Hungarian University of Agriculture and Life Sciences

Factors of food security: agricultural price transmission and volatility spillovers

DOI: 10.54598/004900

Doctoral (PhD) dissertation

by

Marwa Ben Abdallah

Gödöllő, Hungary

2024

Hungarian University of Agriculture and Life Sciences

Name of Doctoral School: Doctoral School of Economic and Regional Sciences

Discipline: Management and Business Administration Sciences

Head of Doctoral School: Prof. Dr. Bujdosó, Zoltán, PhD,
Institute of Rural Development and Sustainable Economy,
Hungarian University of Agricultural and Social Sciences (MATE)

Supervisors: Prof. Dr. Lakner, Zoltán DSC.
Institute of Agricultural and Food Economics
Hungarian University of Agricultural and Social Sciences (MATE)

Prof. Dr. Farkasné Fekete, Mária, PhD
Institute of Agricultural and Food Economics
Hungarian University of Agricultural and Social Sciences (MATE)

…………………………………………… ………………………………..

Approval of Head of Doctoral School **Approval of Supervisor(s)**

TABLE OF CONTENTS

List of Tables

List of figures

ABBREVIATIONS

ADF	Augmented Dickey Fuller
DALYs	Disability- Adjusted Life years
DCC	Dynamic Conditional Correlation
PP	Phillips Perron
GARCH	Generalized Autoregressive Conditional Heteroscedastic
UN	United Nations
EIU	Economist Intelligence Unit
SDG	Sustainable Development Goal

1. INTRODUCTION

It is evident that food security always presents a challenge for most countries, mainly in the African continent. Despite, the endeavors that aim to develop the agriculture sector and provide enough food to the increasing population, governments still struggle to face this concern.

Due to the constraints of a rising population and limited arable area, food security has attracted considerable awareness for many years. The food situation has been altered as a result of some factors, such as the increased urbanization and changes in the food system, that cause enormous issues for the expanding populations (Ritchie and Roser, 2018). Food systems could boost human well-being as well as the green environment. Nonetheless, they are now jeopardizing both of these. It is an acute problem to provide a rising global population with nutritious meals derived from sustainable agricultural systems. A gap appeared between the global food production and the population expansion, showing a marked growth of the accounted people who are facing serious food insecurity. Hunger depicts an acute issue, approximately 8 million people, yearly, pass away of hunger that means more than 20,000 people per day. In 2015, the number was counted at 80 million, it jumped to 108 million in 2016, and 124 million in 2017. The demand for food is flourishing, FAO estimated that there will be a food demand upward in 2050 by fifty percent of the total food amount in 2013. Meat products are predicted to witness the highest demand increase, in 2050, of 76%, while dairy products will mark an increase of 65 percent, as long as grain products with 40 percent. Developing countries are the most concerned by this increase, they will register greater than 80 percent of food and beverage demand by 2030. We cannot deny that to feed the population, governments should focus on the production input expenses because they reflect food prices later on. Any increase in agriculture input price will be reversed to an augmentation in food prices. To comprehend such circumstances, it needs to understand the risk that can agricultural price contributes to aggravating food insecurity status.

These facts lead to the emergence of food security debate. As a consequence, consumers face the effect of increasing food prices, as well as producers, feel the pressure from the increasing input costs. Agricultural price changes are caused by a number of determinants. The increasing food demand joined with the slowed agricultural productivity growth and the dependence between the agriculture and the fluctuating energy price are among the identified reasons.

Food price increase impedes food security and restricts the access to the food. Also, price volatility menaces farmers from having stable income. The increased prices which happened between 2007 and 2008 led to 40 million more undernourished people in Asian and Pacific regions, and more than 20 million in Sub-Sahara Africa. In general, high food prices could affect the currency which could lose its value by the high inflation. The merger of the economic stagnation and the increased inflation form a detriment for economic recovery. More recently, prices move to drop again, but they remain significantly above the pre-crisis level.

Achieving the answer for this upward deviation in food price level and volatility are still the interest of many scientific researches. Some researchers focus on finding an explanation of the disequilibrium which exists between supply and demand, with demand trend rising faster than supply trend, through the concentration on the food demand strength which launched a considerable shifting in the world, which could explain this quickly and unexpected movement in price levels. Trade policies are implemented in order to protect the markets from the price fluctuation, such as the trade restrictions which is considered as a measure among others. The higher cost of production as a result of price fluctuations in certain production elements, particularly energy, was also a key factor in explaining the upward trend in commodity prices, indicating an imbalance between global demand for and supply of limited resources.

Regardless of these achievements, Africa has attracted global attention for significant issues including social inequality, food insecurity, poverty and unemployment (World Bank, 2020). Agriculture has heavily relied on the petroleum industry for inputs such as fuel and fertilizer, but aggressive biofuel regulations in petroleum refining have strengthened ties between the energy and agricultural commodities markets. Countries regularly interfere in the case of major oscillations in global food prices to mitigate the effects of world food price rises on domestic prices and to ease the adjusting pressure on vulnerable populations.

1.1. Problem Statement

Food price volatility and spikes provoke governmental, professional, and public concerns about food security across the world. Food price volatility in 2007/2008 harmed millions of individuals, undermining their nutritional condition and food security. The Food and Agriculture

Organization (FAO) has foreseen that the 2007/08 price increase raised the number of undernourished people. It went from about 850 million in 2007 to about 1023 million in 2009.

According to FAO in 2011, because of price fluctuations in staple foods, such as wheat and maize, the African continent has a significant number of undernourished individuals, which has reached 240 million. In addition, the appearance of the Covid-19 pandemic, has aggravated the situation of food security because of the restrictions that have been imposed (De Paulo Farias and de Araújo, 2020). The uncertainty has been developed which harms further the food availability, thus food price. Commodity price volatility, unpredictable supply chain interruptions, and weather and climate change all pose a significant risk to food markets, making the mission harder for the government to assure consistently and regularly accessible food, putting food security at risk.

Household earnings and buying power decline as price volatility increases. Price change is linked to the idea of food security. A shock price could disrupt the four pillars of food security (i.e. availability, access, utilization, and stability) (FAO 1996, 2015). Although, price volatility disrupts the different level of supply chain, upstream and downstream. Also, the price volatility magnitude could undermine the economic growth and the poverty reduction (HLPE, 2011). An enormous food price increase aggravates the poverty, especially in low income countries (Ivanic and Martin, 2008 ; Ivanic, Martin and Zaman, 2011).

The price spike affects all stages of the supply chain. Unexpected price volatility decreases the farmer's productivity; thus, they reduce their investment. (Rezitis and Stavropoulos, 2009; Piot-Lepetit & M'Barek, 2011; Taya, 2012). Additionally, agricultural inputs became subject to price volatility, driving retailers, and processors to adjust their supply strategies to mitigate the supply uncertainty (Rabobank, 2011). Unpredictable price change endangers food security status. It harms households who allocate a high percentage of their income for food purchases (Hernandez et al., 2014). Therefore, to avoid price shocks, efficient price management should be applied in the food market to ensure the stability of food supply chains.

Due to the market interconnections, it is crucial to understand the price dynamics within the market. To analyze the link between the food prices and food security, a research study has been established in Kenya. The aim of the study was to assess the link between the maize price and the low birth weight as an indicator of food security and account its effect. A positive correlation has been detected. This result could not be generalized for all Kenyan households. In other word, some households got advantages from maize price increase (Grace et al, 2014).

The food price increase could worsen the health status of poor households by preventing them to have the access to sufficient nutritional food (Mkhawani et al, 2016). Food instability and price volatility will be major concerns in the future.

For long-term growth, governments must adopt clearer policies that address agricultural risk management effectively. It is critical to have the tools and information necessary to recognize and identify the factors of food security, as well as to be aware of the interventions available to protect individuals from food deprivation. Therefore, it is pivotal that the government should undertake a background study of the forecast of a food security index. In this regard, the results of this study would be a useful reference for the government in intending to practice a global model forecast of food security index.

1.2. Significance of the Study

Crude oil has long been acknowledged as the world's most valuable raw material and vital energy resource. It has now become a critical component of socioeconomic progress and sustainability.

Petroleum products, such as diesel, gasoline, and other fuels, are also an essential source of energy for farming machinery, since they are used by fleets of agricultural transportation equipment vehicles that are employed in the production chain in agricultural areas.

Agricultural sector plays an important place in the economic growth. However, the agricultural development, the poverty decrease, and the food security are subject to risks. Unexpected shocks such as climate change, crude oil price, pandemic spread, input price increase, and the appearance of new plant diseases imply a real harm for food yield. Also, they interrupt the food supply and burden people from having access to suitable quantity and quality of food. Furthermore, the decrease of rural population creates a gap between the rural production (supply) and the demand from the rising urban population, leading to price shocks mainly for importer countries which are more sensitive to the price change.

For this purpose, forecasting price transmission and volatility spillovers between the global and domestic food price help to understand the speed and magnitude of price dynamic between domestic and international prices. It plays a pivotal role for policy makers to manage and understand the responsiveness of domestic market to international shocks. The food price changes count on the vulnerability of the country and the agricultural product upon a price shock. Firstly, my thesis examines the volatility spillover between the domestic and global food prices. Energy products, such as crude oil, represent important energy source for farming machinery, being consumed by fleets of agricultural machinery and transport vehicles used for the production process in agriculture fields (Rafi et.al, 2009 and Adam et.al,2016). Therefore, examining the price spillover between crude oil and food price gives a clear image about the vulnerability of food price face to a change of fuel price. My research contributes to establish an updated price investigation based on recent price series.

On the other hand, the food security index is always a primordial subject, especially, after the pandemic of Covid-19 spread, causing an unexpected shock for the food supply, the food consumption, and the trade restrictions. It creates a disruption the food supply due to the lockdown which harms the planting season, therefore a lower production could be the consequence. After the elaboration a bibliometric analysis to discover the link between food security and food price, an important interest was focused to this research idea, especially with the lack of previous studies that forecasted the food security. Based on highlighted keywords, mainly supply and food intake, and to fill the gap, the food security index based on the gap of food supply should be a contributive finding for food security topic.

Domestic price volatility, which is associated with international price volatility to varying degrees in various nations, has an impact on food security at the national level. Various indicators (e.g. local regulations, high shipping costs, inadequate infrastructure, consumption patterns, and exchange rate fluctuations, etc.…) might hinder price transmission from global to national prices.

.

1.3. Research questions and hypotheses

The main question of my research is there interconnectedness between agricultural producer price and food security? Food security is perceived as the sufficient supply of the required food for people. Here, the question is how to estimate the aggregated food insecurity index based on the supply gap of food subcategories? And How to weight each food subcategory?

Four main ideas are considered in my study:

- Firstly, global food price examination: Assessing the magnitude of the global food price volatility transmissions of food and food subcategories:1. Own price volatility: How an occurred past price shock is transmitted to the present value? Energy, particularly crude oil, , is regarded as a crucial input in different sectors (e.g transportation, industry, agriculture, etc.).

It is extensively utilized to supply agriculture as a raw input; thus, it has a high value and influences the pricing of agricultural commodities. 2. Interdependence between the global food prices and crude oil price: Is there a significant interdependence between crude oil and world food prices?

- Secondly, spatial volatility spillovers:1. from one side we estimated the extent of the price volatility that could transmit from the global level to the domestic level. How much the domestic food price is vulnerable to a global food price shock? 2.From the other side, the connectedness between the global crude oil price and the domestic food price has been estimated. How much the domestic food price is vulnerable to a crude oil price shock?
- Thirdly, quantitatively assessing the food security index: it aims to build food security index based on food supply indicators: The gap between the supplied food intake and the required food intake. A food security index will be forecasted based on deficit food subcategories supply: The weighting method is determined from the DALY (Disability-Adjusted Life Years) value (World Health Organization, 2020a). Each food subcategories have been weighted based on its rate of the Disability-Adjusted Life year.
- Fourthly, implication of price dynamic and macroeconomic variables on national food security and sustainability: how vulnerable nations and populations can ensure the food availability when volatility causes market disruptions.

Hypothesis:

- **H1:** Food prices are significantly impacted by its own past values: a past volatility is significantly transmitted to the present value.
- **H2:** Crude oil price is significantly impacted by its own past values: a past volatility is significantly transmitted to the present value.
- **H3:** Crude oil price has a significant volatility spillover on the global food price.
- **H4:** Highly perishable agricultural commodity price (meat price) has the highest own price volatility among other commodities.
- **H5:** The global food price volatility is significantly transmitted to the domestic food price.

- **H6:** The crude oil has a significant influence on the global and domestic food prices: energy and food price and highly interdependent.
- **H7:** The agricultural producer price has a significant negative effect on forecasted food security index
- **H8:** Macroeconomic variables (i.e. Trade openness, Exchange rate between local currency and USD, Inflation rate, Interest rate (long term real interest rate),Employment rate, Crude oil price) have a significant effect on food security index.

1.4. Theoretical framework

Prior to assessing agricultural price effect on the national food security, it is quite important to understand how much the domestic food price is correlated to the international food and the energy (crude oil) prices. The magnitude of the price volatility transmission from the global food price to the national prices is constrained to different factors, such as, the implemented trade policies, and the exchange rate. African countries are most vulnerable to an increase of food prices. They have the large share of income expenditure on food. However, the two first countries with the highest income share spent on food are Nigeria and Kenya with 59% and 52% respectively. Algeria and Egypt as well have a high share of income expenditure on food, with 38% and 37% respectively (give references for the data). Figure 1 described the general theoretical background of my dissertation.

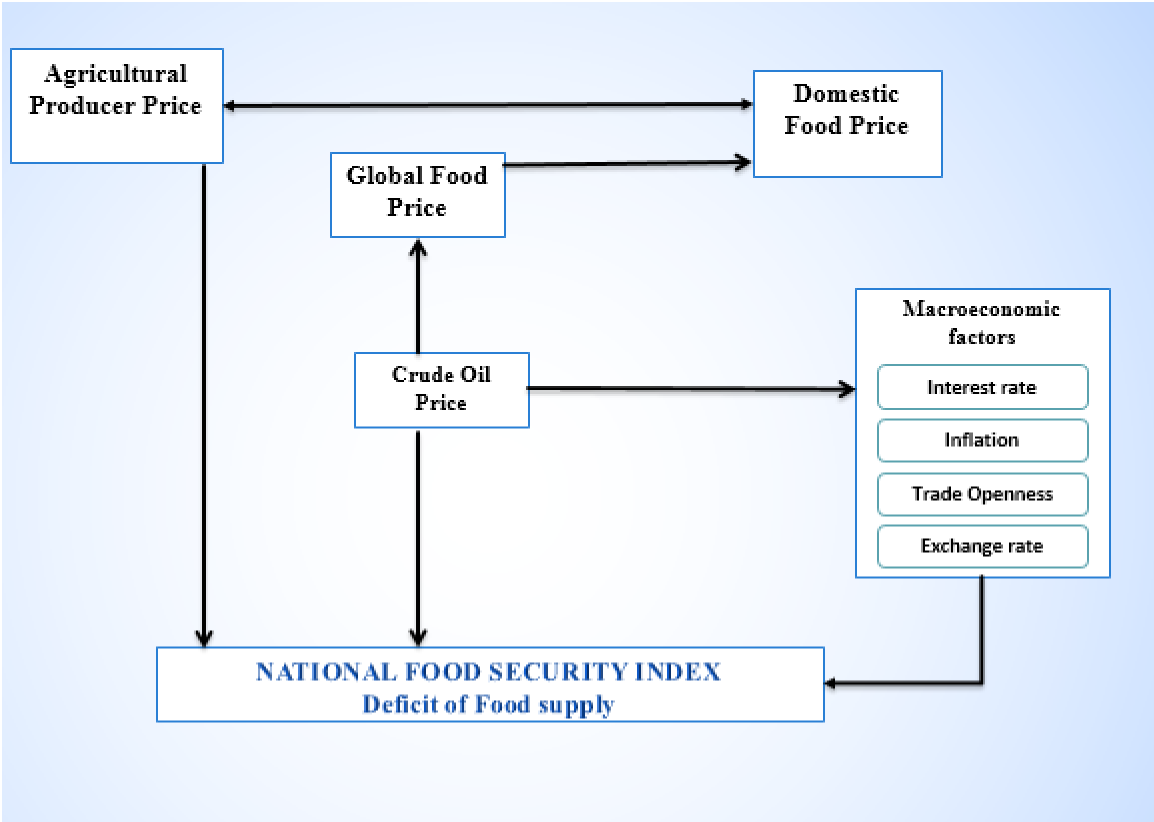

Figure 1. Conceptual model of the research: Connections between food prices, crude oil price, macroeconomic indicators, and food security index

Source: Author's own construction

At the beginning, my research tried to examine vertical price volatility of selected agricultural commodities (i.e. meat, milk, and wheat) in the selected 8 African countries (Tunisia, Algeria, Morocco, Egypt, Kenya, Nigeria, Congo, and Uganda), to understand the characteristics of the domestic market. Because of lack of data, especially the producer price, we could not examine the relationship between the producer and the consumer. As mentioned in Figure 1, the arrow linking the agricultural producer price and the domestic food price is not going to be taken in consideration. Figure 2 illustrates the modified theoretical framework of my dissertation, showing the relationships that were incorporated in the analysis.

