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ESTRATÉGIAS DE HEDGE ENVOLVENDO COMMODITIES AGRÍCOLAS: UMA REVISÃO SISTEMÁTICA DA LITERATURA

HEDGING STRATEGIES INVOLVING AGRICULTURAL COMMODITIES: A SYSTEMATIC REVIEW OF LITERATURE

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Resumo

Finalidade – Sintetizar evidências recentes sobre a efetividade de hedge com futuros de commodities agrícolas e esclarecer como estratégias e modelos são usados para gerir o risco de preços e de basis. Design/metodologia/abordagem – Revisão sistemática com os procedimentos PRISMA nas bases de dados Web of Science e Scopus (2015–2024); 66 artigos classificados em um framework de seis dimensões: contexto, fonte de dados, commodity, tipo de hedge e abordagem de modelagem. Resultados – Contratos futuros, sobretudo de grãos, predominam; modelos GARCH são os mais usados para a volatilidade e os hedges ratios, enquanto VAR e VEC captam a dinâmica spot–futuro; por sua vez, métodos de machine learning, mercados emergentes e de fronteira, custos logísticos e de combustível, estratégias de cross-hedge e ativos alternativos são raramente tratados. Limitações/implicações da pesquisa – Restrita a duas bases e a artigos em inglês e em português; oferece uma agenda estruturada para mercados, riscos e métodos negligenciados. Originalidade/valor – Fornece um mapa transparente e codificado da produção recente sobre a efetividade do hedge agrícola, evidenciando lacunas teóricas e empíricas.

Palavras-chave: commodities agrícolas;mercados futuros;efetividade de hedge;revisão sistemática

Abstract

Purpose – To synthesize recent evidence on hedge effectiveness in agricultural commodity futures and clarify how futures-based strategies and models are used to manage price and basis risk. Design/methodology/approach – Systematic literature review using PRISMA in Web of Science and Scopus (2015–2024); 66 articles classified in a six-dimension framework (context, data source, commodity, hedge type, and modeling approach). Findings: futures contracts, especially for grains, predominate; GARCH-type models are most commonly used for volatility and hedge ratios; VAR/VEC models capture spot–futures dynamics; whereas machine learning, frontier/emerging markets, logistics, fuel costs, cross-hedging, and alternative assets are rarely examined. Research limitations/implications – Restricted to two databases and to articles in English and Portuguese; supports a focused agenda on neglected markets, risks, and methods. Originality/value – Provides a transparent, code-based map of recent studies on agricultural hedge effectiveness, highlighting overlooked markets, risk drivers, and methodological gaps.
Keywords: Agricultural commodities; futures markets; hedge effectiveness; systematic review.

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1. Introdução

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 for managing price and income risk in agriculture, and futures contracts allow market participants to protect themselves against adverse price movements by transferring price risk to other market participants, thereby minimizing market price risk and stabilizing income (Penone et al., 2021). The pursuit of hedge efficiency by companies for value creation and preservation, especially in highly volatile markets, requires the development of effective strategies to mitigate 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 on the hedge ratio, leading to the extensive use of econometric models to enhance hedge effectiveness (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, a myriad of hedge instruments, ranging from exchange-traded futures to over-the-counter options and swaps, as well as cross-hedges and

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spot/market hedges, are available. Given different quantitative hedge ratios and various calculation methods, these combinations require a multidimensional approach to evaluate their impact on market risk management. This complexity necessitates a thorough review of the existing literature to identify best practices and innovative strategies that 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. Moreover, our purpose is to pave the way for future empirical studies, open avenues for knowledge on the topic, and identify research priorities to enhance hedging strategies for 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 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

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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, after accounting for 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 futures and spot markets, convergence typically occurs as a futures contract approaches maturity, driven by arbitrage that exploits price discrepancies. This is supported by the cost-of-carry 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 market imperfections 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 Hazelkorn et al. (2023) focus on the stock market, they claim 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 be adapted to the characteristics of the hedging process in agricultural commodity markets by incorporating specific 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, futures contracts emerge as a crucial instrument for achieving hedge effectiveness, owing to their solid theoretical foundation in the LOP and the liquidity of derivative markets.

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LOP and MPT support the pricing and risk-return drivers of 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 substantial empirical evidence on futures hedging in commodity markets (Białkowski et al., 2023).

Hedging effectiveness in commodity markets using futures assumes a protagonist position and shall be measured using quantitative tools and econometric modeling that demonstrate 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, which can be mitigated by employing multivariate models such as Vector Autoregressive (VAR) and Vector Error Correction (VEC). VAR and VEC models are system-based approaches that can analyze relationships among multiple time-series variables, such as commodity cash and futures prices (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 that deviations from equilibrium are mean-reverting, thereby constraining persistent arbitrage opportunities and supporting 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 MGARCH(Multivariate Garch) models, are employed to capture variance and correlations between spot and futures prices on a time-varying basis

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(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 series' variance and covariance. Each model is specifically designed to capture evolving volatility structures over time (Diego Pitta de Jesus et al., 2021; Izadi & Hassan, 2018). Although copula functions such as the Gumbel and Frank outperformed DCC-GARCH models for cultures like wheat by 11% to 29% (Louhichi & Rais, 2019).

Additional approaches include quantile regression, which examines how hedge ratios vary across the return distribution and, for agricultural commodities, documents an inverted-U-shaped pattern with lower hedge ratios in extreme market conditions (Lien et al., 2016). Overall, the literature reveals a broad spectrum of econometric tools built upon the same core economic principles: no-arbitrage, convergence between spot and futures near maturity, and the influence of structural factors—such as contract design, sample period, and logistics—on the dynamic relationship between derivatives and the underlying commodity.

3. Methodology

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

The use of quantitative techniques not only eliminates subjectivity and personal bias in selecting 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

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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, WoS) and Scopus. The search process was carefully documented to ensure objectivity and enable replication by other researchers (Linnenluecke et al., 2020).

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Figure 1- Prisma method .

