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A systematic review on price volatility in agriculture

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# A Systematic Review on Price Volatility in Agriculture

## **Abstract:**

The recent extreme volatility in agriculture prices determines serious repercussions to various stakeholders and levels in the food value chain, *i.e.*, producers, intermediaries, and customers, at micro-, meso- and macro-economic governance levels, respectively. Persistent high/low degree of agriculture prices leads to unsustainable production/consumption patterns, thus representing an impediment to reaching the goal of *responsible consumption and production* (UN-SDGs 12). The lack of comprehensive real-time information on price volatility's internal and external factors often resulted in an inconclusive and counterintuitive outcome while performing empirical estimation. The present review was conducted using the *PRISMA* framework to systematically identify and analyze literature from two important databases. Papers have been grouped by volatility drivers, governance levels, theoretical approaches, and background data types. The present review is a valuable starting point to understanding the links between multi-dimensional factors affecting the persistent price volatility and the theoretical and empirical analytics trends to provide the computational advancement needed to cope with model estimation issues. It also highlights the importance of a paradigm shift in researching agriculture price volatility to addressing food crises, considering principal objectives and perspectives such as food security, poverty alleviation, sustainability in food value chains, and resilience of food systems across the globe.

**Keywords:** Price volatility; food crises; microeconomy; macroeconomy; nonlinear time series analysis.

## **1 Introduction**

The recent abrupt surges in agricultural prices have triggered a global crisis requiring researchers' attention to understand its nature, drivers, and destined impacts across the globe. The persistent low and high degree of price changes refer to *price volatility* in agricultural markets. They determine serious repercussions to various stakeholders' representing or forming various governance levels of the economy, *i.e.*, farmers (production), middlemen (marketing), and customers (consumption) at micro-, meso- and macro-economic levels, respectively (Fofana et al., 2009). The subsequent unsustainable production and consumption decisions (patterns) also impede the UN global goal of *responsible consumption and production* (SDGs 12).

Price volatility is the primary source of uncertainty, and its identification and measurement require comprehensive real-time information on internal and external factors, often known as price dynamics. Using known partial price dynamics in any numerical estimation/equation often results in inconclusive and counterintuitive outcomes.

The existing literature on price volatility suggests that agriculture price dynamics synergized with macroeconomic forces [phenomena]. These macroeconomic phenomena are the potential source of explaining economic fluctuations in the economy to devise effective policies. However, their [phenomenon] complete dynamic impacts are still unknown (Winne & Peersman, 2016). The numerical estimation/prediction of macroeconomic phenomena like the *food crisis*<sup>1</sup> frequently resulted in contrasting outcomes, and models fall short of the policymakers' expectations. The reason behind inconclusive results is the intrinsic nature of food crisis drivers. These drivers often co-exist, reinforce each other (FSIN, 2021 a) and are linked at various levels of economy. The existing numerical models on agricultural price volatility used known partial dynamics that increased the modelling error while using a growing number of irrelevant regressors [explanatory variables], called the "*curse of dimensionality*" in literature (Gouel, 2012). This issue raises the importance of selecting representative factors (internal or external), hereafter *feature selection*, for statistical analysis and to make predictions with various available methods. Without completely known dynamics of agriculture price volatility, there is no *perfect solution*<sup>2</sup> available (Al-Tashi et al., 2020). Therefore, a complete structural/ theoretical estimation (Legrand, 2019) and conclusive results may only be possible once the drivers of price volatility are dynamically mapped against macroeconomic phenomena (such as food crises) at different levels of governance in the economy. This dynamically linked approach will provide answers to *understanding and a methodological way* to address food crises.

Among other things, the literature suggests that volatility comes in waves (pulse) with changing amplitudes that superimpose during crises, with an irreversible growth of prices. Both signal (price) components may be observed at the national and international scale, encompassing complex rippling and memory effects propagating from one country to another (Aizenman & Pinto, 2005). The wave of crisis may change researchers' and policymakers' viewpoints as methodological approaches/issues, frequency of data used, and theoretical framework has been evolving continuously.

Studying past food turmoil in agriculture has an important implication in understanding the food crises and evaluating agriculture markets (Blanco et al., 2017) for public policy concerns and achieving SDGs for sustainable agriculture and resilient food systems. For this reason, the global network against food crises (*GNAFC*) was founded by the European Union (EU), Food and Agricultural Organisation of United Nations (FAO), and the United Nations World Food Programme (WFP). The *GNAFC* aims "to prevent, prepare for, and respond to food crises and support" the UN SDGs to end hunger (SDGs 2).

This global alliance aims to reduce vulnerabilities related to acute hunger and promote sustainable and resilient food systems, using a "3x3 approach" to addressing food crises. This approach has required concentrated efforts to understand food crises (Dimension I), support investment in agriculture, food and nutritional security (Dimension II), and identify various drivers of food crises and their linkages to the economy (Dimension III) (FSIN, 2021 b). To the best of the authors' knowledge, no comprehensive study is available that addresses the issues of price volatility in agriculture, mapping drivers of change (Dimension III) at various economic (governance) levels to provide answers to *GNAFC* framework. The present systematic review provides a basis to understand the nature of research dynamism during the wave of food crises (Dimension I) with fruitful insights for future research.

Moreover, the present review also highlights the dynamic research transition related to popular trends about data types (sources) and methods used in commodity and price volatility financialization. This mapping will provide a comprehensive overview of uncertainty in agriculture market dynamics to answer drivers of change and its nature — it helps re-examine conclusive and persistent futuristic results. The final aim is to prepare a background study to find past approaches' weaknesses and gaps and suggest more effective modelling approaches. This approach helps us address agriculture price-volatility-induced food crises and possibly identify key impediments to inclusive growth and sustainable development.

To achieve this goal, we systematically reviewed the current literature available from the two leading and most comprehensive academic research databases (Scopus and Web of Science) from the year 2000 to the year 2021. We report the article selection process using the Preferred Reporting Items for Systematic Reviews (*PRISMA*) framework. The theoretical underpinnings about drivers of change and nature are underlined while empirically analyzing the research approaches/method used for various agriculture enterprises. The previously published reviews predominantly cover price volatility in agriculture in connection with the oil/energy sector