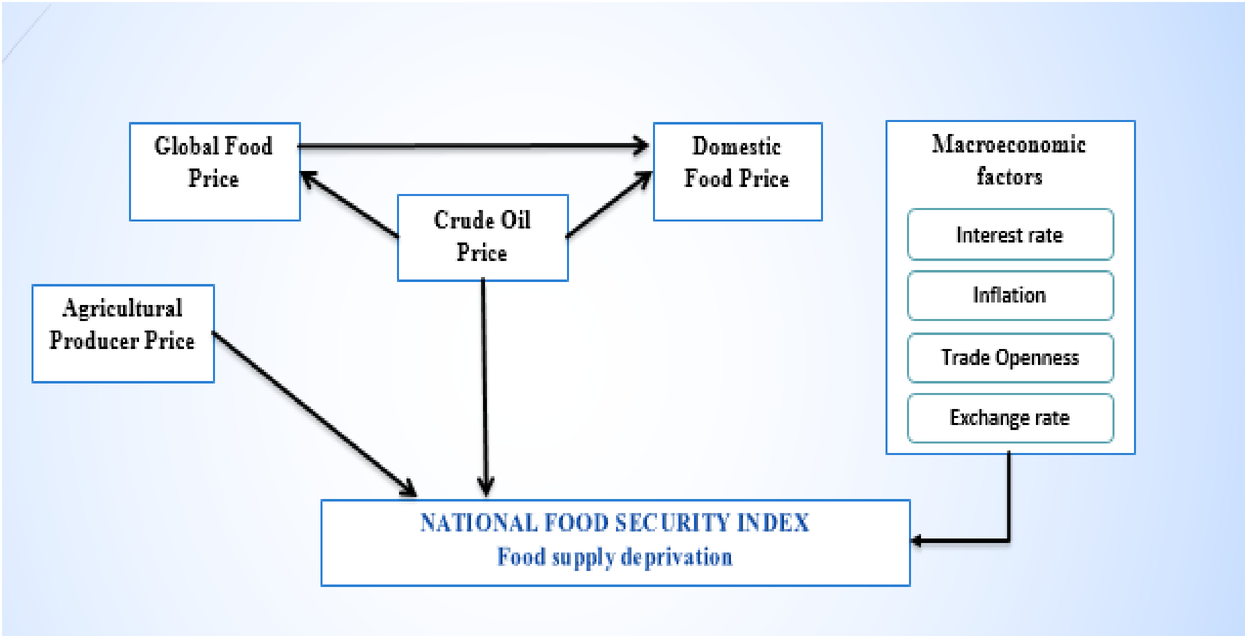

Figure 2. The modified Conceptual model of the research: Connections between food prices, crude oil price, macroeconomic indicators, and food security index Source: Author's own construction

The increasing concern in investigating the co-movement of fuel and food prices was ascribed to the capability of agricultural commodities financialization. Mainly, after the financial crises, and with the era of food crisis between 2006 and 2008. Energy, particularly crude oil, is a critical component of every economy's development. It is widely used to supply many sectors like as transportation, agriculture, industry, and households.

As a result, it has a high value and influences the prices of other commodities. After1973, oil price shock is one of the most important concerns in energy economics. Many studies (Wang, Wu, and Yang, 2014; Ahmadi, Behmiri, and Manera, 2016; Bhat, Ganaie, and Sharma, 2018) evaluate its implications on other sectors that are related. Price volatility may lead to the uncertainty and the fluctuation in agricultural markets and generate crucial unpredictability between stakeholders. Though some countries utilize trade measures to protect their domestic markets from variations in international food prices, the volatility is exacerbated.

As a result, more countries will follow similar measures. Countries should intervene in the case of major world food price fluctuations to mitigate the impact of international food price spikes on domestic prices and to ease the adjustment burden on disadvantaged population groups. The international pricing instability is exacerbated by fluctuations in trade barriers, especially food products, which may cause crucial effect on the national food security status. To determine to which extent the international food price volatility may be transmitted to the domestic food price help policy makers to intervene and stabilize the market. The food price has been linked to food security in some research papers (Amolegbe et al., 2021). Prior to examine this relationship, we notice that there is different method to weight different indicators to estimate the national food security index. It is quite important to forecast food security index and to provide a mathematical and scientific weighting method. Finally, explaining the link between the food price and national food security with some selected macroeconomic indicators could draw a clear image for the governments to implement the suitable policy measures.

2. OBJECTIVES

My dissertation focuses on quantifying the speed and the extend of price adjustment relationship between international and domestic prices of food and some food subcategories (i.e. meat, cereal, and milk). African countries have been selected for this examination of market interaction. GARCH family models haven used because of their ability to catch the dynamic volatility and its transmission.

In the dissertation the examination of global food and sub-categories prices was highlighted. The dissertation follows this line and focuses on the national food security. It aims to forecast the national food security index based the gap in food supply. My research work aims to suggest a food security index based on the gap in food supply, and introducing a weighting method based on the DALY indicators.

❖ ***Main objectives:***

1. Measuring the interdependence and the dynamic correlation, firstly between global food price and crude oil price, secondly between domestic and international food prices, and thirdly between the domestic food and crude oil prices.
2. Forecasting a national food security index, based on the deficit in the food supply (food subcategories).
3. Determination of the relationship between the forecasted food security, agricultural producer price and macroeconomic indicators.

The United Nations' Vision 2050 for food security calls for doubled food output by 2050 to ensure adequate food availability (McKenzie and Williams).. To achieve this goal, an appropriate planning at the national level is required.

The price fluctuation of agricultural commodities has raised a concern for studying the volatility of different agricultural products. A persistent volatility in prices causes continued uncertainty in the market. It causes an increased management costs which is converted into higher producer prices.

My thesis considers the examination of the relationship between, crude oil price shocks, food price, and agricultural commodities. Crude oil is a key element for socio-economic development and stability.

The data used for volatility examination covers the two global crises: Global Financial Crisis (2007-2008) and Covid-19 pandemic crisis (2020). International agricultural prices and fluctuations are spilled-over horizontally to domestic markets, thus affecting the national food security. It is important for countries to have enough knowledge concerning the co-movement between crude oil and food prices.

For this purpose, and to fill the gap of the existing studies, my dissertation is going to examine firstly, the dynamic relation between crude oil and international food prices, secondly between the global food price and selected African countries (Tunisia, Morocco, Algeria, Egypt, Kenya, Congo, Uganda) domestic food prices, and thirdly, between the crude oil and domestic food prices of the selected developing countries. These examinations are aiming to determine the magnitude of interdependence between different prices during food crisis and Covid-19 periods.

3. LITERATURE REVIEW

Challenging driving factors that threaten the agriculture sector and the food security, such as the climate change, economic issues, political instability, and the Covid-19 pandemic, make the mission of reaching the United Nations (UN) to reach goal 2 of zero hunger harder (SDG 2) (UN, 2015). Agriculture sustainability is the key expression to fight the food insecurity and erase hunger.

3.1. Agricultural and food security situation in Africa

Africa is witnessing a lower agriculture growth accompanied by high population growth with the fastest hunger expanding comparing other continents. Hunger affects 21% of the population in Africa, 9% in Asia and 9% in Latin America and the Caribbean. Africa has higher than one-third in Africa (282 million of 768 million) of undernourished people in 2020 (FAO et al., 2021).

Africa's prevalence of malnutrition increased from 17.6% of the population in 2014 to 19.1% in 2019, more than twice the global average and the highest of all continents (FAO et al., 2020). Sub-Saharan Africa's population is expected to expand from 1.07 billion to 1.40 billion by 2030, and to 3.78 billion by the end of the century (United Nations, 2019). Africa has a highly young population, with 41% of the population under the age of 15 and another 19% between the ages of 15 and 24 in 2017. This means that even if growth rates are instantly slowed, more than half of the expected growth will still take place (United Nations, 2017).

Even according to a recent study by Vollset et al. (2020), which found that current world population forecasts are exaggerated, the population of Sub-Saharan Africa will exceed 3.07 billion by 2100. Given existing reliance on cereal imports, rapid population increase, and stagnant agricultural production, Sub-Saharan Africa is the world's most vulnerable region to food insecurity (van Ittersum et al., 2016). The expanding population in Sub-Saharan Africa necessitates an adequate supply of inexpensive and nutritious food.

Agriculture, on the other hand, contributes significantly to African economies' balance of payments. As a result, Africa's agricultural production must significantly rise to fulfill the needs of both domestic and foreign markets (Giller, 2020).

Here some review is needed about the selected 8 African countries. What is the food consumption pattern – what food is consumed in what quantities, what is the daily intake, what is the recommended intake by WHO, what is the self-sufficiency ratio of these food items? It can be described in text, or summed up in a table, with proper references. This information is needed to put the following figures in context. Explain here the reason why these countries were chosen, and not Ethiopia, Somalia, Tanzania, Mozambique, Sierra Leone, Lybia, … etc.

3.2. Food supply in selected African countries

In this section, we are going to describe the characteristics of different staple food and their change along the time. Below figures (from figure 3 to figure 7) illustrate and describe time trends in the supply of different food diet in 8 countries; 4 North African countries (i.e. Tunisia, Morocco, Algeria, and Egypt), Nigeria, Kenya, Congo, and Uganda from 1961 till 2018. The data is taken from the food balance sheet elaborated from FAO.

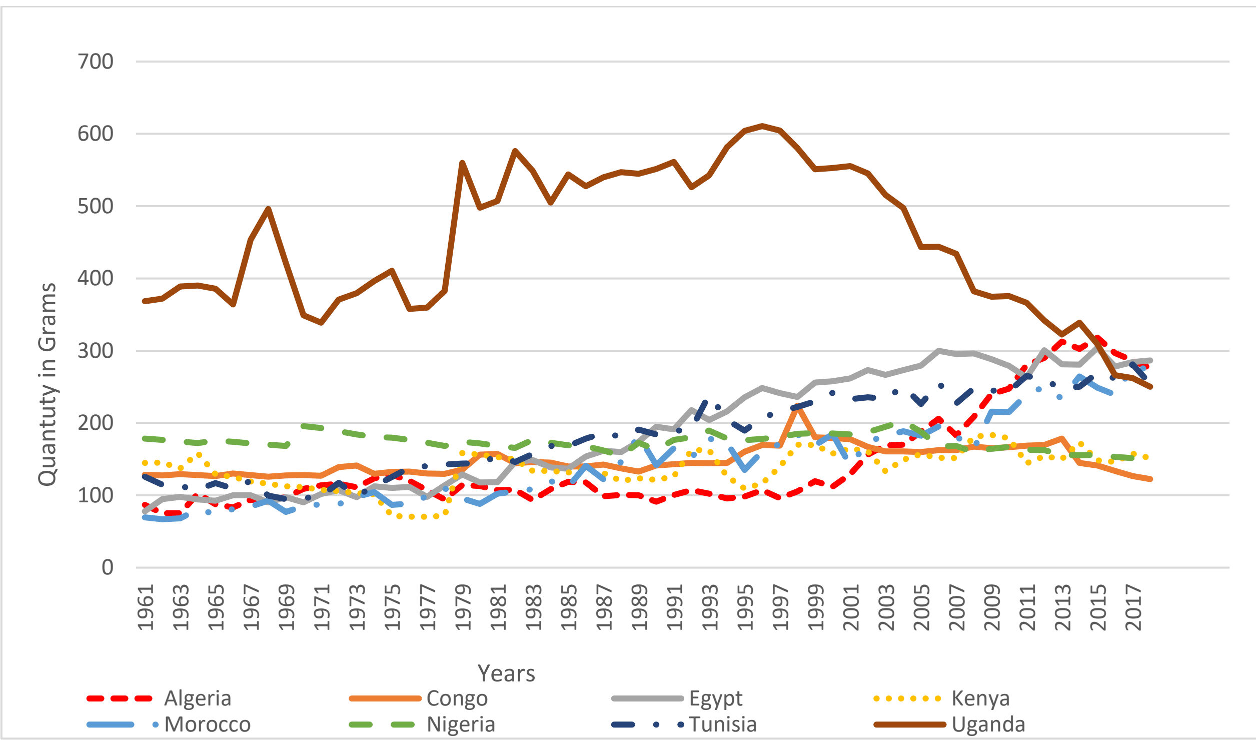

Figure 3. Fruit supply in selected African countries in grams/day/ person

Source: Food and Agriculture Organization food balance sheets (FAOSTAT)

The period 1961–2018, fruit supply increased steadily in all north African countries (Algeria, Morocco, Tunisia, and Egypt) while it is almost constant for Nigeria, Congo, and Kenya afford almost the same quantity of fruits. As highlighted in Figure 3, the highest fruit supply was registered in Uganda in 1995 in Uganda (604 g person^{-1} day^{-1}), and it decreased to 250g/person/day.

The lowest fruit supply in Morocco (70 g person^{-1} day^{-1}). In 2018, Congo, Nigeria, and Kenya did not reach 200 g person^{-1} day^{-1} while Morocco, Tunisia, Egypt, and Algeria had registered a fruit availability higher that 200 g person^{-1} day^{-1}.

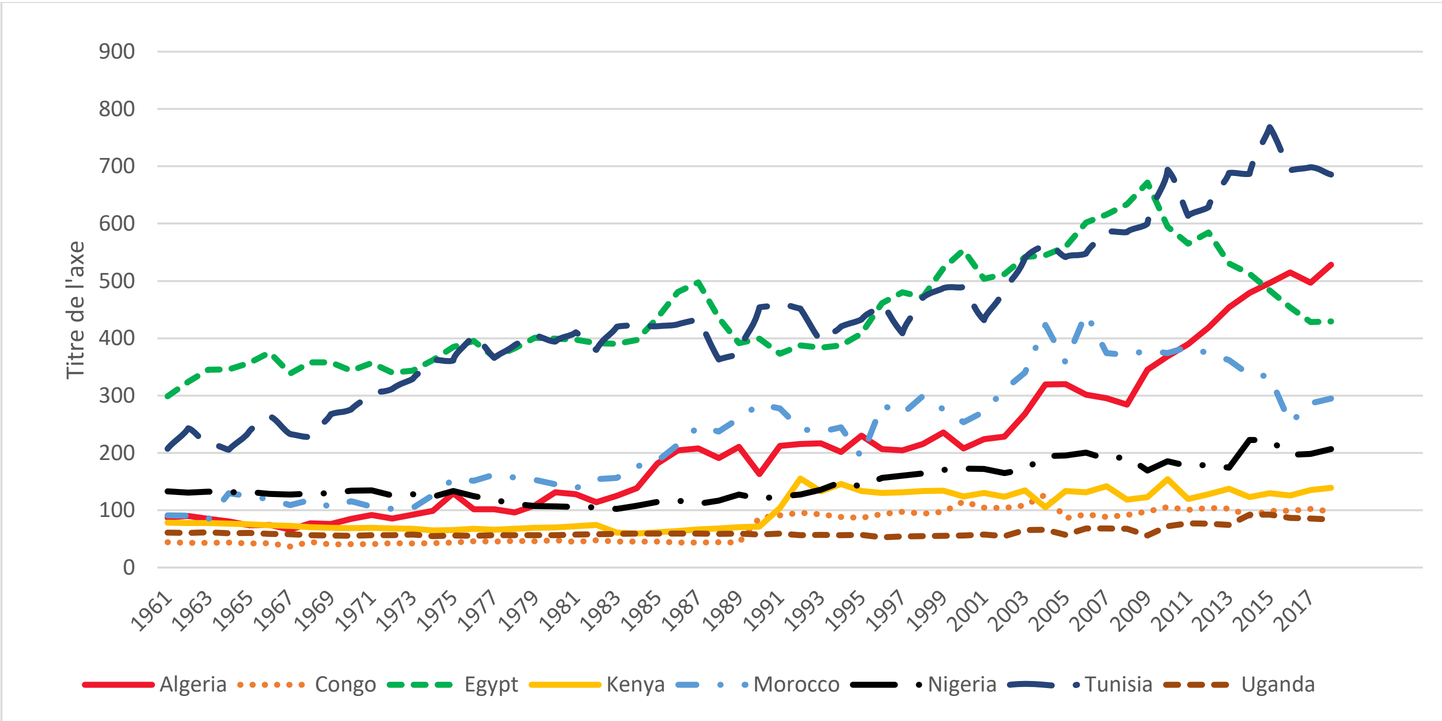

Figure 4. Vegetable supply in selected African countries in grams/day/ person

Source: Food and Agriculture Organization food balance sheets (FAOSTAT)

Figure 4 illustrates the vegetable supply in the selected African countries. During 1961, vegetable supply was very low in Congo, Uganda, Kenya, and Morocco, intermediate in Nigeria and in Tunisia (133–207 g person^{-1} day^{-1}), and very high in Egypt (298 g person^{-1} day^{-1}). Since then, it has increased in all countries, particularly in Tunisia, which presented around 770 g person^{-1} day^{-1}. Other African countries (i.e. Congo, Uganda, Kenya, and Nigeria) have witnessed a slow increase, barely constant during the period (1961-2018), they did not reach 200 g person^{-1} day^{-1}, except Nigeria. Tunisia and Egypt during the whole period have afford more than 200 g person^{-1} day^{-1}.