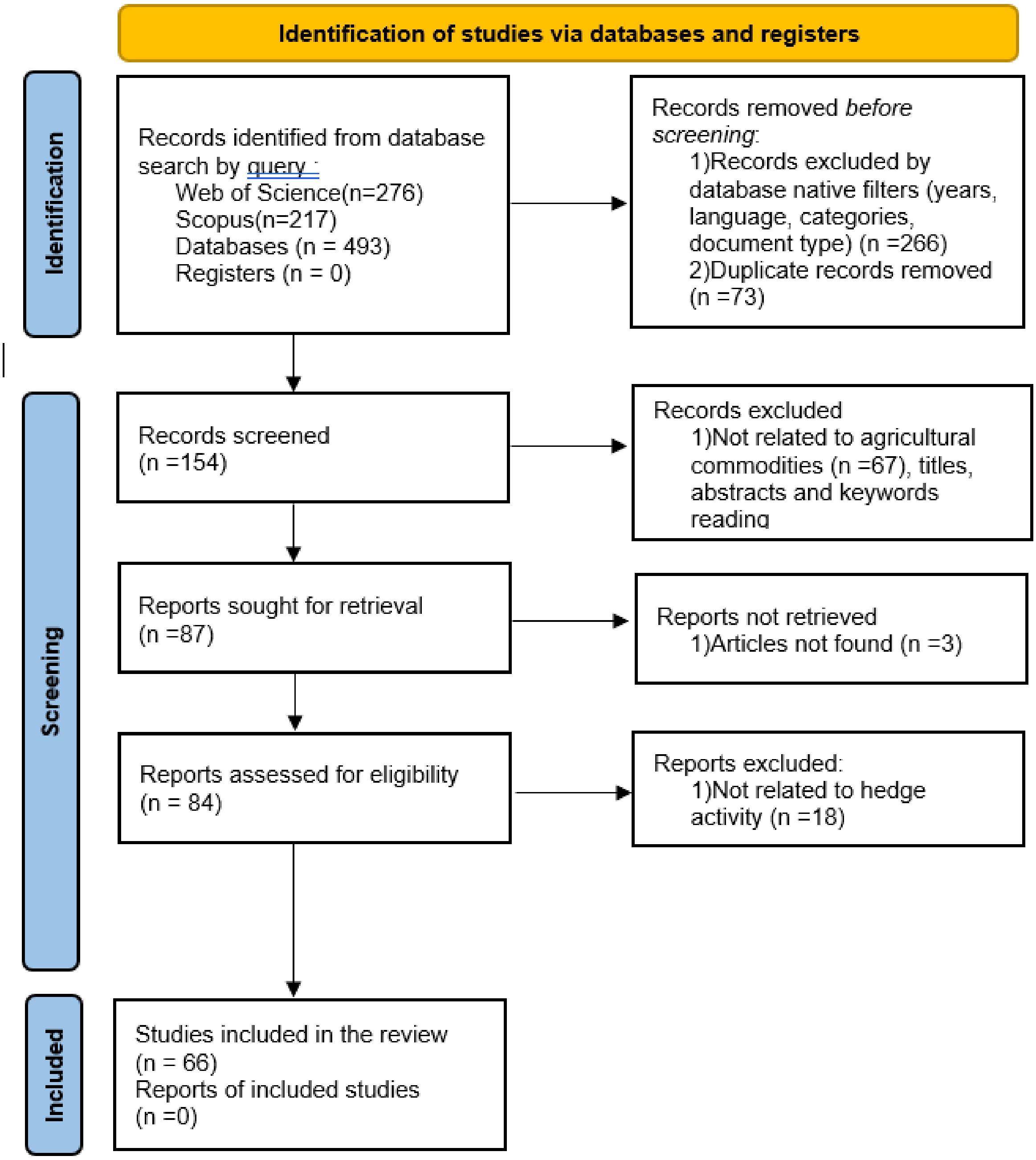

Figure 1 summarizes the steps according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol of systematic review of literature to ensure transparency.

The definition of search terms was based on the 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

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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 term (ratio or basis) was included to encompass articles that use the Minimum Variance Hedge Ratio (MVRH) and to materialize a sample that could not exclude the fundamental relationship between cash and futures prices.

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 each database's native tools. Only journal articles were considered, and only publications from 2015 to 2024 were retained. This time span was chosen because it encompasses major crises in Brazil's soy and corn crops, which, as a major producer, affected global prices: 2017, Brazil´s truck drivers' strike; 2018/2022, the presidential election; and 2020/2021, the COVID-19 pandemic. In addition, the 2016 drought in Brazil significantly affected corn price dynamics (Tonin et al., 2020), shifting some demand from poultry feeding to biofuel, thereby confirming the chosen interval.

Subsequently, only specific subject categories were included: for WoS, the categories Business Finance, Economics, Management, and Business; and for Scopus, the categories Economics, Econometrics and Finance, Business, Management, and Accounting.

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

3.2. 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

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Scopus, RStudio was used. This step reduced the initial dataset from 227 articles (130 from WoS and 97 from Scopus) to a unified set of 154 unique articles.

3.3. Screening by deletion of Articles Not Related to Agricultural Commodities (Criterion I)

In this stage, we applied Criterion I to retain only articles that actually addressed agricultural commodities. First, we checked the titles, abstracts, and keywords of all 154 records to determine whether any record contained quantitative data for at least one agricultural commodity.

When this was unclear, we conducted specific content verification in ambiguous cases (28 articles) to confirm whether an agricultural commodity was the underlying asset in the analysis.

After applying Criterion I, 67 articles were excluded, and 87 remained. The excluded papers dealt only with non-agricultural assets, such as: ten on precious and base metals (copper, aluminum, zinc, lead, tin), ten on oil and oil products (including natural gas and heating oil), nine on crude oil only, five on stocks and metals, four combining stocks, oil and metals, three on stocks only, three on stocks and oil, and three on the real estate market.

3.4 Reports not retrieved

Three articles could not be obtained in file or physical form. However, not a content exclusion, this technical issue obstructed their utilization, and they were therefore removed from the sample, reducing the sample to 84 articles.

3.4. Eligibility by deletion of Articles Related to Agricultural Commodities but Unrelated to Hedging (Criterion II):

The initial screening of titles and abstracts focused on identifying studies related to agricultural markets. Additionally, to preserve the specific focus on commodity price risk mitigation rather than speculative financial performance, articles that did not explicitly present hedging as a primary objective (i.e., protection against price fluctuations of underlying assets inherent to operational activities) were excluded at this stage.

This eligibility criterion required a full reading of the articles, reinforcing methodological rigor by excluding articles that, although including agricultural

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commodities in their datasets, were unrelated to hedging. Given that Scopus encompasses a diverse range of journals with varying quality levels, this approach to assessing eligibility was deemed prudent (Anas et al., 2024).

The articles excluded for eligibility (Criterion II) were classified by 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-Excluded articles after criterion II.

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

Table 1 indicates the topics of the articles that were not related to hedge purposes and were excluded after the eligibility step. After excluding 18 articles, the dataset under Criterion II comprised 66 articles; the final sample of 66 articles is presented in Table 3.