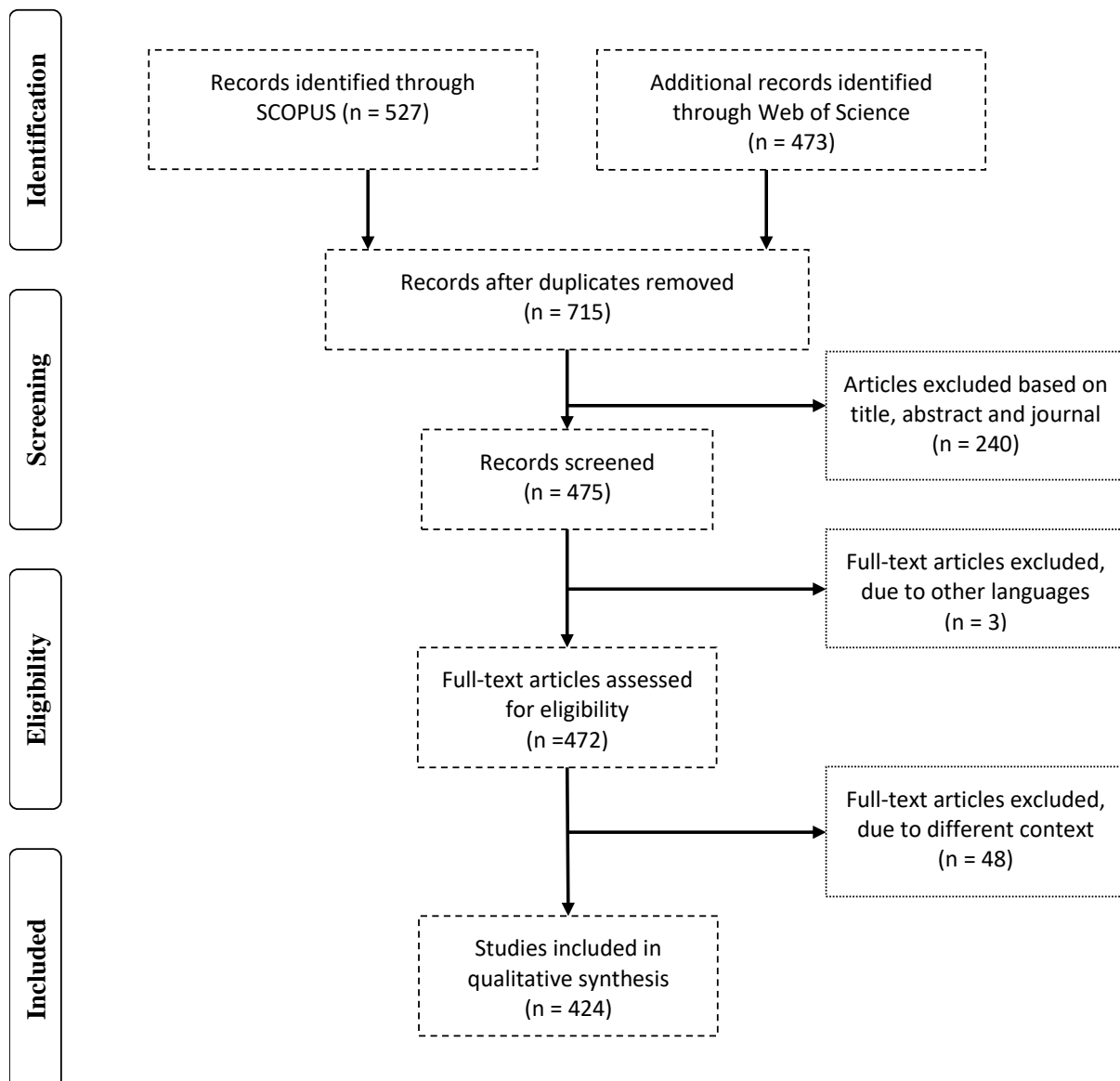
spillover phenomenon, and empirical findings of previously conducted studies showed contrasting outcomes. The agriculture markets (prices) have unique dynamics (endogenous factors) and may be influenced by oil/energy sectors (exogenous factors). However, these dynamics may also change, impeding macro-economic [food] crises.

The structure of the paper is as follows. Section 2 describes the search strategy and selection criteria applied to identify the papers for the current literature review. Section 3 collects the results on identified categories. Future research areas and conclusions are presented in Sections 4 and 5, respectively.

## 2 Methods

Search strings' construction and validation are paramount in a systematic review (Marcos-Pablos & García-Peñalvo, 2018). A three-stage search query was developed to identify articles on price volatility in agriculture. The first two stages were related to the *construction* of search strings, while the third stage was about *validating* the selected keywords. In the first stage, during January 2021, general keywords, *i.e.*, agriculture, price, and volatility, were used to formalize the search string. The initial search string results were compared to a set of highly cited manuscripts on agriculture price volatility and covered only 66% of the critical studies. The exclusion rate of 44% suggested re-formulating the search string and including additional keywords, *i.e.*, market and commodity, while excluding the studies focusing on energy. Therefore, the search string was revised and re-run in both databases during June 2021: (*price AND volatil\* AND agricultu\* AND (marke\* OR commodit\*) AND NOT energy*). As a confirmatory analysis, retrieved records have been searched for concurrent keywords to validate the search string further at the third stage. The strength of the *top-20 keywords* has been measured in terms of word frequency cloud and co-occurrence dendrogram.

We use the structured PRISMA framework (Moher et al., 2009) to show the procedure we implemented to identify, select and analyze the literature on price volatility in agriculture (Figure 1). The research papers have been retrieved through a systematic search of peer-reviewed journals cited in reputed databases. Two databases have been consulted to collect the published literature: SCOPUS and Web of Science. The timeframe considered is from the year 2000 to June 2021<sup>3</sup>. Only papers written in English were considered. The search string was performed on *title, abstract, and keywords* in SCOPUS, while Web of Science covers the *topic* only. We included only peer-reviewed journal articles and review articles. Other documents, such as books, book chapters, and conference papers, were excluded.



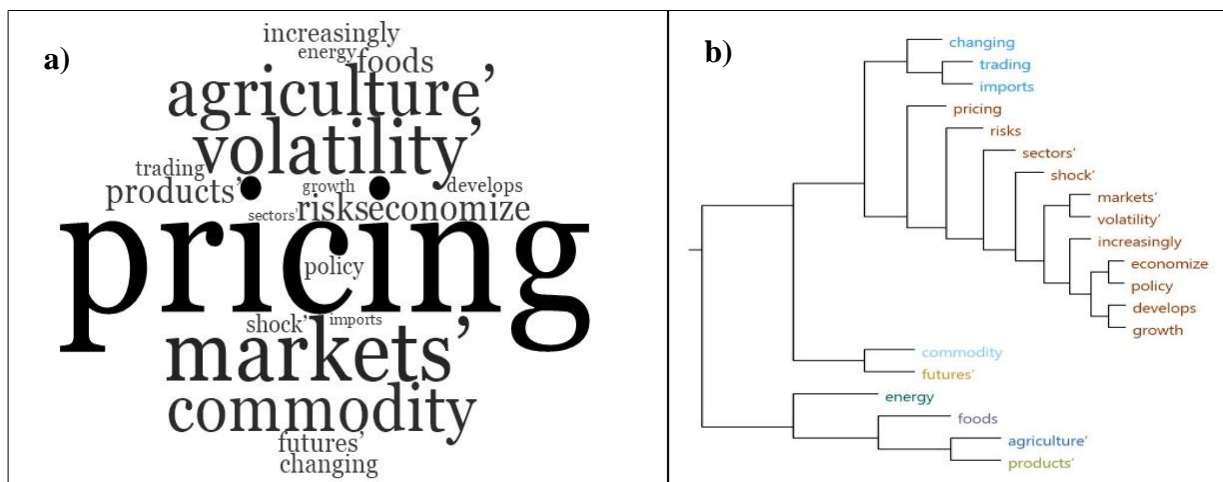
*Figure 1: PRISMA framework for present systematic review*

The search conducted on SCOPUS and Web of Science identified 527 and 473 articles, respectively. After removing duplicates, 715 articles have been evaluated based on a) abstract, b) title, and c) keywords in line with the defined objective of the research. A total of 240 articles were excluded, and 475 were found eligible. Three articles were further excluded because of the full-text language, and 48 records were found out of context after the full-text assessment. These articles are not exclusively studying the price volatility phenomenon (quantitatively or qualitatively) in agriculture. As a result, the original database was reduced to 424 articles. In contrast, price volatility was also mentioned or reported implicitly to other impeding phenomena, such as rural livelihoods and energy markets.

A comprehensive database was built to record and analyze the critical content of each study. The critical information incorporated is (1) author, (2) year of publication, (3) objective, (4) measurement method, (5) sample size, (6) sample composition, (7) methodology, (8) main research topics, (9) country, (10) crop, (11) theory and (12) issues. This information can be found in Appendix-A. Thematic groups based on drivers of price volatility in agriculture were categorized and linked with levels of the economy. The weather was identified as a cross-cutting category (simultaneously affecting more than one economy level).

