China and Brazil lack a more liquid and diversified futures exchange. Measures to enhance their futures markets and develop new products can provide rich research opportunities for futures gaps.

4) The small presence of cryptocurrencies and alternative assets as diversification products to promote cross-hedge or portfolio hedge creates an interesting research gap.

5) The search for more cross-hedge alternatives could be increased; moreover, depending on transaction costs, it could become an alternative to future markets that are more susceptible to financialization.

7) The minimal frequency of IA and machine learning tools to model and forecast hedge ratios and hedge effectiveness is an important fact, as the adaptability of machine learning models grants them the power to optimize participants' behavior in markets having heterogeneous investors and no linear interactions that traditional economic models fail to capture (Zhao & Ju, 2025).

5. Conclusions

This study uses a systematic literature review to conduct comprehensive science mapping procedures. A classification framework was constructed using six categories, framing a standardized understanding of knowledge regarding hedging strategies in agricultural commodities. The gaps listed by this research address RQ3, representing avenues for futures researches: (i) the lack of no linear forecasting models, based explicitly on "machine learning" and "AI" approaches, (ii) the high presence of emerging markets as corresponding author´s countries confirming the protagonist role of these countries in global agricultural commodity producing and a dispersed network of collaboration among authors, (iii)the necessity to develop new agricultural exchange products that fit to local characteristics of the emergent market. These products can be Exchange Traded Funds or any tradable agricultural commodity index or derivative, whose properties may help increase hedge effectiveness. iv)Significant influence of fuel prices and logistics costs in countries with high dependency on oil imports.

One of the limitations of this study lies in its exclusive focus on futures markets and the basis. Other derivative instruments, such as options and swaps, warrant further investigation into future research. Also, future studies should explore the research questions through an empirical manner, such as meta-analysis, forecasting model performances, or identifying the conditions under which specific methods are more effective.

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