3.5. Classification and coding

The categories and subcategories were chosen to best describe the trends in methods, data sources, and geographic locations inherent in the hedging process for agricultural commodities. To perform this analysis, the categories should reflect the key factors that producers, elevators, and market participants consider when engaging in hedging operations. And features that may cluster hedge operations, paving the way to map the current landscape of hedge activity involving agricultural commodities. To address these issues, the classification framework comprises six categories, numbered 1-6, each subdivided into letter subcategories (A, B, C, D, and so on). 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

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analyzed after a full read, and each may have been assigned to more than one subcategory.

Category 1 concerns the economic context of the country or countries under study. 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 2- database location indicates the geographic region or continent from which the research article was extracted. 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 database's continent of origin. In developed markets, the so-called financialization of commodities is more pronounced, treating them as alternative asset classes that help shape risk-return relationships within portfolios, with a focus on financial aspects rather than the demand and supply issues faced by producers or raw material buyers (Zuppiroli & Revoredo-Giha, 2016).

Identifying the various types of commodity markets is essential, given the diverse range of products, including metals, energy, agriculture, strategic metals, and real estate, which will help identify the core object of hedge in each paper. Moreover, the impact of each on portfolio investment, as a mean-variance-optimizing investor, could be to include 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 or market type category 3 was created to cover this aspect of the study. The subcategories specified to describe each type are: 3A-Energy, 3B-Metals, 3C-Agricultural Grains, 3D-Agricultural Proteins, 3E-Equities or Stocks, and 3F-Fixed Income and Currencies.

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Table 2-Categories and subcategories classification 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
		3F	FICC
4	Database source type	4A	OTC
		4B	Exchange
		4C	Index
5	Type of Hedge	5A	Spotx Future(Forward)
		5B	Portfolio Hedge
		5C	Cross Hedge

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		6A	Econometric Models
6	Quantitative/Statistical/ Econometric Model	6B	Finance Theory
		6C	Machine Learning
		6D	Not specified

Table 2 summarizes the description of each category and subcategory used for article classification and coding to achieve a comprehensive Systematic Review of Literature on hedging involving agricultural commodities.

It is essential to determine the type of derivative deployed and the underlying commodity (Białkowski et al., 2023). Participants in agricultural commodity markets may opt for forward contracts rather than futures to achieve greater flexibility in contract specifications (Vollmer & Von Cramon-Taubadel, 2020). Forwards are primarily over-the-counter (OTC) contracts, exhibiting higher hedge-object adherence, although lower liquidity. The need for subdivision by market type led to the creation of category 4—Database source type—and its subcategories: 4A-OTC, 4B-Exchange, and 4C-Index. Although an index can be traded on an exchange or OTC, this type of hedge using benchmarks must be isolated to accommodate necessary adjustments to the classification framework during the creation process (Cardillo & Basso, 2025).

Our study examines derivatives markets as hedging instruments 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). Nevertheless, 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; 5B-Portfolio Hedge; and, when involving pair hedges of different markets, subcategory 5C – cross hedge. Categories 4 and 5 are essential for addressing RQ2, as they will provide the most widely adopted operational strategy.

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Beyond answering RQ2, the category 6 Quantitative/Statistical/Econometric Model is essential for empirically estimating hedge ratios and hedge effectiveness. It guarantees that the hedge works as well as possible, reducing swings in profit and loss (P&L) for market participants.

A myriad of models, including OLS (Ordinary Least Squares), GARCH, copula-GARCH, and MGARCH, demonstrate varying 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 widely accepted, but depending on the asset under study, divergences arise. Spencer et al. (2018) indicate that using bivariate models in conjunction with MGARCH models may achieve at most a 0.27% improvement, noting that complex time-varying models do not always outperform constant variance timeframe models. All these methods that incorporate econometric techniques and models to evaluate the hedge ratio or hedge effectiveness will constitute the subcategory “Econometric models”.

The reading of the papers allowed the detection of other quantitative model clusters in which classic utility maximization is performed alongside Var (Value at Risk) and Cvar (Conditional Value at Risk) to assess market risk for commodity market participants (Rad et al., 2020). This cluster, supported by finance theory, will form the “Finance Theory” subcategory.

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Traditional economic methods cannot capture the characteristics of irrationality and turmoil in the future and spot market behavior, and similarly, econometric models like ARCH, GARCH, and ARIMA depend on fitting linear trends of price or returns from assets (Zhao & Ju, 2025) possessing nonlinear characteristics, opening the way to numerical solutions based on computer algorithms, such as machine learning techniques, as represented in this study by the “Machine Learning” subcategory. A residual subcategory (“Not specified”) was included to capture studies that did not explicitly report a quantitative hedging model.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 categories to identify research gaps and the main characteristics 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).

Table 3-Categorized papers based on Table 2 criteria.

#	Selected papers	Codes ocurrence
1	Badshah I, 2019, Energy Econ	1B;2F;3A3B3C3D3E;4C;5C;6A
2	Olson E, 2017, Res Int Bus Financ	1B;2E;3A3B3C3D3E;4C;5B;6A
3	Cui J, 2023, Int Rev Financ Anal	1A;2E;3A3B3C;4A4B;5C;6A
4	Demiralay S, 2022, Energy Econ	1A1B;2A2C2E;3A3B3C3D3E3F;4C;5B;6A
5	Hucher N, 2016, Res Int Bus Financ	1B;2E;3C3E;4A;5A;6A6B
6	Ouzan S, 2025, Eur J Oper Res	1A1B;2E;3A3B3C;4A;5A;6B
7	Penone C, 2021, Risks	1B;2C2E;3C;4A4B;5A;6A
8	Huang H, 2023, J Futures Mark	1A;2A;3A3B3C;4B;5A;6A
9	Bialkowski J, 2018, J Futures Mark	1B;2E2F;3D;4A4B;5A;6A
10	Chalid D, 2022, Journal Of Economic Studies	1A;2E;3A3B3C3E3F;4A4B4C;5B;6A
11	Watugala S, 2019, J Futures Mark	1B;2E;3A3B3C;4A4B;5A;6A
12	Ozcelebi O, 2024, N Am Econ Financ	1A;2C2E;3A3B3C3E3F;4A4B;5B;6A