### 3 Results

Agricultural price volatility is predominantly studied as an oil (energy) sector spillover phenomenon. Therefore, we cannot recover global phenomena such as climate change, food security, and sustainability in the top 20 keywords. The weighted percentages (how often words appear in the text) showed the overall strength (size based on percentage share in total words in a research article) of words in the word frequency cloud (Figure 2a). The result shows that the keywords price, market, volatility, agriculture, and commodity were the top five most frequent words used in previous research with percentages (word counts): 1.67% (14,745), 0.82% (7,217), 0.72% (6,383), 0.67% (5,928) and 0.64% (5,674), respectively.



**Figure 2:** a) Word frequency cloud shows the most frequent top 20 words in the selected studies. b) Word frequency dendrogram shows that the other important keywords for any futuristic systematic research. The diagrams have been obtained by NVivo-10 - query search function.

The word frequency cloud validates the inclusion of the additional selected keywords "markets" and "commodity" in the search string used in this systematic review. The dendrogram (Figure 2b) highlights four main branches, which can be called clusters. The 'trading' and 'imports' on one side and financial terms like 'commodity' and 'futures' on the other were used in two distinct and separate classes of literature. A separate branch of the literature was characterized by the keywords 'products', 'foods,' and 'energy.' In contrast, the wider branch,

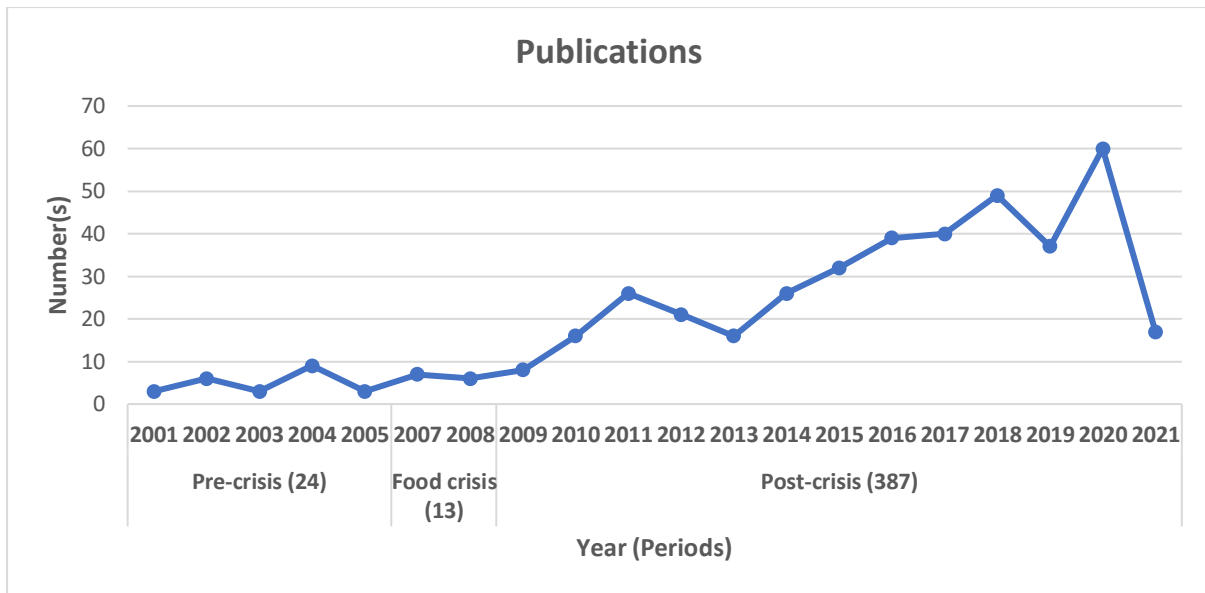
characterized by many interconnected keywords appearing in a cascade, deals with economic and policy aspects within published literature, *i.e.*, 'pricing,' 'risks,' 'sectors,' 'shock,' 'market,' 'policy,' and 'growth.'

### **3.1 The role of the world food crisis**

An overarching aspect emerging in this survey is represented by the so-called World Food Crisis, an upsurge in food prices in 2007/2008. Over just a few months, international wheat and maize prices doubled, and international rice prices tripled. This price increase results in over 130 million people being forced into a vicious cycle of poverty and a 56% increase in import bills of developing countries (Headey, 2013). The commodity price volatility has noticeably impacted the governments and farmers/household decision-making (Dehn et al., 2005). These decisions may reinforce the negative impacts and not counterbalance them during better economic conditions (Cariolle & Goujon, 2015).

World food crises dramatically affected the literature, as they changed researchers' and policy makers' viewpoints and methodological approaches, as much as the frequency of data used and the theoretical framework (Jones & Hiller, 2017). The food crisis in 2007/2008 served as a cut-off period for our research timeline; we have created three critical timelines, Pre-crisis (before the year 2007), food crisis (during the years 2007 to 2008), and post-crisis (after the year 2008).

Figure 3 shows the number of records on the y-axis and the period (years) on the x-axis in the database, highlighting food crisis has caught the attention of various authors as the highest number of articles (an average of about 32 per year) has been published during the post-crisis period. Before this, only 37 records were found in the other two periods (5 per year in pre-crisis and 7 per year during the food crisis period).

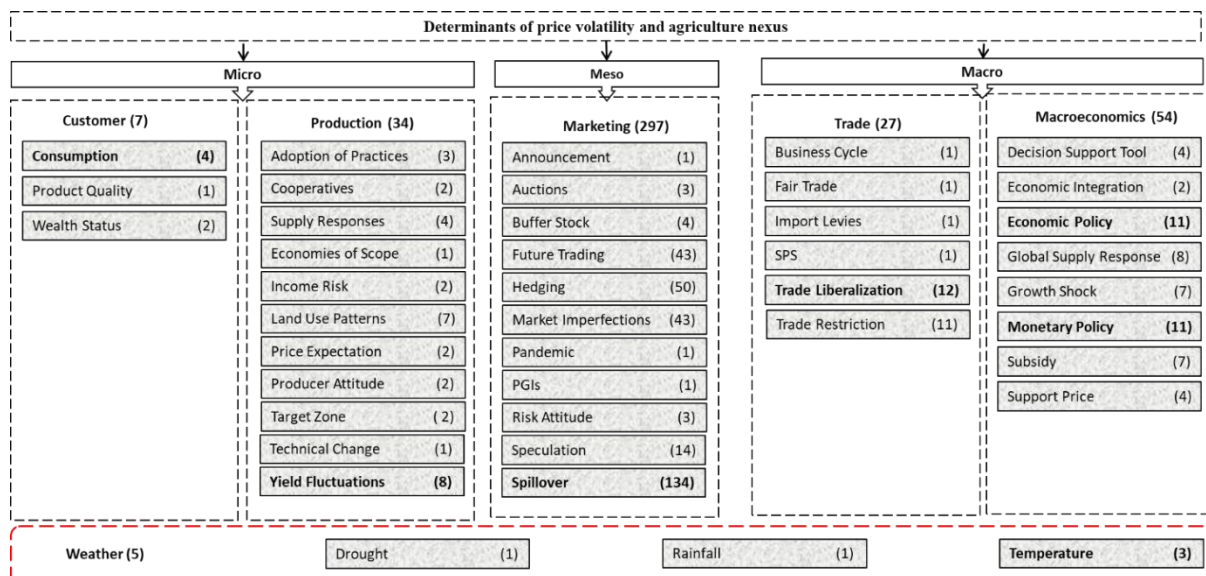


**Figure 3:** Selected articles by publication year (periods).

The highest number of articles (an average of about 32 per year) was published post-crisis. Before this, only 37 records were found in the other two periods (5 per year in pre-crisis and 7 per year during the food crisis period).