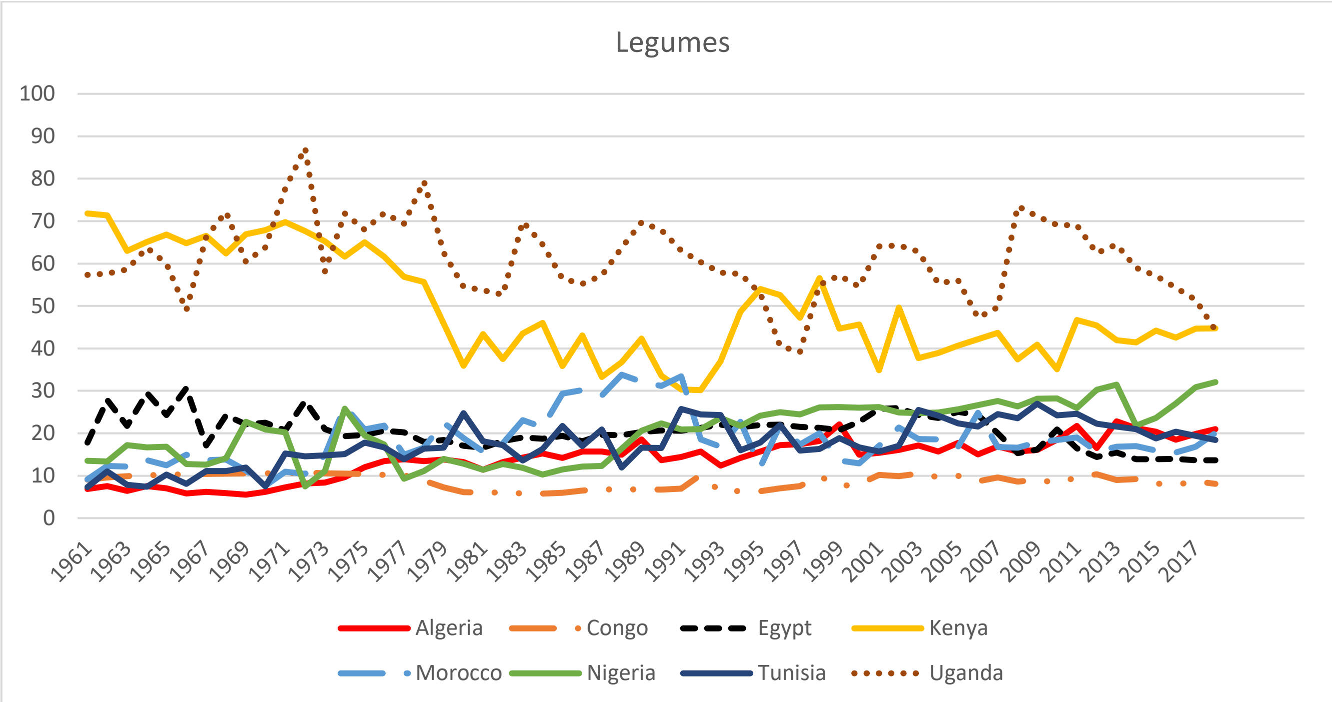

Figure 5. Legumes supply in selected African countries in grams/day/ person

Source: Food and Agriculture Organization food balance sheets (FAOSTAT)

In 1961, legumes supply ranged from 10–30 g person^{-1} day^{-1} in most of countries, only Uganda and Kenya have superior values which are between 30-90 g person^{-1} day^{-1}. As displayed in figure 5, Algeria has registered legumes supply lower than 10 g person^{-1} day^{-1} till 1975, then the legumes availability increased to reach 20 g person^{-1} day^{-1}. Congo, during the whole period, did not supply more than 10 g person^{-1} day^{-1}. Uganda, Kenya and Morocco are distinguished with the most fluctuated legumes supply.

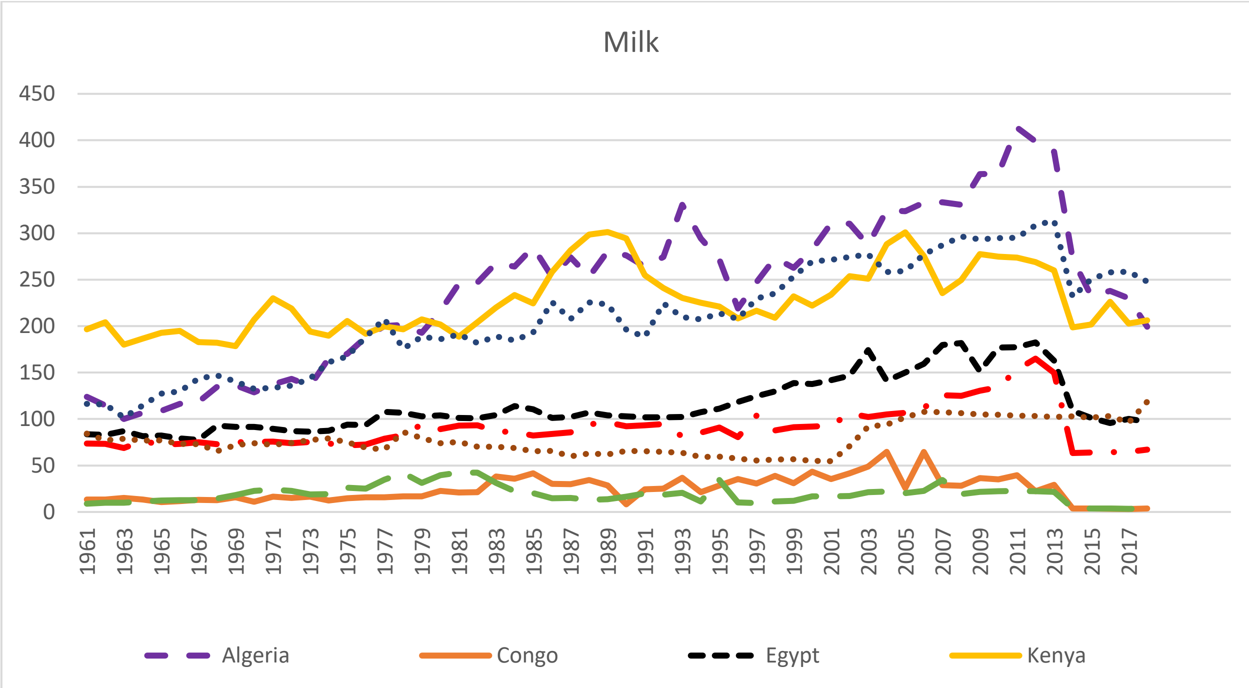

Figure 6. Milk supply in selected African countries in milliliter/day/ person

Source: Food and Agriculture Organization food balance sheets (FAOSTAT)

As presented in figure 6, the milk availability was steadily low in Congo and Nigeria during the studied period, with values of less than 50 ml person^{-1} day^{-1}. On the contrary, milk availability increased in significantly in Algeria, and Tunisia from around 130 ml person^{-1} day^{-1} g in 1961 to 400 ml person^{-1} day^{-1} in 2011, which is decreased later on to reach 200 ml person^{-1} day^{-1} in 2018. Congo and Nigeria had almost null supply of milk in 2017 and 2018. A noticeable decrease has been registered for all countries, except Uganda, where the milk supply declined, and it maintained almost constant till 2018.

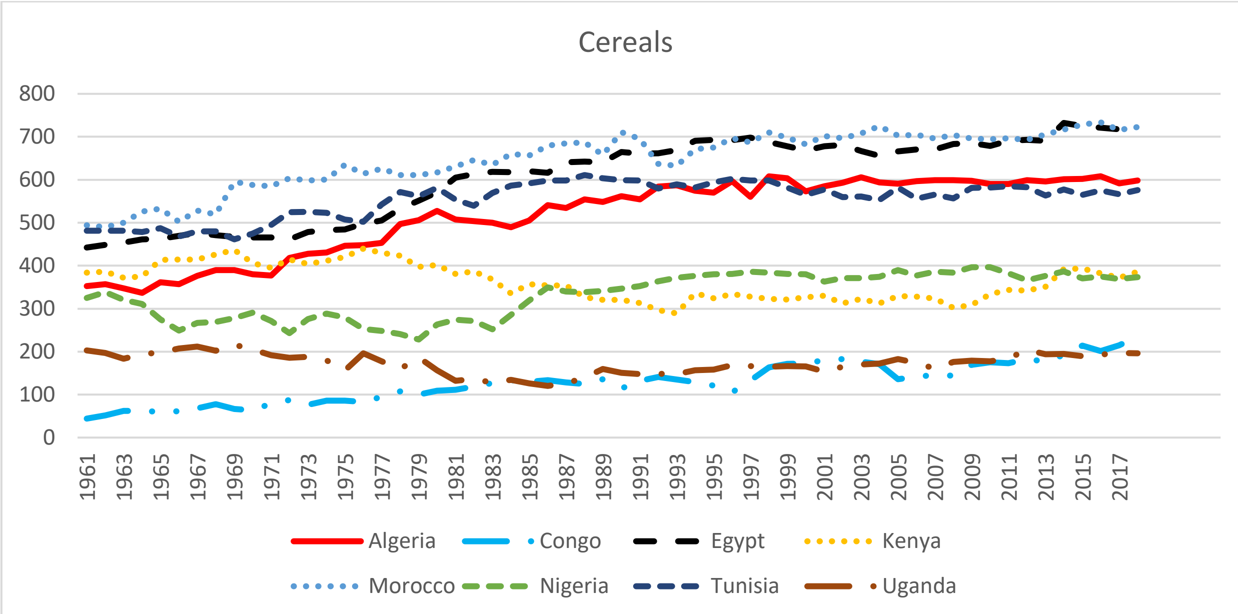

Figure 7. Cereal (Wheat, Sorghum , Millet , Oats , Rye , Maize , Barley , Rice) supply in selected African countries in grams/day/ person

Source: Food and Agriculture Organization food balance sheets

The cereal supply is illustrated in figure 7. It is steadily raising in Morocco, Egypt, Algeria, Nigeria, and Congo, while it is almost constant in Uganda, Tunisia, and Kenya. The highest value is registered in Morocco of 717 g person $^{-1}$ day $^{-1}$. Morocco and Egypt registered nearly same values which is considered the highest comparing other countries. These four countries are counted to have high cereal availability, more than 500 g person $^{-1}$ day $^{-1}$from 1983 till 2018. Kenya and Nigeria had an intermediate level of cereal supply which is between 300 and 400 g person $^{-1}$ day $^{-1}$ from 1985 till 2017. Uganda and Congo had the lowest cereal availability with a quantity between 100 and 200 g person $^{-1}$ day $^{-1}$.

3.3. Overview about global and some selected African food price index

Due to various reasons, agriculture and food prices undergo changes which could be harmful for the consumers. An image has been drawn for the different food price index series of the global food price and different selected African countries.

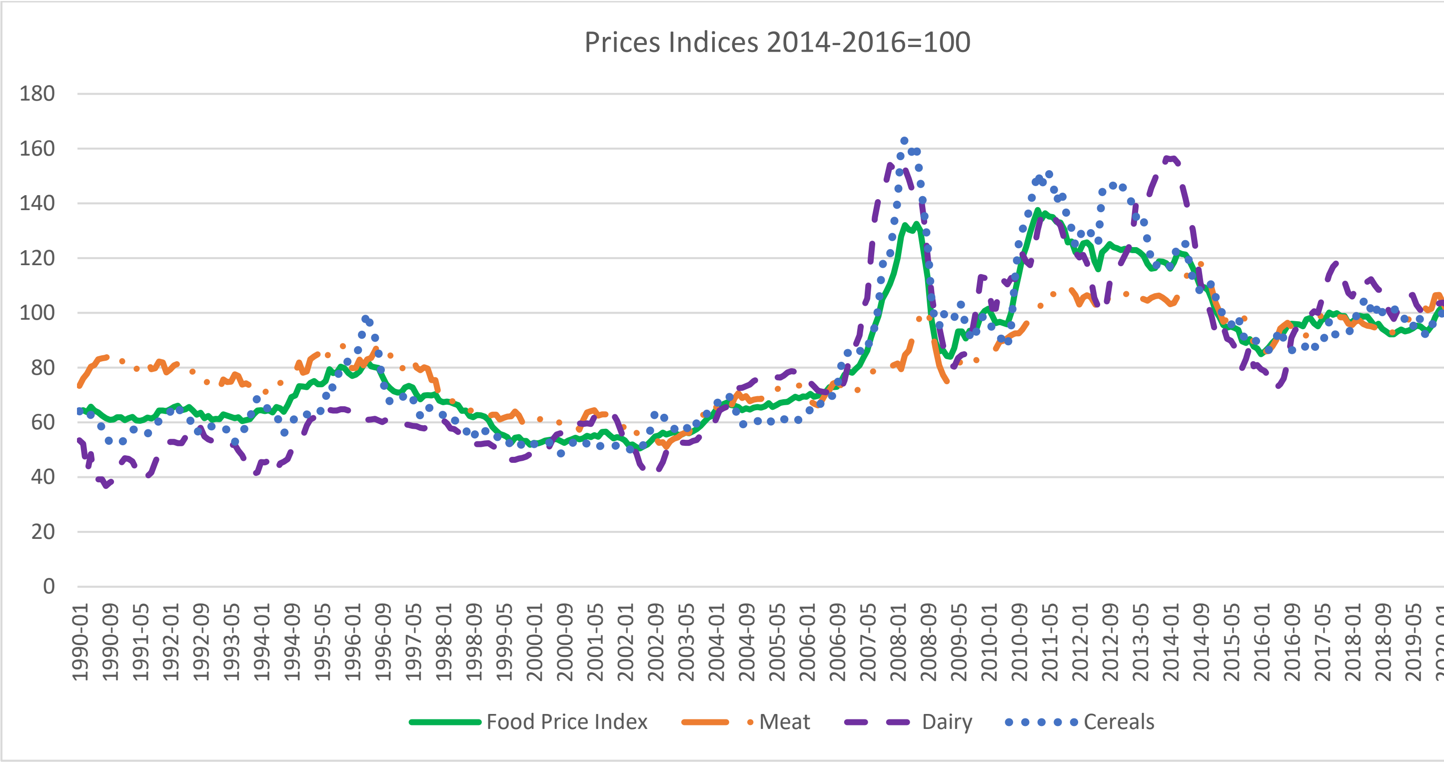

Figure 8. Monthly global food price index changes from January 1990 till September 2021

Source: International Monetary Fund (more precise reference)

Figure 8 draws the price index of food, meat, dairy, and cereals. All prices are fluctuated among the time and three main peaks are noticeably clear. The first peak has occurred in 2007-2008 which is known by the food crisis. A second peak has been registered in 2011 which is caused by the weather condition, fuel inflation that reunited to surge the food price (IMF, 2011). A progressing increase has been started in mid of 2020 due to the Covid-19 pandemic spread.