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#	Selected papers	Codes ocurrence
13	Pandey V, 2023, Investm Manage Financ Innov	1A;2A;3A3B3C;4B4C;5B;6A
14	Nienhaus R, 2023, J Co-Op Organ Manag	1B;2C;3C;NA;NA;6B
15	Chen S, 2016, Can J Agric Econ-Rev Can Agroecon	1A1B;2C;3C;4A4B;5A;6A
16	Drugova T, 2019, J Agric Resour Econ	1B;2E;3C;4A4B;5A5C;6A
17	Ahmad N, 2018, Manag Account Review	1B;2C;3C;4B;5A;6A
18	Spencer S, 2018, J Commod Mark	1A;2E;3C;4A4B;5A;6A
19	Karmakar M, 2020, Appl Econ	1A;2A2E;3A3B3C3E3F;4A4B4C;5A;6A
20	Zhao Y, 2025, Comput Econ	1A;2A;3C;4A4B;5A;6A6C
21	Fuertes A, 2023, J Commod Mark	1B;2E;3A3B3C3D;4A4B;5B;6A
22	Nardino F, 2022, Rev Econ Sociol Rural	1A;2D;3C;4A4B;5A;NA
23	Hachicha N, 2022, Int Rev Financ Anal	1A;2E;3A3B3C3D3E3F;4C;5B;6A
24	Zivkov D, 2021, Agric Econ	1C;2E;3B3C;4A4B;5B;6A
25	Conlon T, 2016, Eur J Financ	1B;2E;3A3C;4A4B;5A;NA
26	Louhichi W, 2019, J Asset Manage	1B;2E;3A3B3C3E3F;4B4C;5A;6A
27	Olson E, 2019, Glob Financ J	1B;2E;3A3B3C3D;4C;5C;6A
28	Singh J, 2019, Resour Policy	1A1B;2E;3A3B3C3D3F;4C;5B;6A
29	Goswami A, 2023, J Commod Mark	1B;2E;3C;4B;5A;6B
30	Barbi M, 2016, Appl Econ	1B;2E;3A3B3C3E;4B4C;5B;6B
31	De J D, 2021, Rev Evidenciação Contab Financ	1A;2D;3C3D;4A4B;5A;6A
32	Mirza N, 2020, J Quant Econ	1B;2F;3D;4A4B;5A5C;6A
33	Jia S, 2023, J Futures Mark	1A;2E;3A3B3C3E;4B4C;5C;6A
34	Kang S, 2017, Energy Econ	1A1B;2E;3A3B3C;4B;5B;6A
35	Ewald C, 2017, Mar Resour Econ	1B;2C;3D;4A4B;5A;6B
36	Goswami A, 2022, J Agric Appl Econ	1B;2E;3C;4B;5A5D;6A
37	Kamdem W;Kamdem D;Fono ;Louis A L	1A;2B2C;3C;4A4B;5A;6B
38	Nekhili R, 2022, Borsa Istanb Rev	1C;2E;3A3B3C3D3E3F;4A4B;5A;6A

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39	Palazzi R, 2024, J Futures Mark	1A;2D2E;3A3C;4A4B;5A;6A
40	Rad H, 2020, J Empir Financ	1B;2E;3A3B3C3D;4A4B;5A;6A6B
41	Bialkowski J, 2023, J Commod Mark	1A1B;NA;3A3B3C3D;NA;;6A
42	Lu R, 2023, Econ Anal Policy	1A1B;2A2D;3A3B3C3E;4B4C;5B;6A
43	Nakagawa K, 2024, Int Rev Financ Anal	1B;2E;3A3B3C3D;4B;5B;6B
44	Magalhaes L, 2022, J Futures Mark	1A;2D;3A3C3D;4B;5A;6A
45	Clement N, 2022, Ann Financ	1A;NA;NA;NA;NA;6B
46	Lien D, 2018, J Futures Mark	1A1B;2E;3C;4B4C;5B;6A
47	Rout B, 2021, Iimb Manag Rev	1A;2A;3C;4B;5A;6A
48	Huang H, 2024, Appl Econ	1A;2A;3D;4A4B;5A;6A
49	Bina J, 2022, J Commod Mark	1A;2E;3C3D;4A4B;5C;6A
50	Wang Q, 2024, J Commod Mark	1B;2E;3A3B3C3D;4A4B;5B;6A
51	Wu G, 2021, J Asian Financ Econ Bus	1A;2A;3A3B3C3D;4A4B;5B;6C
52	Bolandifar E, 2020, Omega-Int J Manage Sci	1C;2A;3C;4A;5B;6A
53	Jitmaneeroj B, 2018, Int Rev Econ Financ	1A;2E;3A3B3C3D;4A4B4C;5B;6A
54	Lien D, 2016, J Futures Mark	1B;2E;3B3C3F;4B;5A;6A
55	Bohl M, 2018, J Asian Econ	1B;2A;3C;4B;5A;6A
56	Tonin J, 2020, Agribusiness	1A1B;2D2E;3C;4B;5A;6A
57	Hrabynska I, 2022, Agric Resour Econ: Int Sci E-J	1A1C;2C2E;3C;4B;5A;6A
58	Impacts Of Changes In Market Fundamentals	1B;2E;3D;4A4B;5A;6A
59	Jacobs K, 2018, Am J Agr Econ	1B;2E;3C;4A;5A;6A6B
60	Thenmozhi M, 2020, J Emerg Mark Financ	1A;2A;3C;4B;5A;6A
61	Boons M, 2019, J Financ	1A;2E;3A3B3C3D;4A4B;5A;6A
62	Goswami A, 2023, J Commod Mark	1B;2E;3C;4B;5A;6A
63	Vashishtha A, 2020, Int Rev Econ	1A;NA;NA;NA;NA;NA
64	Nhung N, 2020, Investm Manange Financ Innov	1A;2A2C2E;3C;4A4B;5A;6A
65	Vollmer T, 2020, German J Agric Econ	1B;2C;3C;4B;5A;6A

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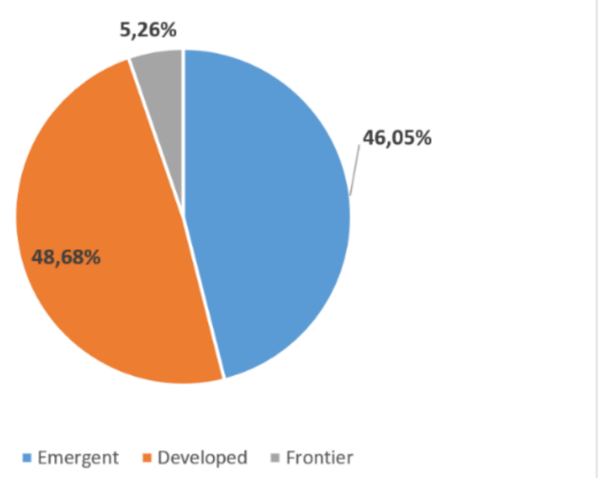
#	Selected papers	Codes ocurrence
66	Izadi S, 2018, Eurasian Econ Rev	1B;2E;3A3B3C3D;4A4B4C;5A5B;6A

Papers that lacked information compatible with the category were labeled "NA" (not available) and were excluded from the category's frequency count but were retained in the database. The result is summarized in Table 3.