### 3.2 Volatility drivers

The analysis of 424 papers provided information about several vital multi-dimensional drivers of price volatility in agriculture. These drivers are classified into *six main categories* and linked with *three economic levels* of governance: micro-, meso-, and macro-level (Figure 4). There are 42 drivers identified and distributed to three economic levels. Marketing (297) is the most diverse category regarding the total number of drivers and frequency count, while weather (5) was the least. Based on existing literature findings, the weather was considered a *cross-cutting category* among all levels (Bhanumurthy et al., 2013; Feng et al., 2014; Kahiluoto, 2020). The weather may influence the changes in production (food availability), disrupt the food volume, and alter the trade patterns in domestic and international markets (Santeramo et al., 2021). In the current literature review, weather can affect the volume of trade and investment (Koizumi 2019; Koizumi & Furuhashi 2020), market imperfections (Larson, 2004 a), and price/productivity risks channels (Mainardi, 2012a).



**Figure 4:** Research topics and frequencies. The number inside the parentheses is frequency as the main topic. The drivers in bold have the highest frequency counts in their respective categories.

At the production level, the variability in prices arises from multiple factors ranging from producers' own decisions (Assouto et al., 2020; Bellemare et al., 2020) about land use (cropping) patterns (Liu et al., 2016), adoption of specific practices, such as environmentally friendly or not (Gródek-Szostak et al., 2019; Lefebvre et al., 2020), and variability in production/area (Fretheim & Kristiansen, 2015; Santeramo et al., 2018). The land-use pattern was studied during the food crisis and post-crisis periods. However, yield fluctuation (8) and land-use patterns (7) were ranked first and second based on total frequency counts. Cooperatives (Bolotova et al., 2008) and producer attitude (Bellemare et al., 2013) were also considered potential sources of price volatility in agriculture at the microeconomic/production level.

Some of the multi-dimensional drivers, *i.e.*, announcement effect of world agricultural supply and demand estimates (Xie et al., 2016), buffer stock (Fraser et al., 2015), pandemic (Ezeaku et al., 2021a), protected geographical indications (Vidaurreta et al., 2020) risk attitude (Franken et al., 2014) and speculation (Bozorgmehr et al., 2013) were the only drivers reported in post-crisis at the marketing level. The most abundant driver was 'spillover,' which appeared 134 times during the pre-crisis (3), food-crisis (1), and post-crisis (130) periods. Most of the researchers' studied commodity market linkages with price volatility, *e.g.*, with energy markets (Awartani et al., 2016; Balcilar & Bekun, 2020) or non-energy markets (Arnade et al., 2017; Awokuse & Wang, 2009). These previous results confirmed that prices move together in response to common macroeconomic shocks, commonly known as the excess co-movement

puzzle in literature; for more details, please see (Pindyck & Rotemberg, 1990). The second most frequent factors within the marketing cluster were marketing imperfections and future trading, with 43 items each. These studies were related to government interventions (Misra, 2012), market infrastructure (Shively & Thapa, 2017) related to marketing imperfection while digital trading platforms (Banker et al., 2011), and speculative behavior (Bohl et al., 2018).

The monetary and economic policies were the only factors studied predominantly during the food crisis (1) and post-crisis (10) periods. However, subsidy (7) and support price (4) were studied during pre-crisis (1) and post-crisis periods (6 and 3), respectively. The issue of subsidy and support prices became critical during the post-crisis period of price volatility in agriculture. These issues first appeared in 2002 and 2004, respectively, with studies aiming to investigate the implications of a government price support program on price dynamics (Chavas & Mehta 2004; Kim & Chavas, 2002). In the post-crisis period, subsidies were studied in connection with food (in)security (Dev & Rao, 2010) and food/biofuel policies (Babcock, 2012).

Extreme weather conditions like drought and climate variability may further exacerbate the conditions and influence different dimensions of food security, bringing undulating effects to various sectors of the economy (Mainardi, 2012b). The researchers have conducted studies highlighting weather's role in increasing production variability (Boyd & Bellemare, 2020), affecting the availability dimension of food security, resulting in product quality issues related to the utilization dimension of food security at the microeconomic level (Carvalho et al., 2016). The missing stability dimension of food security at the meso-economic level has become an essential phenomenon. It has led to study issues related to wildly speculative behavior (Femenia, 2010) and supply disruption during the current global pandemic (Ezeaku et al., 2021b). Trade liberalization (8) was widespread during the post-crisis period to insulate domestic prices (Kunimitsu et al., 2020), whereas further studies conducted during the post-crisis period to define the impact of joining the World Trade Organisation (Chang et al., 2011) and risk associated with trade (Zhang 2015) in relation with volatility.

Mapping multi-dimensional drivers have revealed the overall variability and important contributing channels in the food crisis wave. The researchers are exaggerating production and marketing anomalies, *e.g.*, yield fluctuations and the co-movement of agriculture price volatility.

The role of weather has been studied as a catalytic factor that affects the various dimensions of food security. Previous research paid little attention to business cycle models<sup>4</sup>. These models require validation in the presence of externalities and interactions—between different sectors of the economy at the macroeconomic level.

### 3.3 Market theories

Table 1 reports the dominant theories used in the different types of markets. There are two main types of markets reported in published articles: spot market – which deals with current (cash) values, and future market – which deals with the financialization (contracts) of commodity markets. Some studies reported spot and futures markets related to the reference date. Therefore, we have created a third category, *mixed* market type, to analyze those articles separately. All three types of markets have reported 34 different theories — spanned over 127 articles in different periods. The rest of the 297 records did not report any specific theory.

**Table 1:** Dominant theories during different periods

Theory (Counts)	Market Types		
	Mixed (17)	Future (37)	Spot (73)
Arbitrage Pricing (5)	2018	2007; 2018; 2021	2019
Asymmetric Price Adjustments (1)	-	-	2004
Asymptotic (8)	2019	2014; 2018	2009-10; 2012; 2015; 2017
Central Limit (2)	-	2017 (2)	-
Behaviour (4)	2016	-	2004; 2015-16
Chaos (3)	2020	-	2014; 2018
Cobweb (6)	-	-	2010; 2017; 2019 (2); 2020-21
Cointegration (1)	-	-	2014
Commodity Price Stabilization (10)	-	-	2003; 2005; 2008; 2012; 2016 (2); 2017-20
Competitive Storage (22)	2015-16; 2017 (2); 2018; 2020	2010 -11; 2014-15 2016; 2019-20	2002; 2004; 2011; 2014 (2); 2015; 2018 (2); 2019
Contagion (1)	-	2020	-
Contrary Opinion (1)	-	2020	-
Efficient Market (3)	2012	2016; 2019	-
Endogenous Price Fluctuations (5)	-	-	2011; 2013; 2015 2017-18
Expected Utility (8)	-	2021	2007; 2014; 2018 (3); 2020 (2)
Expertrons (1)	-	-	2020
Extreme Value (4)	-	2010; 2015; 2019	2008
General Equilibrium (4)	2018	-	2016 (2); 2020
International Trade (2)	-	-	2019 (2)
Intraday Patterns (1)	-	2018	-
Islamic Monetary Value (1)	-	2020	-
Market Microstructure (1)	-	2018	-
Microeconomic (3)	-	2010	2009; 2018
Neoclassical (2)	-	-	2017; 2020
Normal Backwardation (2)	2014	2020	-
Political Economy (3)	-	-	2012-13; 2017

Theory (Counts)	Market Types		
	Mixed (17)	Future (37)	Spot (73)
Portfolio Management (7)	2017	2014 (2); 2017	2015; 2018; 2020
Probability (8)	-	2012; 2013 (2); 2014; 2020	2010; 2012; 2020
Quantity Money (1)	-	-	2014
Random Walk (2)	-	2016	2017
Rational Expectations (1)	<b>2005</b>	-	-
Speculation (2)	2014	2019	-
Standard Cost (1)	2014	-	-
Transactions-Cost (1)	-	-	2010

Notes: **Bold** and *italics* fonts represent pre-crisis and food crisis periods, respectively. There was a total of 34 distinct theories reported belonging to 127 different selected articles. The selected records were scrutinized based on market types: spot (current), future, and mixed (combined spot plus future).