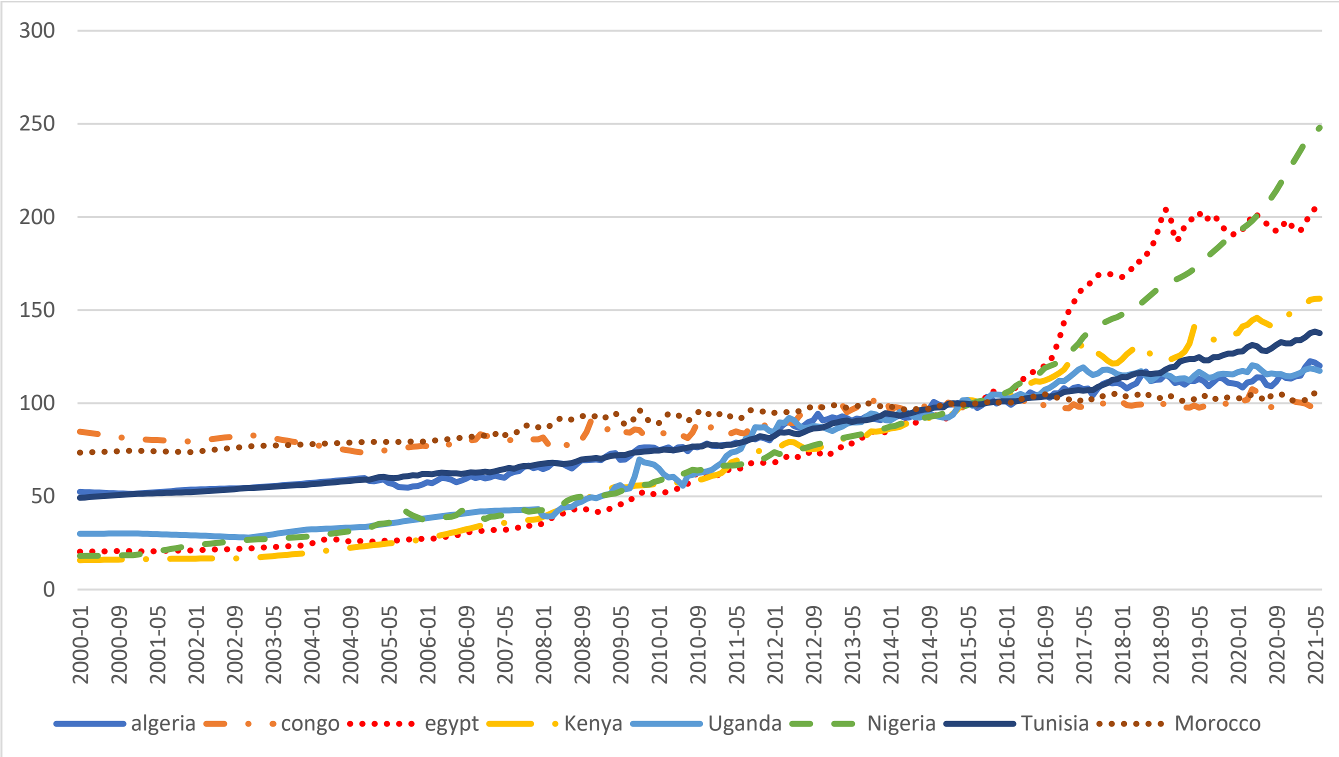

Figure 9. Evolution of monthly food price index over the time (2016=100)

Source: FAO statistics

The Figure 9 shows the evolution of monthly food price of a group of African countries (i.e. Tunisia, Algeria, Morocco, Egypt, Kenya, Nigeria, Uganda, and Congo) from January 2000 till May 2021. All prices show a significant increase. Nigeria and Egypt exhibit higher rising speed compared to the other countries. Nigerian food price has been more than doubled from 2016 till 2021. A noticeable change in the slope has been detected from 2020 in the price rise.

3.4. Agricultural and food price volatility determinants

The majority of agricultural commodity prices are very volatile, owing to a variety of factors connected to the specifications of agricultural goods, including natural disasters and governmental actions that induce price shifts to higher or lower levels. There are several elements that might influence pricing and volatility (Muflikh et al., 2020).

Farmers may be influenced to produce a certain crop by the biological character of the agricultural product, followed by agronomic factors such as weather and soil types. The seasonal pattern of agricultural commodities has a significant impact on pricing, and it can help to minimize price competition and unpredictability (Letta, Montalbano, and Pierre, 2022).

Furthermore, long-term product demand is mostly determined by population and income changes. Both the demographic and economic dimensions of growth are modest. The currency exchange rates, on the other hand, effect price swings in the near term. Then, agricultural commodity exchange rate swings generate price decreases or increases between trading nations, which may happen quickly and have a considerable effect on foreign commerce and pricing. Many farm products prices are based on the prices of other goods (Abrhám et al., 2021; Sun et al., 2021 and Vochozka et al., 2020).

In addition, agricultural product demand and supply are often price inelastic; quantities demanded and supplied fluctuate proportionately less than prices. This means that even little changes in supply can cause significant price swings. The speed and efficiency with which price changes take place is primarily determined by the market structure in which a product is exchanged (Barrett et al., 2022; Assouto et al., 2020; Beghin and Schweizer, 2021).

The following are some common market structure characteristics: (Schnepf and Resources, Science, and Industry Division 2005):

- The proportion of buyers and sellers: more market players are connected with more price competition.
- The number of close alternatives: a larger number of tight substitutes signifies purchasers have more options which lead the market to be more sensitive.
- The flexibility with which commodities may be transferred between buyers and sellers, as well as between markets: higher transportation reduces geographic price disparities; and artificial market constraints, such as government rules or market collusion by a significant participant.
- More artificial constraints make it more difficult for the price to attain its natural equilibrium.
- Import barriers, for example, limit supply and keep prices high, although other sorts of constraints, such as market collusion by a few major purchasers, might decrease market prices. (Piot-Lepetit and M' Barek 2011).

3.5. Previous research of price volatility and price transmission

After the financial crisis, which is overlapped with the food crisis, an increasing research activity has been dedicated in investigating the relationship between crude oil and agricultural commodity prices.

Farmers are subject to the danger of the raising in crude oil price, because they orient their crops to bioenergy crops instead of other crop types, that leads to increasing food price (Pal and Mitra, 2018). This reason for the upward shift of food prices has been confirmed in different studies (e.g. Ciaian, 2011; de Nicola et al., 2016; Nazlioglu and Soytas, 2012; Pal ad Mitra, 2017; Tyner, 2010; Chen et al., 2010; Baek and Koo, 2014). Furthermore, and after the introduction of the conditional heteroskedasticity approach by Engle (1982), various research works have employed this model. The development of the conditional heteroskedasticity to the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models was introduced by Bollerslev in 1986.

Prices represent the market dynamic, and the price adaptation strategy utilized, not only the basic relationship between different market players (farmers, producers, processors, retailers, and consumers). The cointegration approach is used to study the link between prices. Cointegration models are an effective tool for examining asymmetric price transmission between variables. Asymmetric pricing comes in two forms: vertical and horizontal. The study of the link between various prices at different levels of the same commodity supply chain is known as vertical price transmission (Fousekis et al, 2016; Grau and Hockmann, 2018).

Different studies examine and evaluate meat price volatility and the link between producer and consumer prices from a wide approach. A vertical price transmission can be used to assess the effectiveness of several interconnected market participants. In 2020, a research study examined the price volatility spillovers between producer and consumer prices of meat in Finland (Ben Abdallah, 2020a). The degree of price change transmission across market participants might be a useful policy indicator for assessing benefit distribution and how competitive and sustainable the market is (Acosta and Valdés, 2014). Dairy sector has gained attention to examine the price transmission, the dairy sector in Hungary has been analyzed to detect the price transmission between raw milk and the dairy products (Ben Abdallah et al., 2020b, Hill, 2021, and Onegina et al., 2021).

In a competitive market, when price shocks occur at one level of the market chain, the other levels react with the same size, reflecting market efficiency and confirming price stability amongst all players (Serra and Goodwin, 2003).

Horizontal price transmission, also known as spatial price transmission, assesses the relationship between similar price levels but distinct commodities (Dong et al, 2018). A large number of studies have looked into horizontal pricing transmission (Bakucs et al, 2012). The spatial price transmission of pork prices between Serbia and a group of countries (i.e. Hungary, Germany, United Kingdom, Spain, Denmark, and the United States) has been studied, and it has been discovered that the pork price shock in Spain, followed by Hungary, has the greatest impact on pork prices in Serbia (Jeremić et al, 2019).

The dairy sector in 20 European nations was studied to construct a spatial price spread. It emphasizes the favorable impact of milk quantity moved between Europe and the negative impact of geographic distance on milk price transmission in Europe (Bakucs et al., 2019). To find out the pattern of link between mean prices, many econometric models of asymmetric price transmission have been developed. Various studies are developed to give an empirical literature review on econometric models and types utilized in asymmetric price transmission investigations.

Surveys have been established. Meyer and Von Cramon-Taubadel published an assessment of 40 works, mostly in the agricultural area (Meyer and Von Carmon-Taubadel, 2004). They classify price asymmetry using three criteria: reaction magnitude, sign (positive or negative), and direction (vertical or spatial).

Guo and Tanaka (2020) investigated the connections between world prices and U.S. producer prices in the wheat, soybeans, and corn markets in 2020, using a vector error correction generalized autoregressive conditional heteroscedastic model with a multivariate Baba-Engle-Kraft Kroner specification (VECM-GARCH-BEKK) (Engle and Kroner, 1995) and cross-correlation function. Khan and Helmers (1997) found the presence of volatility transmission from the feed (corn) to farm level in a research involving corn, pig, beef, and poultry in 1997, utilizing Vector Autoregressive on shifting variances of prices. They claim that contract production lowers the impact of maize price volatility on beef and poultry farm pricing (Khan and Helmers, 1997). In their study of price volatility transmission of beef meat in the United States, Natcher and Weaver (1999) employed VAR on univariate GARCH conditional variances. They discovered bilateral distributional effects at all levels of the system (farm-wholesale-retail).

The research was made by Buguk et al. (2003) estimates a univariate EGARCH (that also accounts for asymmetries) for the US catfish market, and the most recent innovations from other markets are incorporated as explanatory variable in the downstream market's conditional variance equation.

Furthermore, volatility connections are specified via VAR models (which are generally used to provide foreseen price linkages (Buguk et al., 2003).

In Greece, Apergis and Rezitis (2003) employed the VECM model to model agricultural product volatility. Volatility was found to be transmitted from the feed to the farm and from the customer to the farm. They cited three major factors: a lack of contracts, the natural character of crop output (time lag in production response), and a reduced-price sensitivity of agricultural demand versus retail demand. N their study of retail food in the United States, Zheng et al. (2008) identified two characteristics that influence price volatility spreading. Price shocks are absorbed by large merchants with market strength. Low farm price share in retailer price level, implying that a low-cost portion of farm input leads to low farm price volatility transmission. Serra stated in 2011, when discussing the beef market in Spain, that market power is an essential component that might affect price volatility.

Alexandri (2011) employed the statistical technique of comparing the coefficient of variation of prices to examine agricultural price indices in Romania. The study reveals that merchants use price stabilization as a marketing technique because buyers are sensitive to price variations. Agricultural prices are more variable than market prices due to the low flexibility of farm demand. Rezitis (2012) assessed the price volatility between producers and consumers in four meat marketplaces in Greece: beef, lamb, pig, and poultry. The Diagonal VEC was used to assess price volatilityHe discovered that price volatility in the pig and poultry markets is more persistent than in the lamb and beef sectors. Besides, through all markets under study, price volatility persists longer than volatility's response to fresh market information. He demonstrated that retailer concentration causes volatility transmission from retail to agricultural level in the poultry and lamb sectors as a factor for volatility transmission (Rezitis 2012). In Iran, Khiyavi et al. (2012) analyzed monthly data from 1997 to 2010 to focus their research on the chicken market.

The mean equation was estimated using the VECM model, and conditional variance was estimated using a variation of the VECH model; they discovered bidirectional volatility transmission (from feed to farm and from retail to farm). They claimed that three primary variables led to the increased price volatility at the agricultural level when compared to agricultural input and retail output price volatility. The first is the lack of contraction, the second is the natural nature of agricultural output (time lag in production response), and the third is the lower elasticity of farm-level demand than retail demand.

In South Africa, Uchezuba et al. (2010) look at asymmetric price levels and volatility spillovers in the poultry supply chain. The EGARCH model is employed to quantify price volatility and the volatility impact across different market price levels, whilst the threshold autoregressive (TAR) and momentum threshold autoregressive (M-TAR) models are used to explore asymmetry in price initial moments. Volatility transmission was observed from the agriculture to the retail level using the univariate EGARCH with spillover effect. They stated that retail market power causes this volatility transmission, which implies that merchants utilize their position to asymmetrically communicate unanticipated positive agricultural price shocks.

Guo and Tanake, in 2020 discovered a long-run equilibrium link between international and domestic producer prices for the three agricultural goods, as well as a significant bidirectional causality-in-mean and causality-in-variance relationship between international and US producer pricing for some crops (Guo and Tanaka, 2020). Every economy's progress is dependent on energy, mainly oil and derivatives.

As a result, it has a high value and impacts the prices of other commodities. It is widely utilized to supply various industries as transportation, agriculture, industry, and homes, as well as a raw material in the manufacturing of petroleum goods.

Pursuing the financial crisis of 2008–09, Lu et al. published a study in 2018 that investigates the complexity and dynamics of volatility spillovers between crude oil and agricultural commodity markets. To identify the different terms (i.e. short, mid, and log) spillover effects, they used a flexible bivariate heterogeneous autoregressive model to test for volatility spillovers (Lu et al, 2018).

The price of crude oil and the price of food have a positive relationship (Pal and Mitra, 2018, and Taghizadeh-Hesary et al., 2019). According to a study conducted in Nigeria, there is a considerable volatility spillover between crude oil and food prices (Fasanya and Akinbowale, 2019). The autoregressive distributed lag (ARDL) model (Pesaran, and Shin, 1998; Pesaran, Shin, and Smith, 2001; Shin and Greenwood-Nimmo, 2011; Shin and Greenwood-Nimmo, 2014 and Kharin, 2015), the partial adjustment model (PAM) (Ahn et al, 2002), the error correction model

(ECM) (Fernández-Amador et al, 2010; Rezitis and Tsionas, 2019), the regime switching model (RSM) (Davies, 2006), and their multivariate extensions are the first class of econometric models of asymmetric prices

Asymmetric price transmission in the dairy supply chain of different nations has been assessed using various approaches.

The milk market was studied in 2014 using an error correction model to assess asymmetric price transmission between supplier and retailer (Bor et al., 2014). Threshold error correction models were employed to discover an asymmetric price transmission across three milk products in the United States (Awokuse and Wang, 2009).

The error correction models are used to examine three pricing stages of Slovakian milk products (i.e. producer, wholesale, and retail). The findings show that asymmetric price transmission exists in the short and long run (Weldesenbet, 2013). Meyer et al. (2018) used the nonlinear panel ARDL to examine the asymmetric link between food and oil prices in the short and long term in 2018.

3.6. Previous studies dealing with food security index and its determinants

Food security is always the burden of the world. The burden of food insecurity is spreading crosswise all over the world, as well as to developed nations (Fusco et al.,2020). Many individuals in developing nations are unable to afford the rising expense of nutritious meals, which is one of the main causes of rising food insecurity (FAO, 2020).

Therefore, understanding the main drivers of food security is the key to identify the main factors leading to mitigate the insecurity level and to forecast which country is more sensitive to food insecurity. FAO defined the food security concept as the state “when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food in order to respond to their needs for an active and healthy life” (FAO,1996).

Four pillars have been identified for food insecurity. i.e. availability, access, utilization and stability (FAO, 1996). During the last few decades, the amount and quality of food available to millions of people in developing countries has significantly improved. Despite, food supply interruptions, currency depreciation, and restrictive constraints on agricultural exports, the number of undernourished individuals has increased again in the 2010s. Despite being similar to most countries, these threats to the population’s food security differ based on each country’s degree of economic development and national wealth (Erokhin et al., 2021).