The frequency and statistics for each category allowed the extraction of the knowledge structure and the identification of gaps. The country's economic context was studied, including its classification within the MSCI(Morgan Stanley Capital International) country classification framework, which informed the research. Figure 2 shows that emergent markets account for 46.05% of total category 1, are nearly equal to developed countries at 48.86%, and comprise just 5.26% of frontier countries. Additionally, emergent markets achieved a high participation rate across all crops. Markets like India are more vulnerable to oil market volatility due to their high reliance on imports, as evidenced by a strong interconnection between the agricultural and energy sectors (Thenmozhi & Maurya, 2020). Fuel can be a research gap for countries with high oil import dependence, posing a primary environmental issue for control.

Figure 2-Article Analyzed Country Economic Classification



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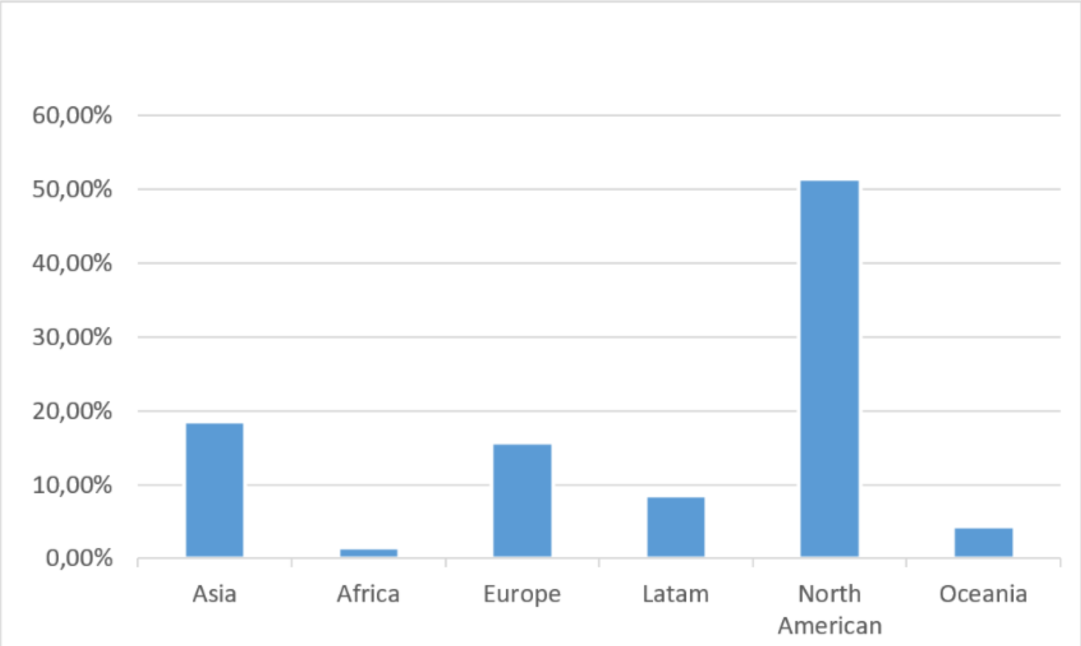
Database location refers to the country's database utilized in each article, covering both spot and derivative markets, for crop hedging purposes. Primary agricultural commodities, such as crops (wheat, corn, soy), are found worldwide.

Figure 3-Studied Region.



The analysis of category 2 shows concentration in different regions, as shown in Figure 3. North America (the US and Canada) accounts for 55.26% of the articles as market data feeders. In the spot market, the US benefits from its technological advancements and large-scale agricultural production capabilities, which enable it to maintain a competitive edge in efficiency and output (Palazzi et al., 2024). U.S. policies to expand the biofuel market have strengthened the link between agricultural commodities such as corn and energy prices, thereby amplifying the U.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

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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 affecting participants, as the cash market drives the futures market, contrary to 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 highly liquid, particularly for corn futures, which are crucial to the stability of the country's food market (Huang & Xiong, 2023). These aspects highlight a research gap regarding how emerging-market exchanges can develop products adapted to local realities, thereby providing more effective hedging instruments.

The commodity market categorization reveals the central role of agricultural grains in commodity markets (Figure 4). The inherent volatility arising from shocks to supply and demand (Spencer et al., 2018) may make grain commodities effective for portfolio risk management. This volatility is often linked to weather conditions, geopolitical events, global supply and demand dynamics, and local logistic issues, which are usually distinct from those affecting financial markets, thus providing diversification benefits (Sadefo Kamdem & Moumouni, 2020).

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Figure 4-Type of commodity.

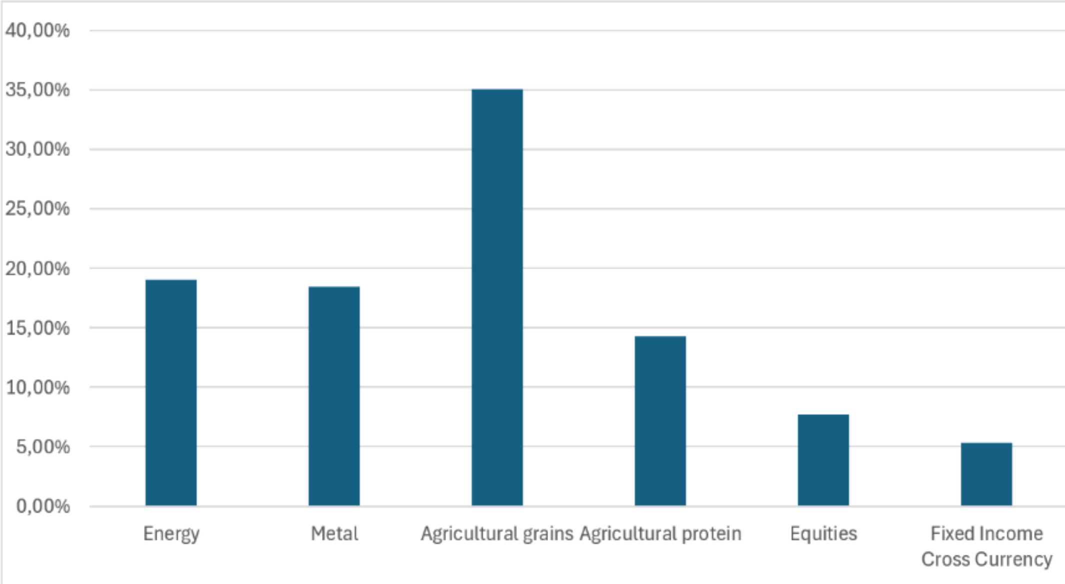

Figure 4 shows the substantial presence of agricultural grains and protein in our sample, serving as the primary hedge object and as an instrument of hedge in cross-hedge roles for equities and FICC (fixed income and cross-currency) portfolios.