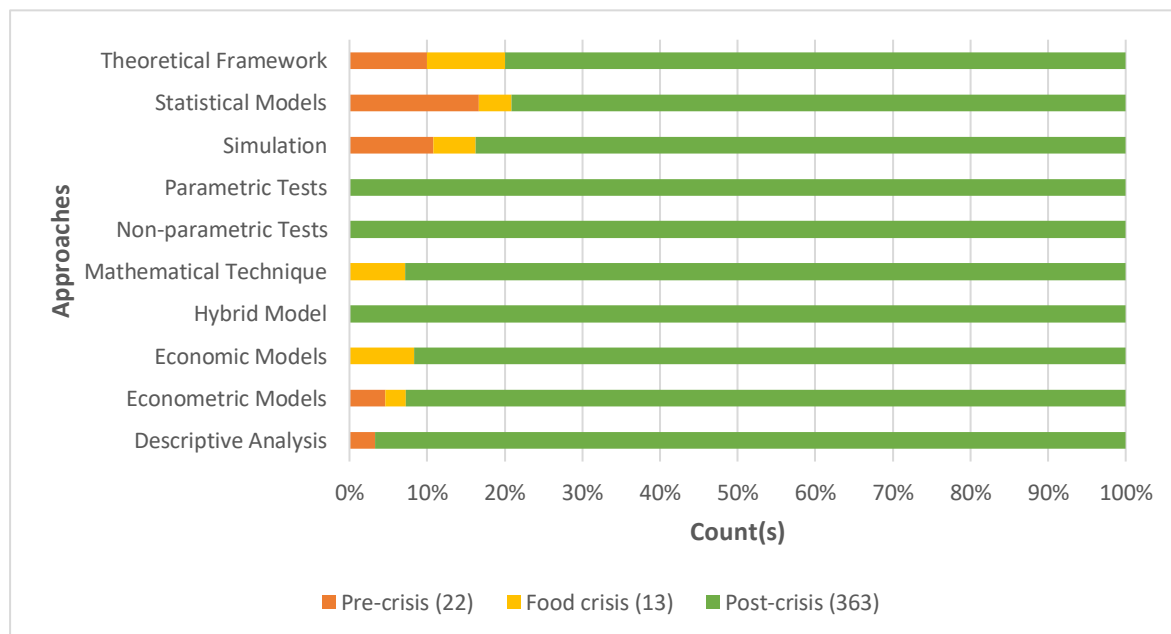
The results reveal that only one study each reported pre-crisis (Yang et al., 2005) and food crisis (Turvey & Komar, 2007) periods representing mixed and future market types, respectively, while other theories were applied during the post-crisis period. The spot market was the most abundant market type in which 73 total articles reported different theories, *i.e.*, pre-crisis (6), food-crisis (3), and post-crisis (64) articles. The remaining 54 records representing 23 different theories fall into the remaining two market types, *i.e.*, mixed and future markets. The competitive storage theory (22) was the most frequently reported in all market types, while twelve theories were studied only once, each in different markets and periods. The commodity price stabilization theory was the only theory studied in all periods of the spot market.

In comparison, the quantity theory of money (Zhang 2014) was the only dominant theory that appeared in the post-crisis period in spot market studies. These studies have gone into great transition in terms of theory starting from price stabilization (Yang et al., 2001) in both market types towards more sophisticated theories for addressing various issues, *i.e.*, arbitrage pricing for asymmetric price adjustments (Mao et al., 2021), cobweb for sustainable food value chain (Muflikh et al., 2021) and expected utility theory for asymmetric information (Huang et al., 2021). The researchers tried a wide range of theories as agriculture markets do not provide a “*natural correction process*” for price volatility and require distinguishing between endogenous and exogenous price volatility (Huffaker et al., 2018). The wave of the food crisis changed the dynamics of conducting empirical research on agriculture price volatility with diverse theoretical backgrounds.

### 3.4 Model-based approaches

The selected papers used diverse methodological approaches to quantify the dynamics of price volatility. Figure 5 shows the reported methodologies adopted during the wave of food crises in research papers.

We have ten different methodological approaches in the present review compared to Frey & Manera (Frey & Manera, 2007), where only econometric models were discussed in detail. These approaches are characterized by 1) type of data used (qualitative or quantitative), 2) distribution (parametric or non-parametric), 3) inferences (econometric, statistical, or mathematical models), 4) prediction (machine learning or hybrid models<sup>5</sup>), and 5) theoretical framework. The pre-crisis and food crisis periods were not significant in terms of the total number of records [pre-crisis (22) & food crisis (13)]; no. of approaches [pre-crisis (5) and food crisis (6)]. This outcome indicates that approaches used to address the price volatility in agriculture from 2000 to 2008 (both regimes) are pretty similar.



**Figure 5:** Methodological approaches used in the selected studies.

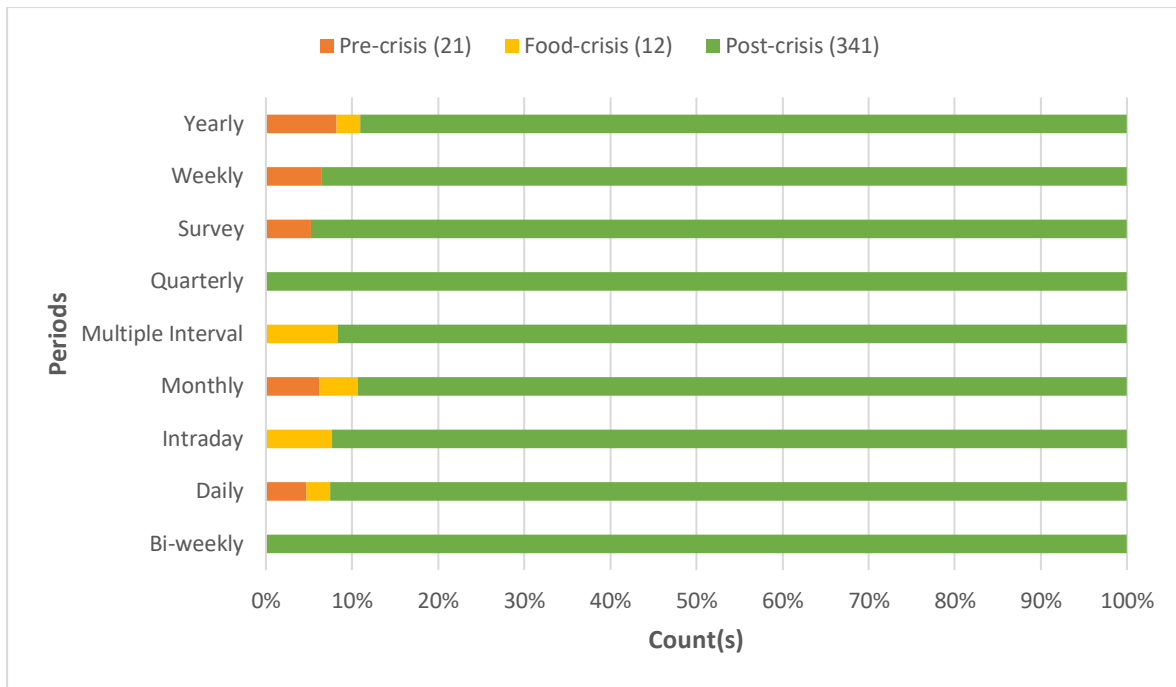
Notes: The post-crisis period was the most distinct in terms of no. of approaches used (10) as compared to pre-crisis (5) and food crisis (6).