The Global Food Security Index (GFSI) is a composite index developed by the Economist Intelligence Unit to give a standard, cross-national framework for gauging food security (EIU 2015, 2016 and 2019).

The GFSI for 2019 includes 34 unique indicators that cover a wide range of topics related to food security, including average food supply, diet diversification, and the presence of a formal grocery sector, among others. Affordability, Availability, and Quality/Safety are the three types of indicators (Allee et al, 2021).

The United Nations (UN) has identified a seventeen goals for a sustainable future for everyone and to eradicate hunger by 2030. Zero hunger is the goal 2, that means all people are free of hunger regardless the situation which they are facing (e.g. War, climate change, etc….)(FAO and UN, 1996). Roser and Ritchie within their research affirmed that the current situation is far from reaching this goal. They found that 820 million people, equivalent to 11% of the world population, are undernourished. About 1.8 billion people, which equals to the quarter of the world population are moderately or severely facing food insecurity (Roser and Ritchie, 2020).

The issue of inadequate food storage will become much more of a problem as a result of climate change and emissions. Every year, an estimated 1.3 billion metric tons of edible food is wasted or thrown away (Gustavsson et al., 2011)(reference?). Even if this meal has little nutritional value, it still has an environmental cost in the air.

Food supply in many low-income nations is vitally dependent on foreign commerce, in addition to low productivity, economic inequality, and food inflation. Interconnection between the domestic supply chains and global food market is often seen as a means of ensuring food security during times of domestic scarcity (Smith and Glauber, 2020; Erokhin, 2018). After 2010, leading nations (e.g. USA, Russia, Europe, etc…) have implemented protection measures to restrict the trade in the international agricultural market (Tanaka and Hosoe, 2011 and Prabhakar et al., 2020).

Aforementioned regulations distort food supply chains, putting food security at risk in low-income nations, mainly net imported nations (Wood et al., 2018).

Between 2010 and 2016, global food waste accounted for 8-10% of all human-caused greenhouse gas emissions. As a result, infrastructure for food conditioning and refrigeration is required to keep food fresher for longer periods of time, as well as to transport and store food (Özkaya and Özkaya, 2022)

At the end of 2019, the spread of the new Corona epidemic (Covid-19) has interrupted the world life. It aggravates the situation of people who already suffer from food insecurity and malnutrition. The Covid-19 makes a pressure for policymakers to take quick decisions to mitigate the effect of the pandemic, such as West Africa which is dependent with rice import. The government has established new policies trying to reduce the impact of the pandemic on the rice trade (Arouna et al., 2020).

The lockdown resulted from Covid-19 has endangered the food security of vulnerable and low-income households which are highly linked on labor income. The imposed rules of lockdown have restricted people to leave their home, therefore, they are prevented to go to their work. Furthermore, different industries were forced to get closed due to the declined production and obliged to fire their employees. Thus, it creates lack of household income that let them struggle to afford food.(Arndt et al., 2020). The world food program forecast a number of 130 million of hunger people resulted from the covid-19 (Khorsandi, 2020). The fast transmission of covid-19 has harmed different sectors leading to various concerns.

The highest concern during this critical situation is that people can find their food needs. However, different studies that have been conducted about this topic reveal the high effect of covid-19 on perishable food, which create a food shortage especially for poor country.

Moreover, Covid 19 endangered as well the food security in some developed countries, but mostly in developing countries which are more vulnerable. (Mouloudj et al., 2020 and Monasterolo et al., 2016). A bibliometric study has been conducted about the relations between food security and food price show the important link between the food price and the nutrient intakes especially in developing countries (Ben Abdallah et al., 2021; Mouloudj et al., 2020 and Sweileh, 2020).

The world population growth leads to the increase of the food demand, which is accompanied by an income growth and urbanization. The problem is how to feed and to respond to the needs of a global population which is predicted to attain near 10 billion by midcentury (2050). The main concern is the ability of achieving the required production increases under the different pressure, demographic, climatic, food system, etc… (Vos and Bellù, 2019). Urbanization is defined by the growing share of people who are settling in urban areas and aftermath; the share of people who are living in rural areas is reducing. (Satterthwaite et al., 2010).

On the other hand, the agriculture is facing a huge task to realize a secure food supply for all the population. In addition to the rapid urbanization, people and governments will be confronting further enormous challenges (Ira and Kohler., 2014). There is lack of research on food security where food security shortage is based. At the beginning, food security research concentrated on economic policy and global issues and later on the literature has been enlarged to include other subjects such livelihoods, health, and the environment (Cooper et al., 2020).

Because of its complexity, estimating a food security index is a challenge. Even though, many researchers try to estimate a composite index to assess the food insecurity status. In order to measure the food security status, two dimensions should be coexisted; the real availability of food and the economic capabilities (e.g. income, food distribution, etc…) (Huang and Hu, 2000).

Two levels are considered to assess the food security; the national level or the household level. To investigate the household level, survey method is needed while secondary data could be used to assess the national level. Blekking et al, in 2020, analyzed the household level, 718 households, using survey data to evaluate the urban food security in Sub-Saharan Africa (SSA).

A comparative study has been established by Omidvar et al, in 2019 to assess food security between different countries within MENA region. They used the food insecurity experience scale adopting different statistical methods (e.g. descriptive, binary logistic regression, etc…) to identify three groups of countries from severe to moderate food insecurity (Omidvar et al, 2019).

The amount of agricultural commodity production and sales were used to estimate the food market power in emerging nations (Kolodina, 2013), whereas Kostrova used demand and supply, pricing level and behavior, market infrastructure, and market rules. (Kostrova, 2014). Different emphasized factors have been united to overwhelm food systems, food security and nutrition, disrupting the food supply chain, engendering income loss which enlarges the inequality, leading to unsteady food prices and perturbing the communal plans (Clapp and Moseley., 2020; Klassen and Murphy, 2020; Laborde et al., 2020). Price could disturb the household diet and force them to change their preferred food (Matz, et al., 2015).

Food security always presents the hub of research especially in this situation of the pandemic. The uncertain spread of the pandemic Covid-19 has aggravated the situation, its evolution around the world menaces food security by reducing food production (HLPE., 2020). Vulnerable households such as small-scale farmers are highly affected by the Covid-19, which threats the food availability and accessibility (Workie et al., 2020). Covid-19 presents a concern in food supply. It weakens the food production, food demand and food access (Devereux et al., 2020; Glauber et al., 2020; Béné, 2020; Pu and Zhong, 2020). Covid-19 presents critical situation for the global food security (Cardwell and Ghazalian, 2020).

To evaluate the food security situation in developing countries, two criteria should be taken into account. The first criterion is about food availability, which means the food which is physically available by production and import. The second criterion is the access economically to food which means that food is well distributed to the population and people have enough income to buy it (Wolfe and Frongillo, 2001).

In 2019, Popp et al., elaborated a study which is considered the first one that focuses on the food supply systems in Africa in order to figure out the most important stages responsible to boost the food security. In order to reach the sustainability of food security, sustainable development strategy should be built, which is provoked to respond the health requirements of contemporary people, without endangering the needs of future generations. For these reasons, various studies have been published trying to estimate food security using different indicators which may cover some of its dimensions (Perez-Escamilla, et al., 2017).

In developed countries, food insecurity could be affected by socio-economic and demographic indicators. It has been revealed that people who live alone and don't have social life are more food insecure (Park et al., 2019). The level of education, number of children and the home location present a significant effect on food insecurity (Grimaccia and Naccarato, 2019).

In 2018, Akinboade and Adeyefa collected primary data to investigate the household food security of low income, poor urban households and city households in South Africa. ANOVA method has been employed to detect the existence or the absence of difference between different analyzed groups. A food insecurity index has been developed as a potential indicator. It has been built with the probability of covariate shock happening, the experience of food insecurity accumulation and household's endurance (Ibok et al., 2019).

After the introduction of food security index by the Economist? Intelligence Unit in 2012 (EUI, 2015), many research papers have been published to assess the global food security, Izraelov and Silber, in 2019, employing the Data Envelopment Analysis (DEA) and Principal Component Analysis (PCA) methods, show how the global food security is sensitive to the selected indicators such as food consumption as a share of household expenditure, public expenditure on agricultural R&D and micronutrient availability. In 2020, Caccavale and Giuffrida built a new composite index by selected variables, weighting, normalization and aggregation and they tested it using Monte Carlo procedure.

To measure the food security index, many researchers have classified drivers in groups. Two main groups of factors are introduced by Smith in 1990, which influence the food security status. The first group involves the supply determinants. It includes the following factors: weather circumstance, imported products, policy inducement, stocks, and production. The second group covers demand determinants and it contains population progress, income development and distribution, and export income (Smith, 1990). Ulezko and Pashina, suggested three groups of indicators; macroeconomic, trade and subjective. The macroeconomic group contains macroeconomic variables such as GDP and the agricultural production. The trade group has data about the volume of agricultural raw materials import and export. The subjective group involves market determinants, commodity suppliers and consumers (Ulezko and Pashina, 2014).

The vulnerability of Sweden to the food security was quantified through a group of indicators, direct trade with suppliers was among these indicators (Horn et al, 2022). A recent study was elaborated to analyze food security index in China, in 2021 by Lv et al., using agricultural, climatic, and socioeconomic factors. An analysis was carried out, using step wise regression, to identify the spatiotemporal prevailing factors leading to food security. Data Envelopment Analysis (DEA) approach has been used by Nehrey and Voronenko, in 2020, to estimate the food security index in some selected countries. In their analysis, they employed the 36 indicators used by EIU (Nehrey and Voronenko, 2020).

There are different methods to assess the food situation. Based on the amount of production and purchases of agricultural commodities, the food market potential in developing economies could be evaluated. Another method of assessment employs demand and supply, the level and nature of the price, market infrastructure, and market adjustment (Erokhin, 2017). In order to predict future food resilience methods, demand and supply-side variables are critical. The Demand Side variable, particularly poverty demonstrates that poverty can affect food resilience, making poverty reduction a critical priority (Nuryartono et al., 2021).

The usability of these methods much depends on data availability and complexity. In 2021, Sam et.al, estimated the food security index in India based on group of factors using PCA method as a weighing method to generate a unique indicator (Sam et al., 2021). By evaluating the GFSI indicators and taking into account the values of the nation being compared, it is stressed how the objective weights should be and which indicators should come to the fore in the comparison of these countries. The global food security and nutrition research focuses on hunger rather than dietary diversity and the nutritional needs of productive people.

While healthy diets are readily available to rich customers, many consumers in vulnerable, marginalized communities face considerable obstacles (Ronto,et al., 2018). A research study has been conducted to determine the level of nutritional requirements satisfaction, they found that every country faces a deficit in a minimum one food subcategory to respond a proper nutrition. Mainly fruits and vegetables are facing a clear deficit to meet the energy needs for a person (Coghlan and Bhagwat, 2019). Many research studies have focused on the food supply in examining the food security (Erokhin and Gao, 2020), while others focus on the nutrition and health side (Fan et al.., , 2020). A complex mix of elements that vary over time influence dietary trends in diverse places of the world. Many countries around the world have made tremendous progress in improving their people's food security and bringing them out of extreme poverty since the 1980s by Erokhin et al.,

3.7. Bibliometrics analysis : discovering the link between price dynamic and food security

An evaluation of the research study is considered an important task to make future adjustments for securing and adjusting policies. This article exhibits the results of a study that intended to explore the researches which have been published with food security, price volatility, and price transmission as keywords.

The study reveals a bibliometric evaluation of statistical outcomes from 899 scientific publications from 1979 to June 2020 related to the subject, registered in the web of science database. The collected articles were used to measure bibliometric indicators and to evaluate the research work on food security and price movement of agricultural products. Also, an analysis of the development and the identification of the related topics of greatest interest on this subject was carried out.

The analysis results found that a rising number of researches has been registered after 2005. Some growing ideas joined food security-price literature, such as climate change, agriculture, health, nutrition, consumption, and income. In other words, the trend scientific researches associate the food security analysis with the health and food nutrition status. Furthermore, the word "impact" is remarkably presented in the analyzed papers which reveals that researchers, highly focus on the examination of the relationship between these keywords.

Food price surges and volatility increase political, professional, and public issues for food security all over the world. During 2007/2008, food price volatility has undermined thousands of people, weakening the alimentary situation and food security. The Food and Agriculture Organization (FAO) has foreseen that the 2007-2008 price increase, led to having higher undernourished people. Thus, the number increased by 173 million people in two years, from 2007 till 2009. According to FAO in 2011, The African continent suffers from a high number of undernourished people which reached 240 million, because of the price fluctuation of staple food (e.g. wheat, rice, maize).

Besides, the price of agricultural products is affected by COVID-19 and therefore the food supply chains (De Paulo Farias and De Araújo, 2020). Facing food deficiency is not caused only by food unavailability on market; but also, by the price increase. People could be prevented from food because of their access to food (Sen, 1982).

Policymakers try always to weaken price volatility and to mitigate its negative impacts on market actors (i.e. Consumers and producers) by implementing strategies in the market or public interventions (Gouel, 2012, and Galtier, 2013).

The commodity price volatility, unforeseen supply chain disruptions, and unanticipated weather change present a crucial risk for food markets, which hamper the government to ensure consistently and regularly available food which threatens food security. Higher price volatility depreciates household incomes and purchasing power. Issues related to price volatility are linked with the concept of food security. A price shock could disrupt the four pillars of food security (FAO 1996, 2015).

Due to market interconnections, it is crucial to understand the price dynamics within the market. To analyze the link between food prices and food security, a research study has been established in Kenya. The study aimed to assess the link between the maize price and the low birth weight as an indicator of food security and quantify its effect. A positive correlation has been detected. This result could not be generalized for all Kenyan households. In other words, some households got advantages from maize price increase (Grace et al., 2014).

Food security is always a very attractive topic for researchers. A review paper was published about issues that food security confronts. Food price volatility was among these drivers (Fróna et al., 2019).

Recently after the spreading pandemic of COVID-19, some research has been published, showing the impact of the pandemic on the four pillars of food security (Laborde et al, 2020) and measuring its impact on low-income households (Arndt et al, 2020).

The food price increase could worsen the health status of poor households by preventing them to have the access to sufficient nutritional food (Mkhawani et al, 2016). Climate change and food price change are considered two major drivers for food insecurity for some countries, as affirmed by Alem and Söderbom (2012) and Wossen et al (2018), for Ethiopia and Ghana. Furthermore, evaluating the impacts of price instability on smallholders.

Food insecurity and price volatility are crucial issues for our future period. Thus, Governments need to develop clearer measures that tackle efficiently agricultural risk management for sustainable development. It is essential to have the tools and the necessary knowledge which help in recognizing and identifying the determinants of food security and to know the way of intervention to protect people from insecure food. Therefore, it is pivotal that the government should undertake a background study of the forecast of a food security index. In this regard, the results of this study would be a useful reference for the government for intending to practice a global model forecast of food security index.

Facing the up warded ship of the population and how to afford enough food, the United Nations has set a group of goals for sustainable development in their agenda 2030, among these goals there is Goal 2 which "zero Hunger" (UN, 2018).

An increase in food prices threatens the purchasing power of consumers. Governments need to develop clearer and more rapid measures that tackle efficiently the food market management for sustainable food availability.

It is essential to understand and to identify factors that contribute to determining the food security state and in helping to recognize the way of intervention to protect people from food insecurity. The price is linked to food security; this is could be explained by the fact that there are factors that are in a close relationship between food security and price, such as supply and real income (Kalkuhl et al,.2016).

Therefore, bibliometric studies are considered suitable to assess previous research based on keywords and to offer useful directional themes for new research (Tripathi, 2018). The Bibliometric method has been chosen as a suitable method because of its capability to reveal and identify factors of food security and price volatility. Different studies have adopted a Bibliometric analysis for reviewing specific themes. It has been used to highlight the danger that agriculture is facing. It identifies new directions to investigate future scientific works (Novickytė, 2019). Also, it was a helpful tool to design a comprehensive image of publications in food policy, describing sources and authors' collaboration (Popp et al., 2018).

Using the biblioshiny function in the bibliometrix package in R studio allows us to figure out a simple and clear image of bibliometric analysis. It helps to identify the most important and trend keywords, which serve as a useful and comprehensive tool for communication.