Agricultural commodities such as corn and soybeans are closely linked to fundamental economic activities, such as food production and biofuel production, which ensure consistent demand and makes them reliable hedging instruments (Hrabynska et al., 2022). Moreover, the financialization of commodity markets has increased their accessibility and liquidity, thereby enabling more efficient hedging strategies. Other commodities, such as metals and energy, are present due to their strong correlation with agricultural markets, which motivates the use of cross- and portfolio hedges employing copulas and connectedness GARCH strategies. All those market methods and aspects address RQ2.

Several key factors make agricultural commodity derivatives popular as hedging instruments for other underlying assets. Depending on the market characteristics, the type of derivative may vary. Among hedging strategies involving agricultural commodities, futures markets are the most widely used, as shown in Figure 5. They offer lower credit risk than over the counter (OTC) instruments and typically higher liquidity. OTC instruments, such as index-based price contracts,

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offer flexibility and customization, enabling firms to negotiate terms that closely align with their specific risk management needs. These contracts are particularly prevalent in industries that deal with commodities such as chemicals and agribusiness, where they help link transaction prices to input procurement costs, thereby reducing profit volatility (Bolandifar & Chen, 2020).

As exchange products offer greater transparency and execution conditions, the access and terms of OTC products could be improved to increase their market presence, which should be a promising area to explore. The conditions for this improvement are complex, including the risk of their being converted into exchange products.

Figure 5-Type of market derivative.

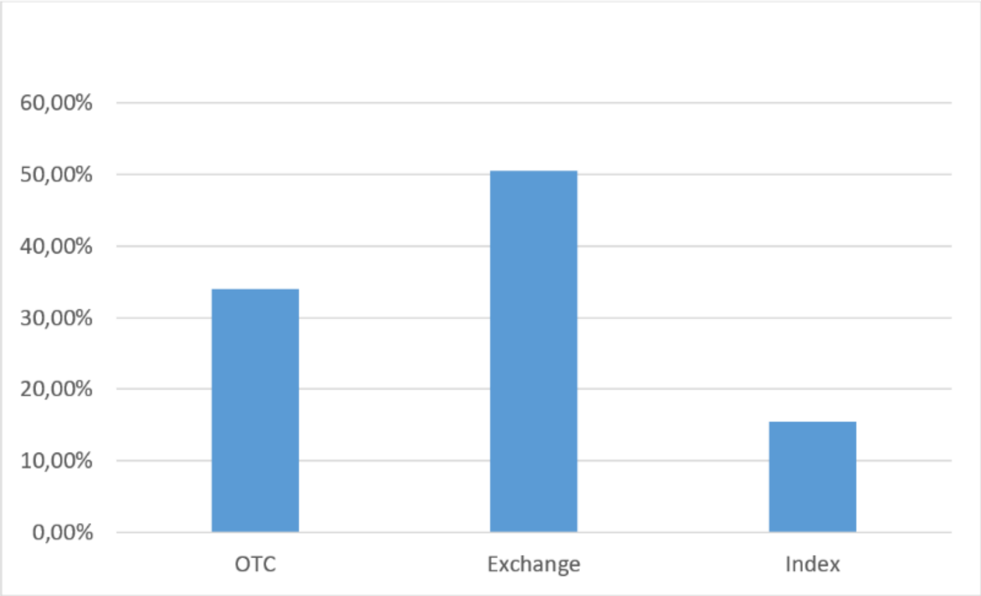

Figure 5 depicts the participation of each kind of market trade and settlement type in our sample.

The design of the hedge plays a vital role in hedge ratios and in estimates of hedge effectiveness. Because the hedge instrument exhibits more characteristics of the underlying asset, we expect higher hedge efficiency for the underlying asset. The absence of convergence between spot and futures markets, caused by transaction costs, supply and demand shocks, and even misspecification in derivatives contracts (Goswami et al., 2023), drives market participants to adopt

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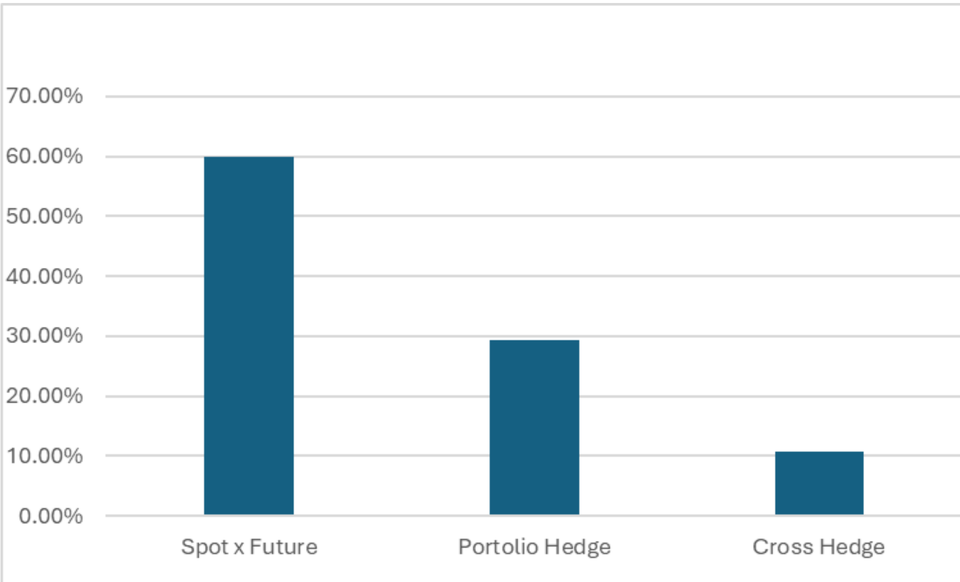
different hedge designs. The frequency of subcategories involving the types in our article dataset is summarized in Figure 6.