The post-crisis period was characterized as the most varied period in which all types of methodologies were used. There were 262 records retrieved, addressing various econometric modeling approaches for short-run and long-run relationships, *such as* autoregressive conditional heteroskedasticity (ARCH/GARCH) models, cointegration, and other dynamic approaches. Contrary to the previous findings of Beck (2001), the researchers' present sampling framework applied both ARCH/GARCH processes to storable and non-storable (perishable) commodities. Moreover, these authors also considered simulation (37) and mathematical

techniques (14) to understand better the recursive character of price volatility (continuous repeating cycles of low/high prices). In simulation studies, Multi-agent systems (LI et al., 2018) and general equilibrium models (Valenzuela et al., 2007) were used extensively. In contrast, in studies based on mathematical techniques, the researchers used dynamic optimization models and wavelet coherence analysis (Zivkov et al., 2019) to detect price volatility's presence, persistence, and co-movement. Various machine learning algorithms analyzed other essential features of the post-crisis period, such as artificial neural networks with backpropagation algorithms for price volatility forecasting (Ayankoya et al., 2016). The machine learning algorithms and hybrid models were introduced in 2011 (Karia & Bujang, 2011) and 2013 (El Benni & Finger, 2013), respectively.

### **3.5 Data sources**

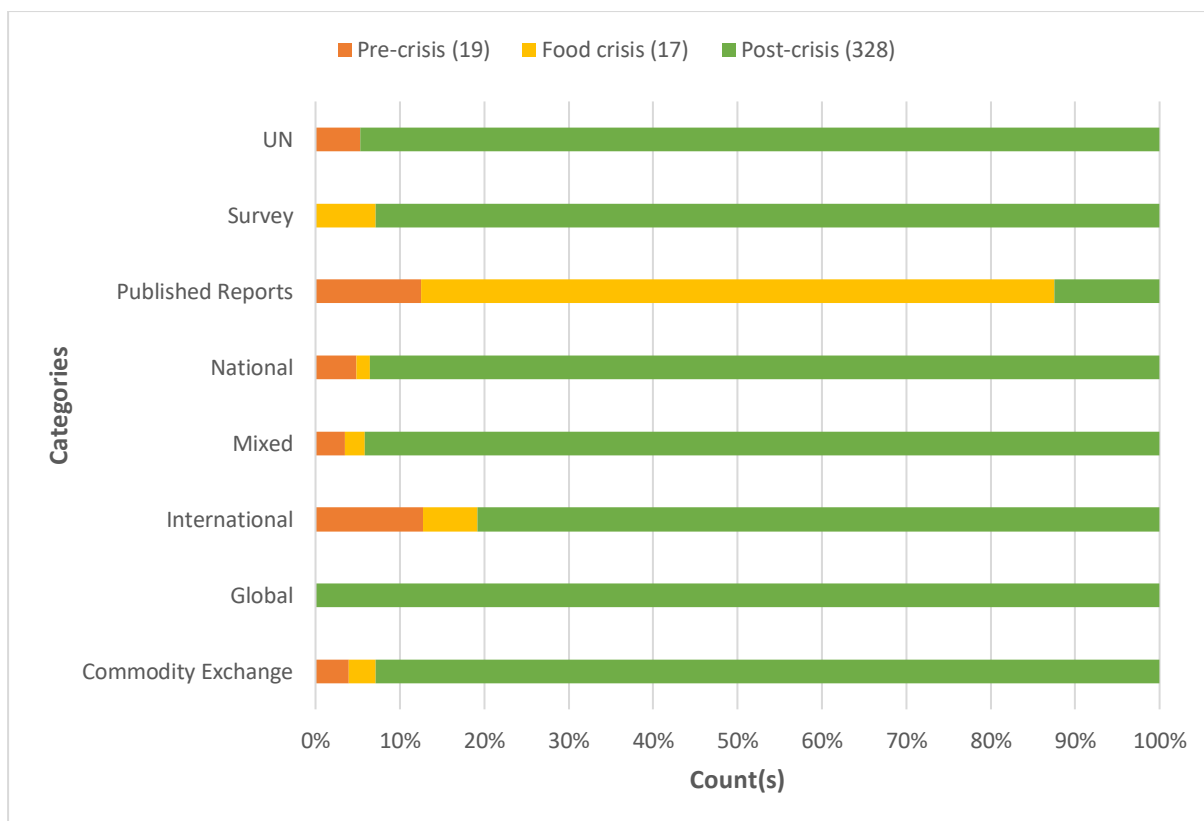
The data(bases) use changes during the food crisis wave were analyzed and grouped into nine frequency types (Figure 6). During the pre-crisis and food crisis periods, the authors used low-frequency data, *e.g.*, yearly (Yoshimoto, 2005) and monthly (Bonroy et al., 2007) data, to identify the presence of volatility in agriculture markets. However, during the post-crisis period, there was a growing concern over the financialization of commodities, which diverted the attention towards high-frequency data in quantification and volatility spillover from one market to another. The researchers used intraday (Adjemian & Irwin, 2018), daily (Monk et al., 2010), and weekly (Istudor et al., 2014) frequency datasets, considering the seasonal variations. Multiple interval type (Ott, 2014) of data was also used to differentiate inter and intra-seasonal responses where authors retrieved multiple time series data, *e.g.*, monthly and yearly series, simultaneously. Different data types (intraday, daily, weekly, *etc.*) and their regime-switching behavior (Santeramo, 2022) due to aggregation characteristics (taking averages and converting various data frequencies, *i.e.*, daily into weekly/monthly) have affected empirical findings. This aggregation decreased the average level of F-statistics relative to daily data — during post-crisis (Bachmeier & Griffin, 2003; Bettendorf et al., 2003; Guerra V et al., 2015; Sarris & Hallam, 2006).



**Figure 6:** Different types of data frequencies used in selected studies.

The data(bases) categorization was consulted during the sampling framework and grouped into nine different frequency types.

Figure 7 categorizes the results of various databases used in selected studies. The most widely used databases were those collecting information about commodity exchange that appeared 118 times post-crisis. The growing financialization of commodities resulted in greater utilization of databases, such as *Bloomberg*, *Thomson Reuters*, *S&P Global*. The upward trend in consulting UN databases, such as *FAOSTAT*, *ILOSTAT*, and *COMTRADE*, was also apparent in the post-crisis period, with 18 records identified in this category.



**Figure 7:** Description of database category used in selected studies.

Notes: Overall, eight different types of database categories were reported in selected studies. Nineteen database categories were found in pre-crisis, while 17 different database categories were reported during the food crisis period.

The international database category also gained momentum and appeared in various published articles during the food crisis (3) and post-crisis (38) periods. Farm Accountancy Data Network – FADN (Ciaian & Kancs, 2011; El Benni & Finger, 2013), United States Department of Agriculture – USDA (Bozic et al., 2012; Isengildina-Massa et al., 2008), and International Monetary Fund – IMF (Elmarzougui & Larue, 2013; Gontijo et al., 2020) were among the most important databases in this category.