The main purpose of this research was to evaluate the previous studies which have been done and combined these two-research topics; the price movement and food security and to identify factors indicators which are linked with food security and price movement. Before, systematic review researches have been elaborated with the major group, and relatively few studies utilized evaluative bibliometric and relational bibliometric studies.

Bibliometric is a developed different methodology from the traditional systematic literature review (De Bakker et al., 2005). Bibliometric analysis is a crucial method for investigating research, and it originated from the subject of library and science knowledge. Analyzing the English articles that tackle food security and the price dynamic in the agriculture field, Bibliometric science has been applied. It grants us to elaborate network analysis which gives us a clear image of the different links between the different scientific research, countries, authors, and keywords (Skaf, 2020). Also, it figures out the co-occurrence of keywords as well as an overview of the different theme evolution.

The bibliometric method allows creating networks that give an overview of the relationship between keywords, authors, and their co-occurrence (Van Eck and Waltmn, 2014, Sarkodie and Owusu, 2020). Different studies have been elaborated on food security using the bibliometric method, such as Bouzembrak et al. (2019), Wahyuni et.al (2019), Okumus et. Al(2018), and Chen et.al (2019a? b?). These studies connect food security, price volatility, and price transmission, to provide a quantitative review paper based on research publications.

The bibliometric method helps to get an overview of the previous research which has been elaborated in the field, food security and price dynamic, trying to shed light on these two important concepts which are always in the main concern of the research. Bibliometrics is a developed method that allows calculating and evaluating written communication (Pritchard, 1969). It has been demonstrated that bibliometric analysis allows identifying quantitatively the trend and the characteristic of a specific research topic based on different indicators (Kumar et al., 2020).

The bibliometric method focuses on analyzing the qualitative aspect of research fields, concentrating on research titles, keywords, affiliations, authors, and journals where they were published (Gupta and Bhattacharya, 2004). In our research work, the bibliometric method permits us to pinpoint the important factors involved in the analysis of the relationship between a price change and food security. Web of Science provides the necessary database in our analysis (Harzing Alakangas, 2016 and Liu, 2020). It is chosen in our research study as the source which affords the articles.

The analyzed documents used in this study have been extracted from the Web of Science with advanced research, on 9th of June 2020 using the keyword ***TS*** = *((“food security” OR “food security index”) AND (“price” OR “price volatility” or “price transmission”) AND (“food” OR “agriculture” OR “agricultural commodity” OR “agricultural product”)).*

The inputs are the downloaded papers from the Web of Science on June 9, 2020. Articles in the English language are the only documents that have been considered. R Studio is free, open-source software and it could be installed easily.

There are numerous open-source packages available that help to carry out the specific user-driven functions in R Studio. Bibliometrix package is one of the different available packages dealing with bibliometric analysis. It is fundamentally established for bibliometric analysis. In this research, the Bibliometrix package was employed for data investigation and explanation.

The R studio software was used to perform the bibliometric analysis in this study. Using the bibliometrix package and the biblioshiny command in R studio, we could conceive, observe, and investigate the different networks based on bibliometric outcomes. The findings are displayed in this section.

3.8. General characteristics of the bibliometric analysis

Bibliometric analysis allows to figure out the statistical analysis of the previous research studies that have been elaborated to link between food price movements and food security. First, we describe the data used to achieve the objective.

The bibliometric analysis is based on web of science scientific published research papers.

As highlighted in Table 1, the web of science database search output is 899 publications during the period from 1979 to June 9th, 2020. These articles have been elaborated by 2566 authors and published in 429 sources.

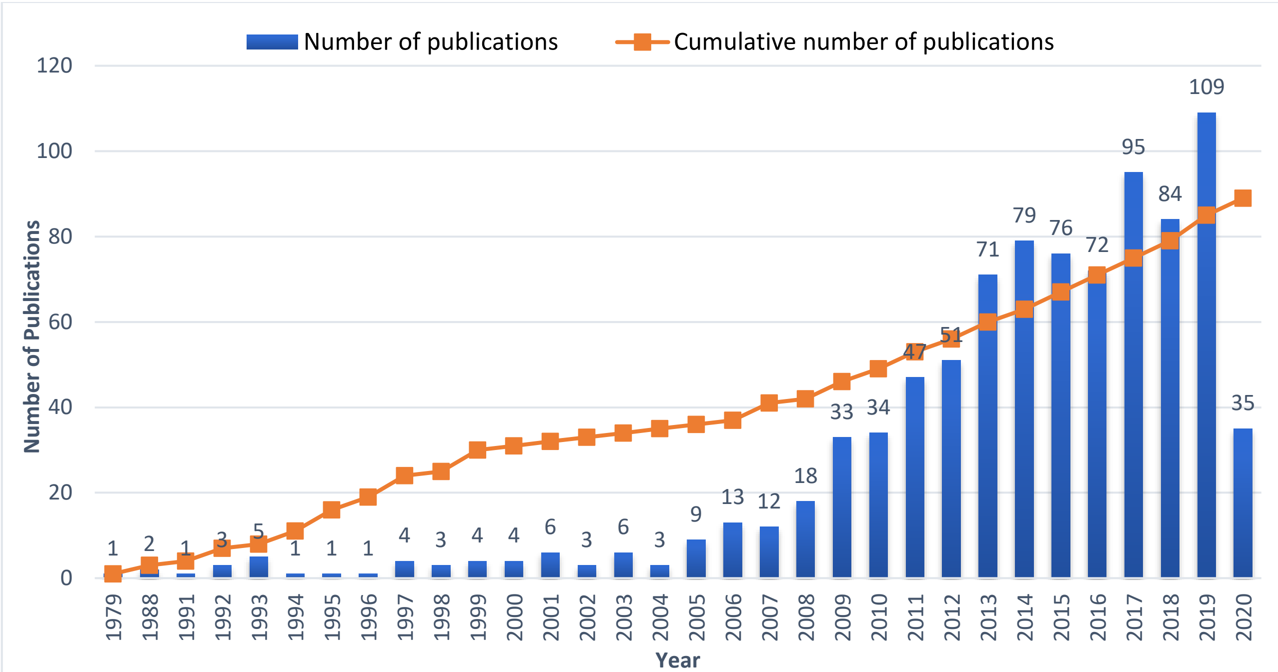

Figure 10. Distribution and cumulative publication over the years

Source: R studio results

Figure 10 shows the repartition of the number of publications over years and the curve presents the cumulative publication number. It reveals an expanding, with some fluctuation, of the number of publications, starting from 2005, which could be explained by the developing focus on the topic. From 2007 to 2014, the number of publications was noticeably increasing from 12 papers to 79 papers it reached 109 research papers in 2019.

The cumulative number of publications was following an upward trend. It could be divided into three phases according to the speed of the increase. The first phase spanned from 1979 till 1998. The second one, which had a lower speed than the first phase, covers the period from 1999 to 2007. The last phase, which had the highest speed of increase, started from 2008 to 2020.

3.9. Verification of Lotka's Law

Lotka's law (Lotka, 1926) indicates author productivity. It exhibits the relationship between the author and the publication numbers. The general form of Lotka's law is $X^n = \frac{C}{Y}$ where X is the number of publications, Y is the number of authors who published X publications, n, and C are constant. Using the function in R studio language, L=lotka(results), n= 3.626, C=0.778, R^2= 0.975 and p-value is 0.056. C=0.778 is the percentage of the total author number which is equal to 1996. Table 2 illustrates the frequency of the number of published articles by the number of corresponding authors.

Table 1. Number of articles published by the number of corresponding authors

B= Number of articles	N. of Authors	A=Frequency
1	2314	0.902
2	203	0.079
3	29	0.011
4	12	0.005
5	3	0.001
6	3	0.001
8	2	0.001

Source: R studio results

Figure 11 presents the curve of Lotka's law. It shows a strong correlation between the Percentage of authors and the number of publications R^2=0.975. Only 7.9 % of the total authors (203 authors) have published 2 articles. 5% of the total authors (12 authors) contributed with 4 articles.

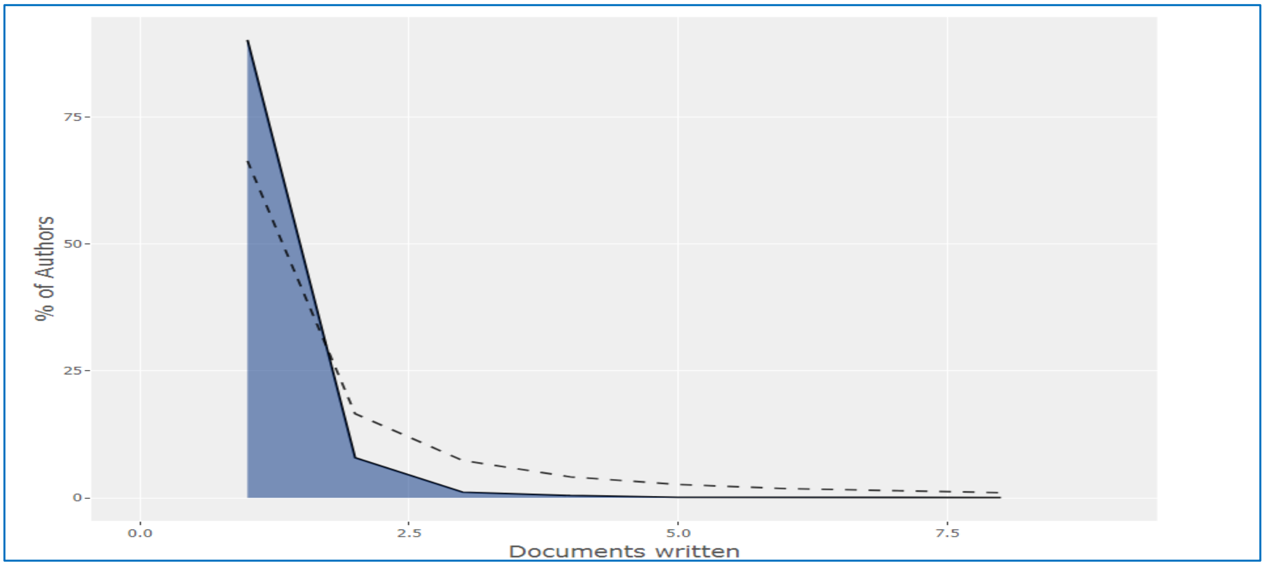

Figure 11. Lotkas's law curve

Source: R studio results

3.10. Sources patterns

899 scientific papers have been produced between 1979 and 2020 in 429 journals. As displayed in figure 12, there are two most relevant and top-ranked sources. The first source is the Journal of food security, which has the first place with the highest number of publications (58 articles), followed by the food policy journal (53 articles). Both journals are Q1 ranked. The sustainability journal occupies third place with 17 articles.

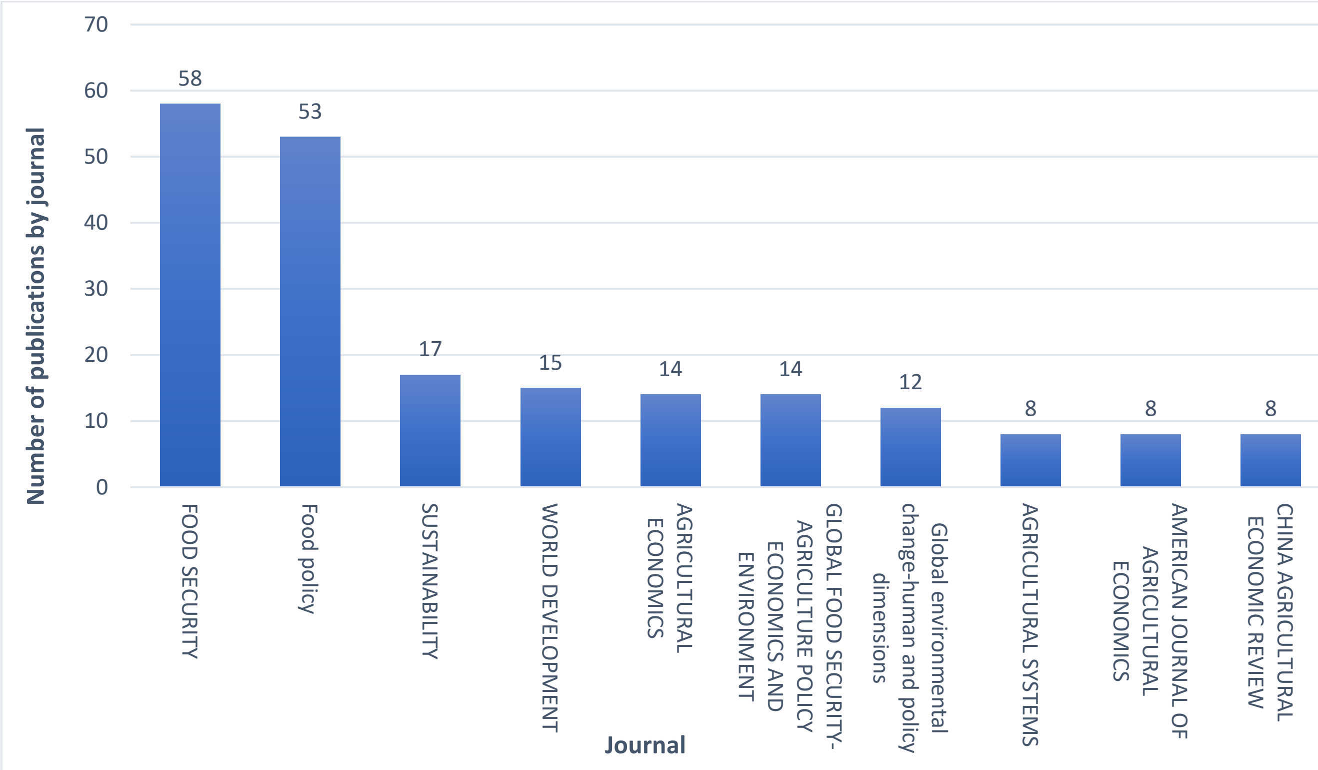

Figure 12. Classification of journals according to the publication number

Source: R studio results

In order to understand the main sources, where research papers have been published, the journal are classified based on the number of the citation in table 3. The two main sources are food policy and food security journals, where they have the highest H-index (Hirsch, 2005) and the highest number of citations.

3.11. Keywords and network analysis

Constructing the keywords co-occurrence is an informative tool that recognizes the research composition. This method refers to the use of correlation measures between words, revealing their appearance relationships. Co-occurrence network highlights the link between keywords, forming a network map.

In the investigation of related keywords to food security and price dynamics, we present the first ranked 10 keywords based on their number of associations and the intensity level of their relationship. The first keyword was “food security”. Figure 5 identifies the keyword network. The color represents the cluster and links between rectangles show the strength level of the relationship between these keywords, shorter distance signifies more intense association.

Figure 14 illustrates the co-occurrence of the key words. There are two different colors, the blue and the red. Each color describes a group of interconnected networks. The size of each rectangle designs the importance of the key word, the bigger size means the more important key word. The distance of the lines that link the different key words proves the level of connectedness. The shorter line designs the more connected words.

As highlighted in figure 14, food security occupies the hub of the network, presented by the biggest rectangle. The keyword “Agriculture “is superposed on the “food security “, reflecting the closeness between them, in other words, we cannot separate agriculture from food security.

The main focus of the research was placed on socio-economic and environmental aspects of food security such as climate change, health, poverty, price, and nutrition.