Futures markets are often used for hedging because they transfer price risk and facilitate price discovery, making them a preferred choice for traders seeking to manage volatility in commodity prices (Zuppiroli & Revoredo-Giha, 2016). The financialization of commodity markets can affect the effectiveness of futures as a hedging tool, as increased speculation may lead to a divergence between futures and spot prices, thereby reducing hedging effectiveness. The presence of arbitrage opportunities and the ability to execute cross-hedges depend on the correlation between different commodity prices (Olson et al., 2017) and the availability of suitable futures contracts. Hedgers often use the agricultural commodity futures market to cross-hedge. However, they are susceptible to volatility spillovers between markets, leading to unpredictable results (Rout et al., 2021). The low frequency of cross-hedge can create a research gap. Its 10% presence relative to 60% in spot and futures may indicate a market predisposition to trade underlying assets and their futures, even before considering cheaper, more liquid alternatives across markets.

Figure 6-Type of hedge.



The frequency count of hedge types in our sample in figure 6 demonstrates the use of spot (cash market) against future as the primary strategy.

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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 about hedge amounts of instrument of hedge. To address RQ1, category six was created.

In highly volatile markets, 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 MGARCH(Multivariate GARCH models). The VEC model is particularly valuable when cointegration exists between spot and futures prices, as it incorporates an error-correction term that captures long-run equilibrium adjustments (Vollmer & Von Cramon-Taubadel, 2020).

In the context of variance GARCH models represent the sample's most frequently employed class of econometric models, accounting for 38% of the total. These models are particularly effective at addressing heteroskedasticity, as they allow the conditional variance to evolve —an essential feature for capturing volatility clustering, a well-documented characteristic of financial markets (Olson et al., 2017). Figure 7 illustrates the application of various GARCH extensions, 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 econometric approaches. Their prevalence underscores the importance of multivariate modeling in our systematic review. These models are particularly effective in forecasting returns and generating residuals; researchers and market participants can then model these residuals using GARCH-type frameworks to capture time-varying volatility. One econometric approach not captured in our frequency count is the use of GARCH-X and MGARCH-X models, which incorporate exogenous variables such as fundamental and behavioral factors, storage conditions (Goswami et al., 2023), and market

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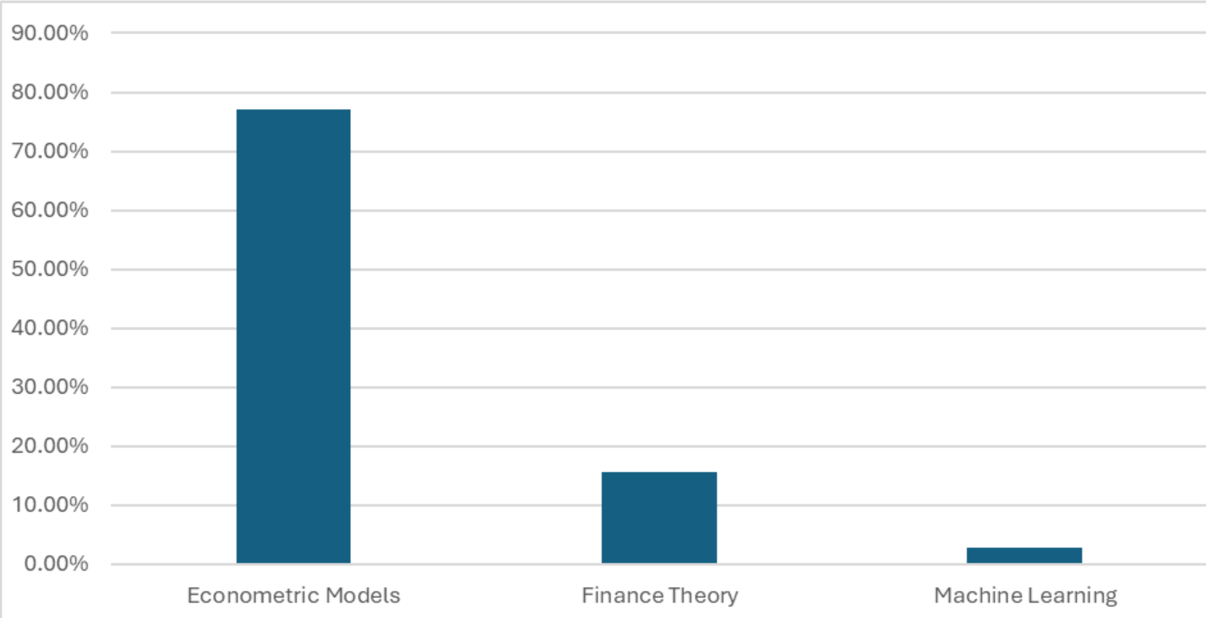
participants' positions. Their scarce adoption, together with the additional complexity of specifying and estimating these models, likely explains their absence in the mapped sample.

Figure 7-Quantitative model type.



In figure 7 all econometric and statistical models were aggregated in subcategory 6A-Econometric Models representing the dominant cluster having 77,14% of the total category. Subcategory 6B-Finance Theory represents 15,71% of the category, mostly represented by studies focusing on utility functions to stimate hedge ratio by maximizing utility of wealth (Kamdem et al., 2020), or utility as a tool to quantify behavioral finance decisions (Ouzan & Six, 2024).

In our sample, the near absence of neural network and machine learning models, accounting for only 2,86% of models subcategorization (6C-Machine Learning), indicates a significant research gap. This underrepresentation is substantial, as machine learning models can capture nonlinear interactions among spot, futures, and exogenous variables and achieve superior predictive performance, underscoring the need to further explore these approaches. While machine learning and deep learning models have been increasingly adopted in recent empirical studies to capture cross-market interdependencies and enhance

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portfolio analysis, they remain largely unexplored in the core literature under review (Demiralay et al., 2022).

Quantitative modelling in agricultural hedging identified the main econometric models and techniques utilized by policy makers, investors and market participants. To strengthen the conceptual structure, we collected information on hedge ratios and hedge effectiveness. Hedge ratio and hedge effectiveness values were identified through a structured full-text keyword search within each included study using the term “hedge ratio” and “hedge effectiveness”. The unity of analysis is the individual article. As aggregation conditions, if a study reported multiple hedge ratios (e.g. across alternative models, commodities, type of hedge , or type of market derivative), the retained value corresponds to the study’s primary empirical specification or baseline model, otherwise the model most emphasized in the Results and Conclusions. Only studies reporting hedge ratios between spot and futures of the same agricultural commodity were retained for numerical aggregation, ensuring methodological comparability. If more than one agricultural commodity was present in the article , corn was selected as a crop.

Table 4-Spot–futures hedge ratio reporting under strict comparability criteria.