Among other things, the researchers retrieved data from national (62) and mixed category (86) databases in the selected studies. In the mixed category, researchers retrieved data from multiple national and international statistical databases and conducted studies only during the post-crisis period. The remaining records fell into primary studies (14) through well-defined questionnaire surveys administered in person (Haile et al., 2019) or online surveys (Heyder et al., 2010), while secondary studies (8) retrieved data from published reports– predominantly in the food-crisis period. The result reveals that the dynamics of data sources had changed quite enormously during the wake of the food crises. The use of index-based commodities was quite common during post-crisis period. This was one of the possible sources of irregularities and

inconclusive inferences in selected studies. Therefore, the commodity-specific research work required to avoid such irregularities for conclusive results (Ghoshray, 2011).

### **3.6 Geographical locations**

Geographical dynamics in previously published research have provided significant insight into current research trends in comparison with drivers of price volatility in agriculture across the globe (Table 2). The global category was created if research was conducted in more than one country. At the macroeconomics level, two studies were reported in pre- and food-crisis periods. In pre-crisis, studies were related to an agricultural price support program, *i.e.*, subsidy and support price (Chavas & Kim 2004), while studies published during the food crisis catered towards macroeconomic policy measures (Bonroy et al., 2007; Kilima et al., 2008). The global level studies mainly referred to macroeconomics (4), marketing (34), and weather (3) levels, while surprisingly, Asian region studies were prominent at the production (3) level. This result implies that food availability is still an important issue in Asia. Most of the studies at the marketing (meso-economic) level were conducted during the post-crisis period, except for 13 studies in the other two periods (pre-crisis (10) and food-crisis (3)). The highest reported frequencies for Africa (10), Asia (28), Global (34), and North America (17) level studies were for spillover determinants in the marketing category. This finding shows the overemphasis of the researchers on *price transmission* mechanisms for different oil/energy markets onto agriculture commodity markets (spot/future). The EU region (11) also emerged at the marketing level. Still, the researchers aimed to work on hedging mechanisms, *i.e.*, risk management strategies (Roussy et al., 2018) or risk margins in agricultural insurance (Url et al., 2018). The global (5) and Asian (5) level studies were prioritized related to trade (macro-economic level) openness. Most studies were conducted post-crisis except (Elobeid & Tokgoz, 2008; Srinivasan & Jha, 2001). This implication implies that the researchers were greatly concerned about the greater role of government for public policy interventions in markets and economies at the meso- and macro-economic levels, respectively.

**Table 2:** Location and year of publications of main research topics.

Category	Main Topic	Location	Pre-crisis	Food crisis	Post-crisis
Customer (7)	Consumption	Africa (01) <b>Asia (02)</b> N. America (01)	-	-	2015-16, 2018-19
	Product Quality	S. America (01)	-	-	2016
	Wealth Status	Africa (01) Oceania (01)	-	-	2016, 2021
Macroeconomics (46)	Decision Support Tool	Africa (01) EU (01) N. America (01) Oceania (01)	-	-	2016, 2018 (02), 2019
	Economic Integration	EU (01) Global (01)	-	-	2019 (02)
	Economic Policy	Africa (01) <b>Asia (03)</b> EU (01) <b>Global (03)</b> N. America (01)	-	2008	2011-12, 2014, 2016, 2018 (02), 2020 (02)
	Global Supply Response	Asia (01) EU (02) <b>Global (04)</b>	-	-	2010-11, 2012 (02), 2013, 2016, 2018
	Growth Shocks	Africa (02) <b>Asia (03)</b> EU (01)	-	-	2010-11, 2016 (02), 2019, 2020
	Monetary Policy	Africa (02) Asia (01) <b>Global (04)</b> N. America (01)	-	2007	2010-11, 2017-19, 2020 (02)
	Subsidy	Africa (01) Asia (02) Global (02) N. America (02)	2002	-	2010, 2012, 2015, 2017 (02), 2019
	Support Price	Asia (02) N. America (01)	2004	-	2012, 2016
	Auctions	Asia (01) Global (01) N. America (01)	2004	-	2009-10
	Buffer Stock	Africa (02) Global (02)	-	-	2012, 2015, 2018 (02)
Marketing (209)	Future Trading	Africa (03) <b>Asia (07)</b> Global (03) N. America (06)	2002	2008	2010 (03), 2011-14, 2016, 2017 (02), 2018 (02), 2020 (04), 2021
	Hedging	Africa (03) Asia (08) <b>EU (11)</b> Global (10) N. America (06) S. America (02)	2002, 2004, 2005 (02)	2007	2009 (02), 2010, 2011 (05), 2012 (03), 2013(02), 2014 (03), 2015 (03), 2017 (03), 2018 (08), 2019, 2020 (03), 2021
	Market Imperfections	Africa (01) <b>Asia (11)</b> EU (05) Global (05) N. America (06)	2003	-	2011 (04), 2012-13, 2014 (03), 2015 (03), 2016 (02), 2017, 2018 (5), 2019 (03), 2020 (03), 2021
	Protected Geographic Indications	EU (01)	-	-	2020
	Risk Attitude	EU (01) N. America (01)	-	-	2014, 2017

Category	Main Topic	Location	Pre-crisis	Food crisis	Post-crisis	
	Speculation	Asia (05) EU (01) Global (02) N. America (01) S. America (01)	-	-	2009-11, 2013,2015, 2017 (02), 2019-21	
		Africa (10) Asia (28) EU (09) <b>Global (34)</b> N. America (17) S. America (04)	2003 (02), 2004	2007	2009 (04), 2010 (03), 2011 (03), 2012, 2013 (04), 2014 (08), 2015 (06), 2016 (11), 2017 (13), 2018 (11), 2019 (10), 2020 (18), 2021 (06)	
Production (29)	Adoption of Practices	EU (01) Global (01)	-	-	2017, 2020	
	Cooperatives	N. America (02)	-	2008	2016	
	Dynamic Supply Responses	Africa (01) Asia (02) Global (01)	-	-	2016, 2018, 2020 (02)	
	Economic Scope of	Global (01)	-	-	2018	
	Income Risk	Asia (01) EU (01)	-	-	2013, 2015	
	Land Use Patterns	<b>Asia (03)</b> EU (02) N. America (01) S. America (01)	2002	-	2015 (03), 2016, 2018-19	
	Price Expectation	Africa (01)	-	-	2019	
	Producer Attitudes	Africa (01) Global (01)	-	-	2013, 2020	
	Target Zone	Global (01)	-	-	2018	
	Technical Change	EU (01)	-	-	2021	
	Yield Fluctuations	Africa (02) Asia (01) EU (01) Global (01) N. America (01)	2002	-	2010, 2014, 2016, 2017 (02)	
	Trade (23)	Business Cycle	S. America (01)	-	-	2017
		Fair Trade	Global (01)	-	-	2014
Import Levies		EU (01)	-	-	2021	
SPS		Global (01)	-	-	2019	
Trade Liberalization		<b>Asia (05)</b> Global (03) N. America (01)	2001	2008	2010-12, 2015,2016 (02), 2020	
Trade Restrictions		Africa (03) EU (02) <b>Global (05)</b>	-	-	2012 (02), 2015 (02), 2016, 2017 (03), 2018-19	
Weather (05)	Drought	Africa (01)	-	-	2012	
	Rainfall	Asia (01)	-	-	2013	
	Temperature	<b>Global (03)</b>	-	-	2016, 2019-20	
<b>Grand Total</b>		<b>319</b>	<b>15</b>	<b>07</b>	<b>297</b>	

Notes: The **bold values** in the location column indicate the highest rank of location within the category based on the number of frequencies in selected studies.

### 3.7 Agricultural sector

The key information about agriculture sectors was also analyzed (Figure 8). A total of 87 records were excluded because of irrelevance to agriculture. Sub-sectors were created into a two-step verification process. Identifying different sub-sectors (crops) within agriculture was scrutinized based on the highest number of crop (sub-sector) presence in the selected research articles. For example, (Abbott & Borot de Battisti, 2011) first separated biofuel from crops.