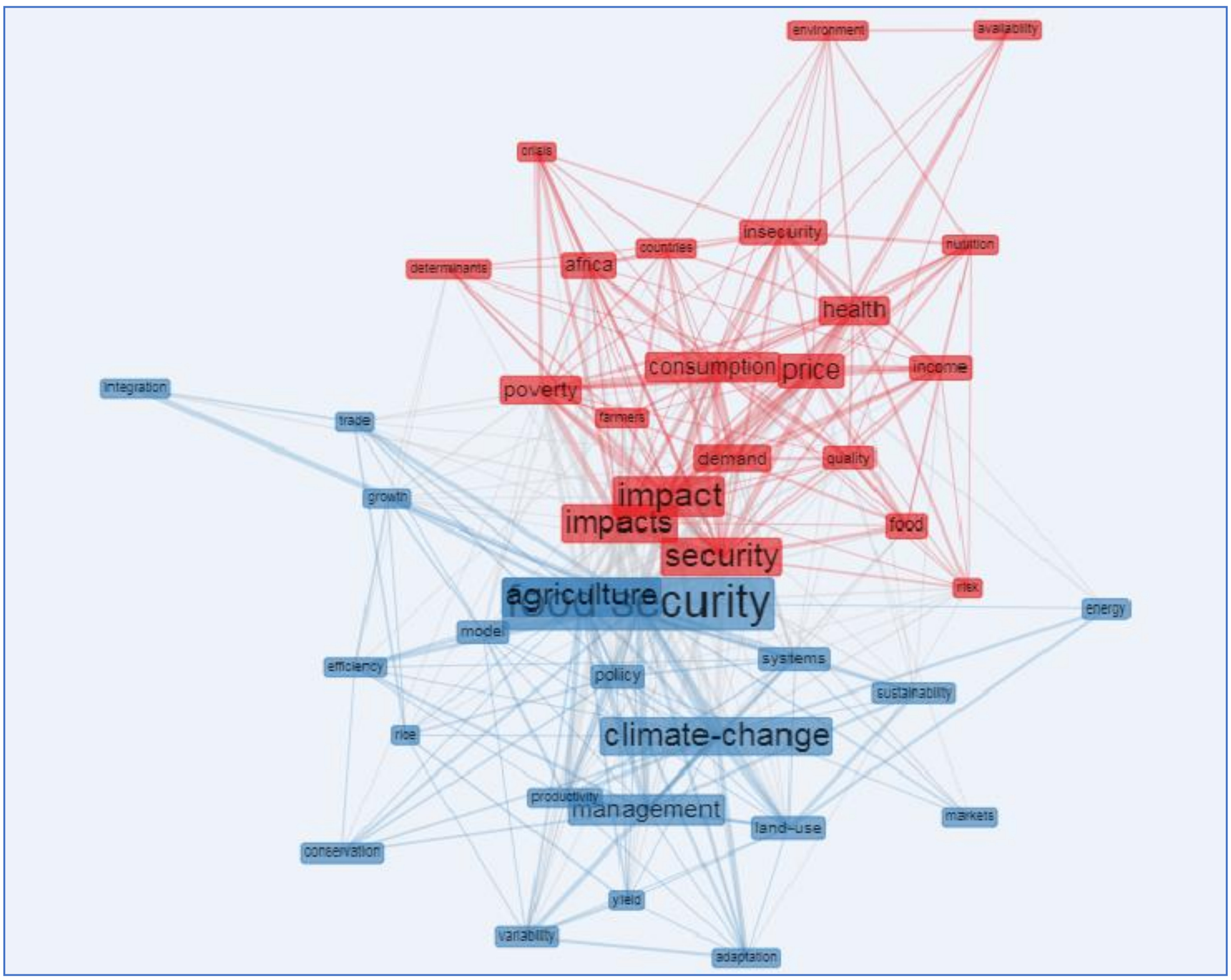

Figure 13. Keywords co-occurrence analysis

Source: R studio results

Based on table 8, we identify the first ranked keywords based on their co-occurrence. Food security has the first place with 77 co-occurrences, followed by the word security. Agriculture has 55 co-occurrences. The keyword price is among the first ranked 10 words with 44 co-occurrences.

We noticed as well the keywords "insecurity", and the word "health" are among the co-occurred keywords. It justifies the importance to refer to the health status while studying the food insecurity.

Table 2. Top ten author keywords and their co-occurrence

Keywords	**Co-occurrences**
Food Security	77
Security	56
Agriculture	55
Impact	53
Climate-change	49
Impacts	48
Price	44
Health	39
Poverty	39
Management	38
Insecurity	35

Source: R studio results

To understand the different group of keywords that gather a sample of keywords which have common similarity. Figure 15 illustrates two main groups. The group 1 with blue color and group 2 with red color.

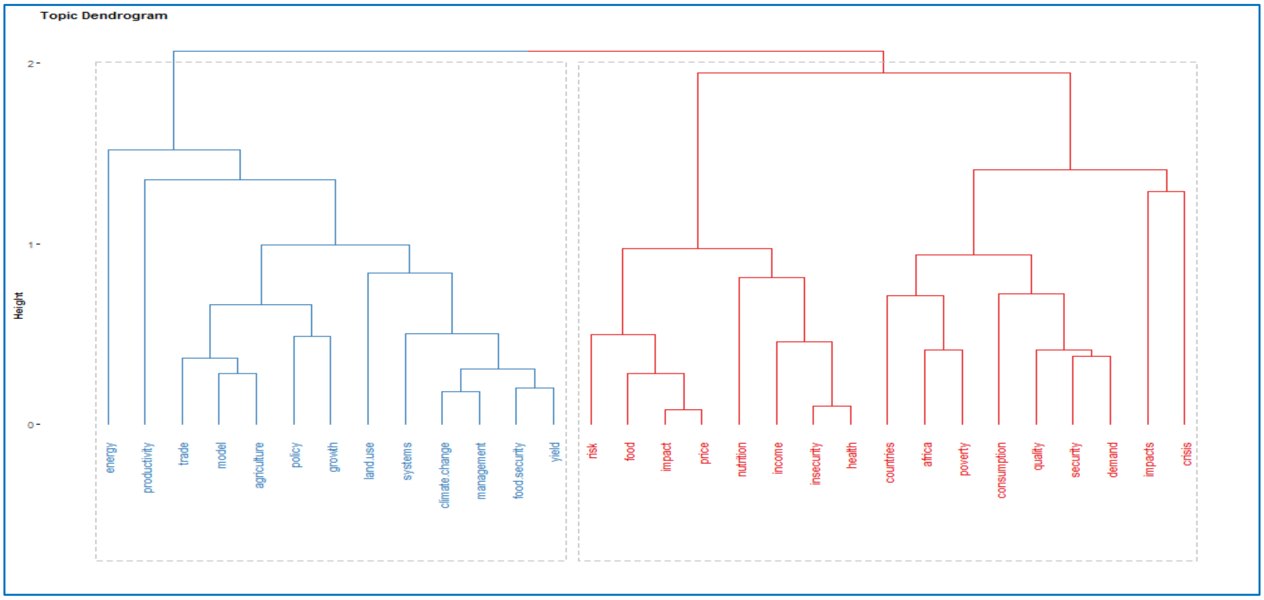

Figure 14. Keywords dendrogram

Source: R studio results

The dendrogram of keywords approves what is presented in the keyword co-occurrence. As illustrated in figure 15, two clusters are identified. In the blue cluster, food security is linked to production and policies. In the red cluster, the insecurity word which refers to food insecurity is linked to quality, health, and income.

Future researches are focusing, in addition to the production, on the household income and their access to healthy food which affords them the necessary nutritive needed value to protect their health status.

Figure 15. Word map of Keywords

Source: R studio results

In parallel with the decreased rate of undernourishment people, the research on food security has followed an exponential movement. It confirms that research considers food security a crucial issue for the whole world. The keyword map displays that food security presents a complicated issue that is related to different fields, such as human health and nutrition, and climate (environment). The size of words refers the importance of the keyword to be redundant in the world.

Figure 16 shows that agriculture; security and climate change are always the core of the analyzed research papers. We notice as well "consumption" and "price" are present with high importance. From this point, a relationship has been exposed in previous research using these keywords in the same research topic.

A relationship could be established linking agriculture, security, food, price, and consumption. It proves well the importance of research in food security and its impact as well as the word "price". The increasing curve of these two keywords "food security" and "impact" and "price" confirm well the raising research linking these three key-words.

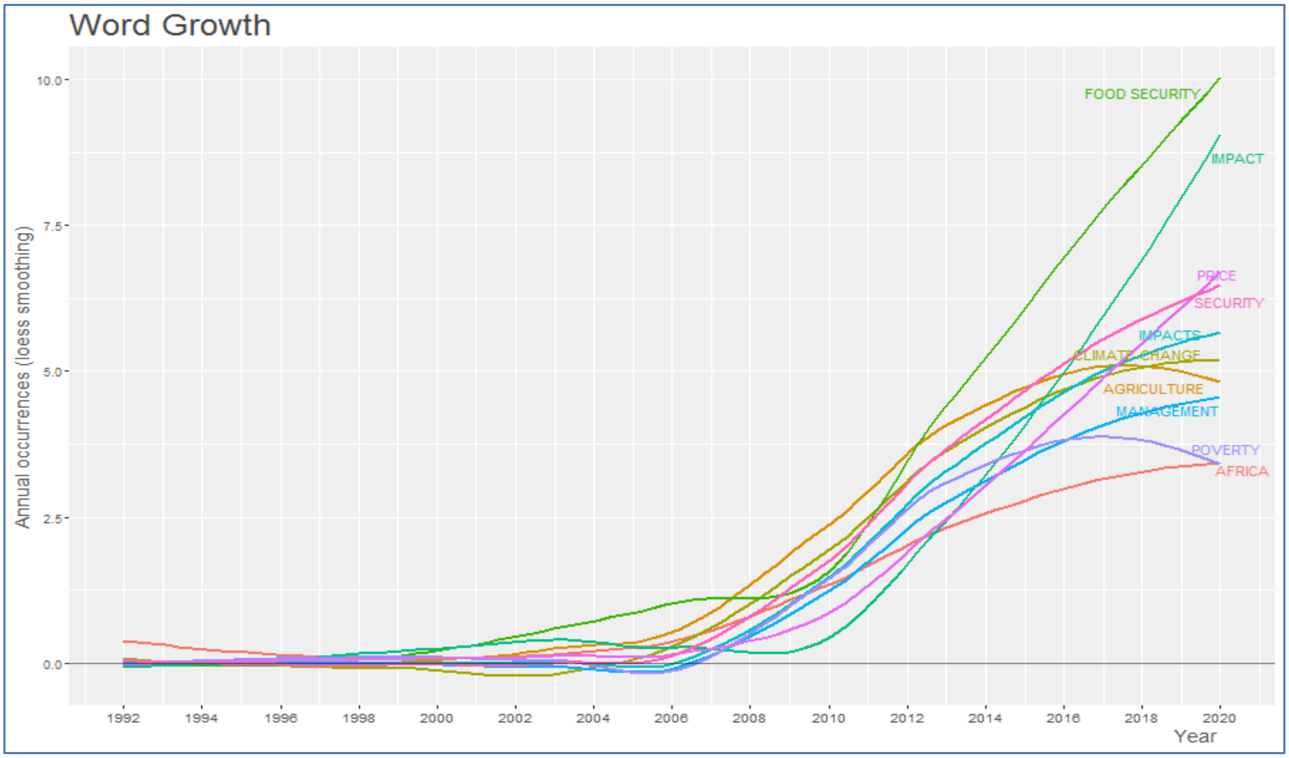

Figure 16. Change and evolution of keywords over time

Source: R studio results

Figure 17 affirms the increasing research papers with the "food security" as a key word. The first three words with an upward trend are food security, impact, and price. That means the importance of investigating the impact of the price on the food security.

This study is considered the first bibliometric study which joined between food security and price change as keywords. Based on these words, we identified the research fields which are increasing. The current study provided global scientific literature on food security and price dynamic. It analyzed the main characteristics of journals, authors, countries, and keywords. It investigated the relationship between them. It is highlighted that price, food security, and impact are growing over time in the research keywords. As it highlighted not only developing countries are interested in food security and price analysis.

Further research is needed to investigate and to measure the empirical impact of food price volatility on food security. It is noticeable that climate change, health, and income appeared with keywords. It gives the attention to associate the food security assessment with the people's health status, food nutritive values, and the capability of earned income to ensure stable nutritious food.

In their seminal work, Muñoz-Leiva et al. (2012) have analyzed the relative position of different topics according to their relationship within a network of a set of articles. In this way, combining the network and cluster analysis, they have defined four types of topics depicted in a two-dimensional coordinate system.

These dimensions are suitable to describe the centrality and density of different topics.

The so-called motor themes are at the center of the research field: they are well developed and have a wide and intense relationship with other topics. The basic or transversal themes appear in the lower right part of the graph and can be considered as the backbones of the given set of publications. They can be characterized by high centrality and low density.

The highly developed but isolated topics can be characterized by high density and low centrality. There are intense academic communications within these topics, but their contribution is relatively marginal to the set in general. The emerging or declining themes can be characterized by low centrality and density.

We have divided the investigation period into two parts for convenience: up to the world economic crisis in 2008 and after this period. We have applied this approach to reflect the changes in economic thinking: the crisis has highlighted the vulnerability of the global economic system (Brown and Ulgiati, 2011), and on the other hand- has shown the importance of new market players, first of all of China (Bouis, 2008).

The basic themes in the first period (Figure 19) were the supply of a rapidly developing population with rice and stabilization. Other important basic topics were the set of costs –price relationships, access, and availability.

The application of cointegration has been on the border between basic and motor themes. The most important emerging topics at this period were the effects of climate change on hunger, heals, and the environment. Interestingly, the studies analyzing the problems in Africa were rather peripheral ones.

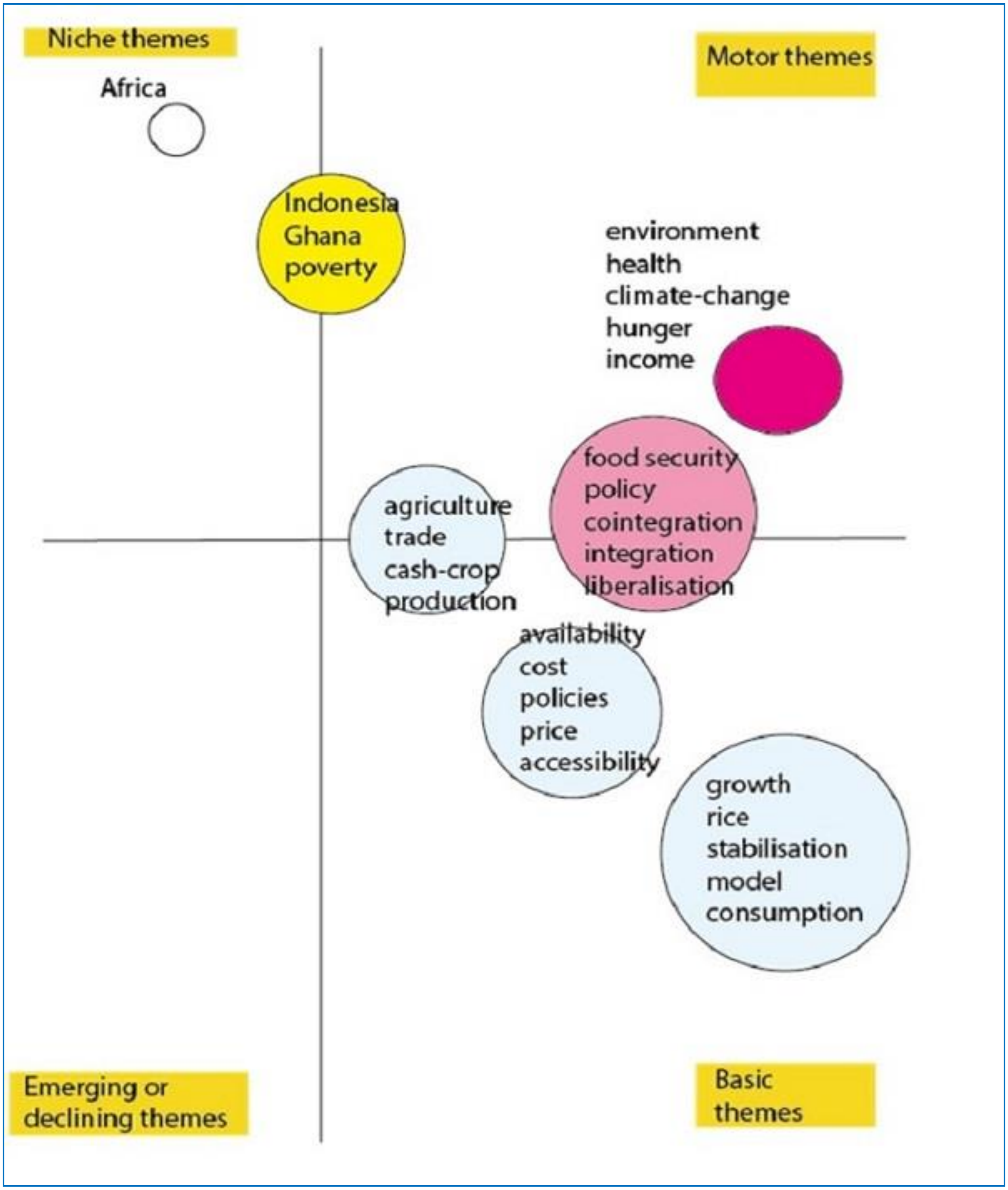

Figure 17. Strategic map of publications up to 2008.