N	Median HR	Max	Min
16	47,50%	191,50%	1,00%

Table 4 shows sixteen HR (Hedge Ratios) which met all conditions of aggregations criteria. Regarding Hedge Effectiveness, only six studies reported variance-based hedge effectiveness measures under comparable spot–futures specifications, ranging from 0,00% to 32,20% indicating limited standardization in performance reporting. The six-hedge effectiveness selected obeys the relationship of decreasing variance of hedge portfolio using hedge ratio compared to unhedged portfolio (Ederington Louis H., 1979). The limited number of directly comparable estimates reinforces the decision to adopt a descriptive aggregation approach rather than a formal meta-analysis.

The dispersion observed in Table 4 indicates substantial heterogeneity in reported spot–futures hedge ratios across studies (minimum 1,00%, maximum

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191.50%, median 47,50%). This variability reflects differences in sample periods, commodities, markets, and econometric specifications adopted in the respective studies. The descriptive statistics reported do not imply convergence toward a common hedge ratio across agricultural commodities

To enhance the comparability of the reviewed articles, a reporting transparency assessment was performed using four objective criteria: 1) explicit reporting of hedge ratio values, 2) explicit reporting of hedge effectiveness measures ,3) clear specification of sample period , 4) clear identification of empiric model across the 66 papers sample. The results are in table 5.

Table 5-Transparecy Assessment.

Criteria transparency assessment	% Sample
1)Hedge ratio explicitly reported?	66,10%
2)Hedge effectiveness explicitly reported?	43,94%
3)Sample period clearly reported?	89,39%
4)Empirical model clearly identified?	93,94%

Table 5 shows that most articles clearly identify the empirical model utilized (93,94%) and the reported the sample period (89,39%). However, only 66,10% explicitly reported the numerical hedge ratio values, and 43,94% presented quantitative hedge effectiveness measures.

These results indicate that although the methodological structure of the papers is generally crystalline, performance metrics are not consistently reported. This may be one of the reasons why only 16 papers met the strict comparability criteria for hedge ratio aggregation and why only 6 articles could be included in the hedge effectiveness descriptive synthesis.

To complement the reporting transparency assessment, we evaluated methodological robustness based on two objective criteria: (i) the presence of at least one robustness test (e.g., alternative specifications, subsample analysis, or rolling estimation), and (ii) the implementation of out-of-sample validation. The inspection of the 66 article sample shows that 45,45% of them performed robustness tests like alternative forecast horizons or models refits. Regarding the out-of-sample validation, only 28,79% of the sample performed this kind of forecast.

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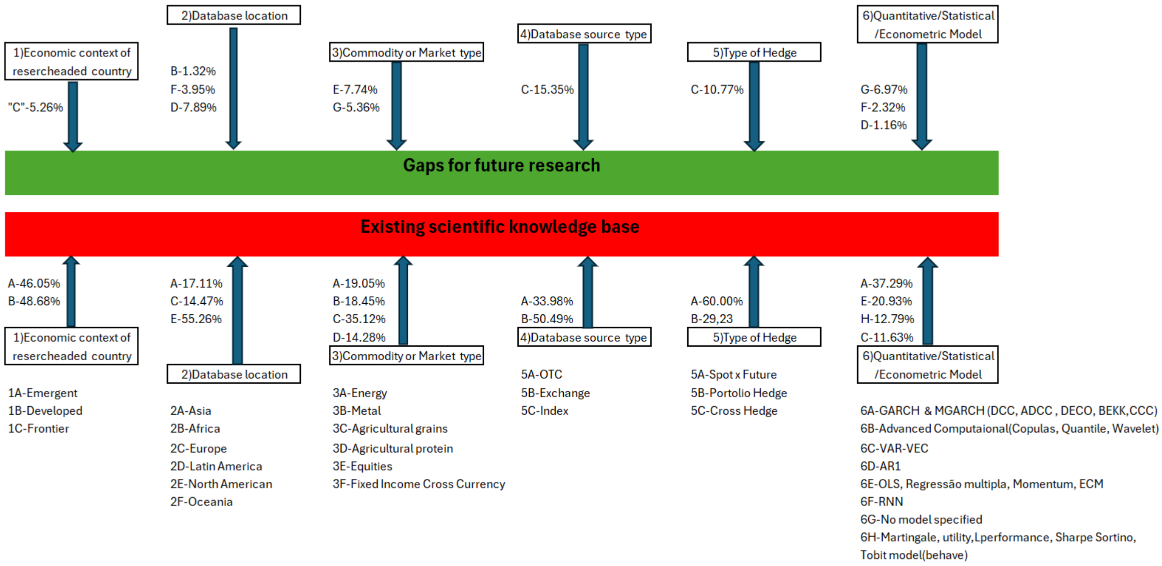
The frequency of subcategories is a vital source of information that can evidence abnormalities and inform the development and improvement of decision-making functions (Pinto & Sobreiro, 2022).

Figure 8-Classification and frequency of Categories and Sub-Categories



The classification and frequency of each category and subcategory 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:

1) Frontier countries had a lower frequency, and their representativeness is very small in World agricultural production. The lack of liquidity and access to foreign investment can create research gaps in the in-depth study of specific agricultural products, such as coffee in Vietnam and spices in India.

2) Emergent and frontier countries usually face logistics issues, such as a poor transport network. These issues raise questions about fuel volatility influencing commodity prices and should therefore be addressed 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

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to enhance futures markets and develop new products can provide rich research opportunities to address gaps in futures markets.

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).

8)The absence of GARCH-X and MGARCH-X models to estimate hedge strategies considering exogenous variables may represent a research gap, if we consider that the basis acts like a summary of all exogenous variables (logistics, climatic, geopolitical crises).

5. Conclusions

This study employs a systematic literature review to conduct comprehensive science mapping. A classification framework comprising six categories was developed to provide a standardized approach to understanding 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 absence of MGARCH-X models to estimate hedge ratios,(iii)significant influence of fuel prices and logistics costs in countries with high dependency on oil imports. (iv)the high presence of emerging markets as corresponding authors´ countries, confirming the protagonist role of these countries in global agricultural commodity producing and a dispersed network of collaboration among authors, (v)the necessity to

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develop new agricultural exchange products that fit the local characteristics of the emerging market.

One limitation of this study is its excessive focus on futures markets and the basis; other shortcomings arise from the statistics on the hedge ratio, hedge effectiveness, and the size of the time spans, which could be explored in depth in a future meta-analysis. Other derivative instruments, such as options and swaps, warrant further investigation into future research. Additionally, future studies should empirically address the research questions, for example, through meta-analysis, performance forecasting, or identification of the conditions under which specific methods are more effective.

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