Then, we categorized millet, rice, sorghum, and wheat into the cereals sub-category. The sub-sector "Fibre" refers to cotton.



**Figure 8:** Distribution of agriculture sub-sectors among periods.

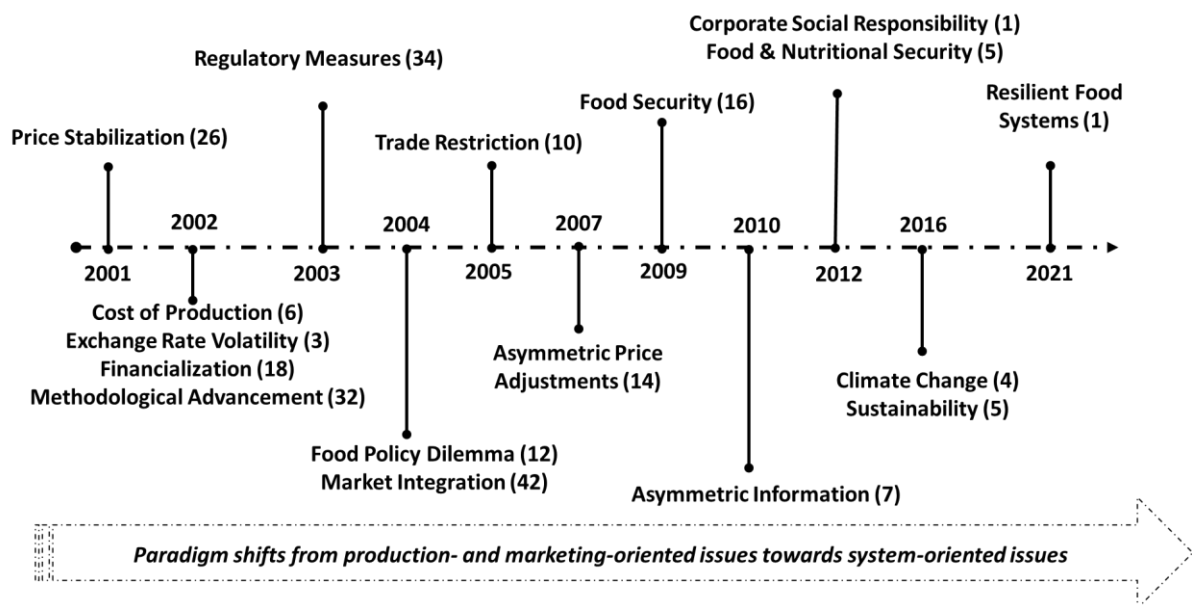
Notes: The distribution of selected articles in terms of agriculture sub-sector shows that cereals (228) were the most prolific sub-sector while the rest of the sub-sectors were least studied, e.g., fiber (1%), fruits (2%), vegetables (5%), etc., within agriculture.

The price volatility studies were saturated with cereals with 228 records and livestock with 35 records to some extent within the studies' sampling framework. The shrubs or small tree crops represent coffee (Larson, 2004 b) got noticeable attention in pre-crisis (2) and post-crisis (11) periods from researchers while the rest of the sub-sectors were least studied, e.g., fibre (1%), fruits (2%), vegetables (5%), etc., within agriculture. The result reveals that the food crisis wave has skewed sub-sector distribution mainly towards cereals, livestock, and shrubs due to greater food security (poverty alleviation) concerns. Another emerging facet of food security revolves around nutrition and health security (malnutrition) during the last decade. This issue can be ensured by researching stabilizing prices in neglected agricultural sub-sectors to receive added micronutrients from fruits and fishery.

### 3.8 Paradigm shift in research

The present systematic review has also compiled points of contentions discussed in selected studies while researching agriculture price volatility. The timeline of issues was created (Figure 9) regarding the total number of counts and the first instance of reporting that studied issue within the sampling framework. These results highlight a clear *four-wave (transition)*

*paradigm shift in research* on price volatility in agriculture due to the wake of food crises. Initially, the issue (counts) was addressed at the farm level with production cost (6), and it was gradually moving towards marketing-related issues, such as regulatory measures (34). Secondly, the transition was seen in 2005 when researchers addressed the trade restrictions (10) issue and its consequences on the economy. The food crisis was a real game-changer for researchers across the globe. Thirdly, a great transition was seen in research orientation towards holistic approaches. These approaches tackle all the dimensions of food security (16), such as food availability, access, utilization, and stability, then involving the private sector through corporate social responsibility (1) and introducing health concerns through food and nutritional security (5) concerns.



**Figure 9:** Research issues timeline based on selected studies.

The waves of research transition resulted in paradigm shifts in price volatility in agriculture and food crisis research.

After the global commitment to *Sustainable Development Goals (SDGs)* in 2015, the researchers brought sustainability (5) and climate change (4) issues into their research domain. The researchers tried to find sustainable solutions to address agriculture price volatility for inclusive and sustainable growth. The fourth transition began right after the world health organization declared COVID-19 as a global pandemic on March 11, 2020. The resilient food systems (1) have now the center of attention related to agriculture price volatility. The researchers were now concerned about food systems' ability to withstand and recover from disruptions to ensure a sufficient supply of acceptable and accessible food.

#### **4 Conclusion**

The multi-dimensional drivers of price volatility have been identified during the food crisis wave to provide an in-depth understanding of price irregularities, and theoretical underpinnings for *GNFACs dimensions I and III* to address the food crisis. There was a clear paradigm shift in the adopted methodologies and data[bases] consulted. In selected studies, the dynamics of chaos and its detrimental impacts were ignored while addressing the issue of price volatility in agriculture. This approach raises a public policy concern about deciding whether to intervene in agriculture markets or not.

The answers to such questions are possible if we test the “realism” of theoretical models from volatile price series in agriculture while assessing uncertain situations like the food crisis. Without considering such a modeling framework, the result of the same model using different data frequencies (use of daily, weekly, monthly, etc. data) retrieved from various locations can be counterintuitive. This behavior may be due to aggregation bias and regime-switching behavior in volatile price series. The sole use of agriculture prices without incorporating quantities was another impediment while empirically analyzing the stylized models. Huffaker (2015) had already provided a *pre-modeling data diagnostic framework (PMF)* to provide evidence of correspondence between models and real-world based on nonlinear time-series analysis. This empirical scheme may validate results, *i.e.*, the magnitude, persistence, and degree of volatility across countries and sectors of the economy (energy vs non-energy) during the unanticipated crisis period. In the present analysis, the various researchers gave overarching importance to cereals and side-lined other important sub-sectors such as fruits, a major source of micronutrients — *pivotal to food and nutritional security*.

This systematic review has shown waves of research paradigm shifts and their triggers for countering price volatility in agriculture. The current food crisis is more about supply disruption revolving around market imperfections, and the recent global COVID-19 pandemic fostered the adoption of holistic approaches to create more resilient and sustainable food systems. The adoption of *PMF* before implementing stylized models may provide a way forward to inculcating price volatility dynamics and contemporary food crisis issues within future research outcomes.

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## Notes

- 1 During a food crisis wave, one can move from food secure to food insecure.
- 2 The reduction of input variables when developing a predictive model reduces computation cost and improves the model's performance. For more details, see (Al-Tashi et al., 2020).
- 3 The prior research on price volatility in agriculture was available in books. For information, please read (Harwood et al., 1999; Winters & Sapsford, 1990).
- 4 These are also called economic or trade cycle models, related to fluctuations of gross domestic product around its long-term growth trend.
- 5 The hybrid models were constructed by combining two or more different modeling techniques/approaches. For more detail, please see (Fang et al., 2020)

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