Source: R studio results

In the second period, as highlighted in figure 20, practically in the last decade, some general topics (e.g., cost-price analysis, cointegration, land use policy analysis) became standard categories and became basic themes. Such, relatively new topics. E.g., economic aspects of bioenergy production have gained importance.

The price distorting effects of subsidies became central topics. In recent years it became obvious, that obesity cannot be considered a local problem anymore. Under these conditions, the economic aspects of obesity became motor themes. Some relatively new topics emerged as new problems, like price transmission, network analysis, and supply chain management.

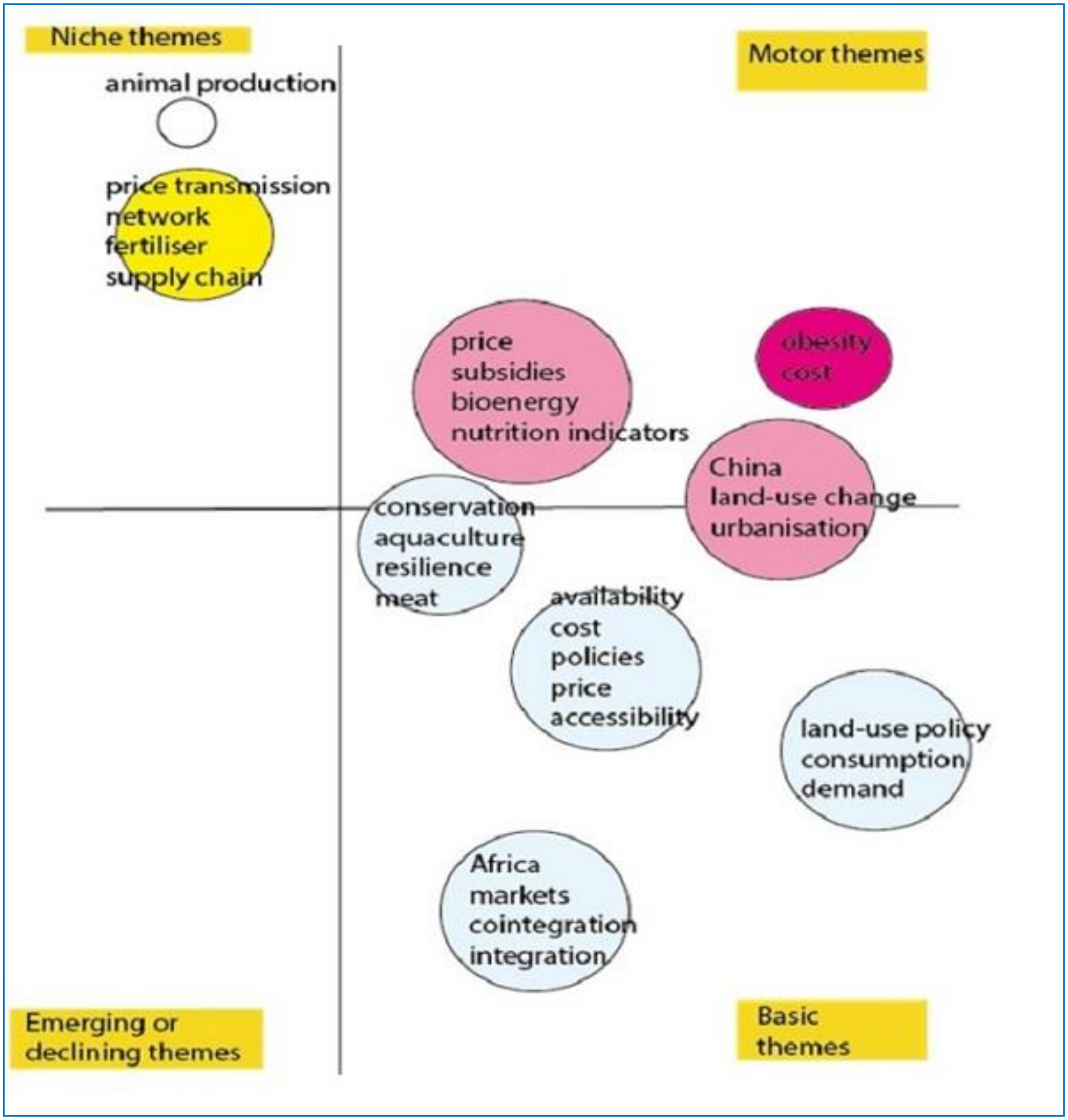

Figure 18. The strategic map of topics between 2009–2021

Source: R studio results

This bibliometric study is considered the first study which joined between food security and price change. Based on these words, we presented a statistical analysis of global scientific literature on food security and price dynamic. It analyzed the main characteristics of journals, authors, countries, and keywords. It investigated the relationship between them.

Developed countries highly participate in developing research in this field, showing important multinational cooperation. Food policy and food security are the two most sources getting high citations.

It is highlighted that price, food security, and impact are growing over time in the research keywords. As it highlighted not only developing countries are interested in food security and price analysis. It has been found that maintaining the same income, an increase of 50% in food prices leads to a decrease of 30% in iron intake (Bouis, 2008).

Further research is needed to investigate and measure the empirical impact of food price volatility on food security. It is noticeable that climate change, health, and income appeared as merging keywords. It gives the attention to associate the food security assessment with the people's health status, food nutritive values, and the capability of earned income to ensure stable nutritious food.

Especially, with the spread of the covid-19, it is crucial to develop empirical studies examining the income, price changes, climate change effect on nutritious food access, and agricultural products and food availability (local production and import) during the crisis (e.g. pandemic situation).

4. MATERIAL AND METHODS

To investigate the price dynamic along the supply chain, there are two principle concepts; price volatility and price transmission. Price transmission and price volatility transmission handle the price relations along the supply chain.

However, price transmission designs to the interconnections between the conditional mean prices, but price volatility transmission concerns the links between the conditional variance of prices (Natcher and Weaver, 1999).

Price transmission investigates the relation between the foreseeable parts of price information whereas price volatility transmission examines the connection between the unforeseeable part of prices. Price volatility spillover is also interpreted as the magnitude of price uncertainty in one market affects price uncertainty in other markets (Apergis and Rezitis, 2003a; Apergis and Rezitis b and Hillen, 2021).

4.1. Area of study

Our study deal with African countries. Africa is a vulnerable continent to food security. It accounts 821 million of food-insecure person, which presents 31% of the global people in 2017(Fan, 2019). Africa, due to its vulnerability, is exposed to many factors that threaten its food security.

First, it witnessed a decreasing animal husbandry and rangelands (Nardone et al., 2010). In addition, to the expanded desertification, that alters 46 African countries and raised dangerous effect of droughts (Intergovernmental Panel on Climate Change, 2020).

Furthermore, the agriculture household's revenue has been deteriorated because of the farmland degradation, which enhances the raise of the poverty rate (Diao and Sarpong, 2011). Therefore, there is a persuasive need for an updated food price analysis and food security status in these countries that provide an accurate result for the governments.

4.2. Price volatility examination

Many researchers have focused on examining price transmission and volatility spillovers in different sectors. Price volatility for agricultural products is a critical issue for countries with large agricultural sectors. Previous researches, mainly, focus on highlighting the magnitude of volatility in different levels.

Price volatility is driven by the set of factors (e.g. weather, inflation, supply and demand changes, consumer income, and government policy) (Borawski et al, 2020). To investigate the dynamic conditional variance of the price, GARCH models are useful tools which could capture the volatility spillovers.

Many aspects of time series data make it more complex to evaluate than cross-sectional data; economic data are frequently time dependent. Most economic time series are tightly tied to their recent past, by which we mean. Another feature that sets time series apart is that they follow particular frequencies and may have the seasonality trend character.

Trend (smooth, long-term/consistent upward or downward movement).

4.2.1. ARCH/GARCH models

For dealing with time series heteroskedastic models, Autoregressive Conditional Heteroskedasticy (ARCH)and Generalized Autoregressive Conditional Heteroskedasticy (GARCH) models have become standard tools; these models give a volatility measure that may be used in price analysis. The ARCH (Engle, 1982) and GARCH (Bollerslev, 1986) models were created to capture such data volatility characteristics. The time-series approach GARCH, in particular, enables for simulating the serial dependency of the volatility. Engle was the first to present ARCH models (1982).

The models aim to explain variance transmission in the residuals.

The basic form of ARCH proposed by Engle (1982) is presented in two equations – the conditional mean and the conditional variance:

$$Z_t = w_t\beta + \varepsilon_t \quad (1)$$

$$\tau_t^2 = \varphi_0 + \varphi_1 \varepsilon^2_{t-1} + \varphi_2 \varepsilon^2_{t-2} + \varphi_3 \varepsilon^2_{t-3} + \ldots\ldots + \varphi_p \varepsilon^2_{t-n} \quad (2)$$

ε^2_t is the squared residual,

φ_p are the ARCH coefficients that quantify the past deviation of conditional variance τ_t.

The Generalized Autoregressive Conditional Heteroscedasticity is abbreviated as GARCH.

Conditional heteroscedasticity implies variable conditional variance, while heteroscedasticity means variable variance.

The GARCH model has four main specifications: conditional covariance matrix models, factor models, conditional variances and correlations models, as well as non-parametric and semi-parametric models. (Silvennoinen and Terasvirta, 2008).

The GARCH(p,q) model performs the conditional variance and it is explained by the lagged squared errors and past conditional variance. P designs the number of lag variances to include in the GARCH model and q designs the number of lag residual errors to include in the GARCH model

$$T_t^2 = \varphi_0 + \varphi_1 \varepsilon^2_{t-1} + \varphi_2 \varepsilon^2_{t-2} + \varphi_3 \varepsilon^2_{t-3} + \ldots + \varphi_p \varepsilon^2_{t-p} + \theta_1 \tau^2_{t-1} + \theta_2 \tau^2_{t-2} + \ldots + \theta_q \tau^2_{t-q} \quad (3)$$

where φ_q are the GARCH coefficients which reflect the effect previous variance information on the present value.

4.2.2. The univariate GARCH

Bollerslev (1986) developed a methodology based on Engle's ARCH models (1982). Engle introduced a conditional variance formula for time series that is dependent on the realized error of the previous period. Bollerslev built the GARCH model by considering his own volatility history, similar to the expansion from AR to ARMA models.

However, the constraints on univariate time series in this paradigm do not account for volatility spillover.

The following is the univariate GARCH (1,1) model:

$$\sigma_t^2 = \gamma_0 + \gamma_1 \varepsilon^2_{(t-1)} + \gamma_2 \sigma^2_{(t-1)} \quad (4)$$

σ_t^2 is the variation of t, based on information up to period t. (conditional error term). Univariate GARCH models do not appear to be appropriate because it is used to forecast volatility of only one time series, hence multivariate generalization appears to be the preferable option.

Modeling multivariate time series may be done in two ways: direct estimating the variance–covariance matrix or indirectly modeling the correlation between the time series

4.2.3. Multivariate GARCH model

While univariate GARCH models are good at modeling the conditional variance of a single time series, they are enabling when it comes to simulating connectedness between two or more-time series.

Multivariate GARCH models provide the benefit of specifying equations for the movement of variances and covariances of many time series across time (Karolyi, 1995). Multivariate Generalized Autoregressive Heteroskedasticity models are the most often utilized price volatility transmission models (MGARCH). Multivariate GARCH models are effective for forecasting multivariate time series volatility and volatility co-movement (Zivot and Wang2006).

Consider a vector of price x_t of dimension a*1:

$x_t = (x_{1t}, \ldots, x_{a't})'$ (5)

$x_t - \mu_t = £_t = A^{-1/2} y_t$ (6)

$\{y_t\}$= a sequence of (a*1) i.i.d random vector with the following characteristics:

$E[y_t] = 0$ (7)

$E['_t y'_t] = B_a(10)$ (8)

$y_t \sim G(0, B_a)$ (9)

G is a continuous density function:

$E_{t-1}(£) = 0$ (10)

$E_{t-1}(£' £'t) = A_t$ (11)

The correlation matrix is :

$Corr_{t-1}(£_t) = R_t = D_t^{-1/2} A_t D_t^{-1/2}$ (12)

$D_t = diag(A_{11,t}, \ldots, A_{aa,t})$ (13)

The general bivariate GARCH model is presented below:

$$A_t = \begin{bmatrix} b0,1 \\ b0,2 \end{bmatrix} + \begin{bmatrix} b11 & \alpha 12 \\ b21 & \alpha 22 \end{bmatrix} \begin{bmatrix} \varepsilon_t^2 1, t-1 \\ \varepsilon_t^2 2, t-1 \end{bmatrix} + \begin{bmatrix} c11 & c12 \\ c21 & c22 \end{bmatrix} \begin{bmatrix} A1, t-1 \\ A2, t-1 \end{bmatrix} \quad (14)$$

where:

$b0,1$ and $b0,2$ are the constants that present the mean equation of the model.

$A_{1,t-1}$ and $A_{2,t-1}$ are the conditional variance at time t-1 for the price series.

$\varepsilon^2_{1,t-1}$ and $\varepsilon^2_{2,t-1}$ are the errors at time–t - 1 of the price series.

b_{11} b_{12} b_{21} b_{22} are the coefficients of the autoregressive errors $\varepsilon^2_{1,t-1}$ $\varepsilon^2_{2,t-1}$. The “b” matrix represents the sensitivity to short-term shocks of the conditional volatility.

b_{11} measures the own short-term shock of the first price vector, b_{12} measures the volatility transmission from the first price to the second price. b_{21} b_{12} measures the short-term shock transmission from the second price to the first price. And finally, b_{22} measures the own short-term shock of the second price vector

c_{11}, c_{12}, c_{21}, c_{22} are the coefficients of the conditional variance $A_{1,t-1}$ and $A_{2,t-1}$.The matrix “c” indicates the persistence of the conditional volatility. $c_{11}$and c_{22} present the magnitude of the conditional volatility of the price series while c_{12} and c_{21} indicates the volatility transmission between the two prices (reference?).

3.1.4.2. DCC-GARCH model (Dynamic Conditional Correlation model)

The DCC-GARCH model is used in order to model the correlation between two price levels. Engle, Lilien and Robins in 1987 have introduced the dynamic conditional correlation model, the DCC GARCH, enabling the matrix of conditional correlations that vary in time. This model is a generalization of the CCC-GARCH model Bollerslev (1990).

$$Y_t = \mu_t + \varepsilon_t \qquad (15)$$

$$\varepsilon_t = \sqrt{H_t}\, \xi_t \qquad (16)$$

$$H_t = D_t R_t D_t \qquad (17)$$

Y_t is n*1 vector of n returns at time t

μ_t is n *1 vector of n expected returns at time t

ε_t is n*1 vector of independent, and identically distributed errors with $E[\varepsilon_t] = 0$ and $cov[\varepsilon_t] = Ht$

H_t is n*n matrix of conditional variance of ε_t, time t

D_t is n*n diagonal matrix of conditional standard deviation of ε_t time t.

R_t is n*n matrix of conditional correlation of ε_t time t

ξ_t is n x 1 vector of i.i.d errors with $E[\xi_t] = 0$ et $E[\xi_t \xi'_t] = I_n$

This is an estimation model in two stages. The first step is to estimate the conditional variance with univariate GARCH for each series. The second step uses the standardized residuals obtained in the first step to estimate the parameters of the matrix of dynamic correlations.

This model includes conditions allowing the covariance matrix to be positive definite at all times and the covariance to be stationary.

The H_t matrix is divided into two matrixes, D_t and R_t. The D_t matrix elements are derived from univariate GARCH estimated for each series:

$$\mathrm{Ht} = \begin{bmatrix} \sqrt{h1}, t & 0\ 0\ 0\ \cdots & 0 \\ 0 \vdots & \sqrt{h2}, t \ddots & \vdots 0 \\ 0 & 0\ 0\ 0\ \cdots & \sqrt{hN}, t \end{bmatrix} \qquad (18)$$

where $h_{i,t} = \alpha_{0,i} + \sum_{q=1}^{Qi} \alpha_{iq}\varepsilon^2_{i,t-q} + + \sum_{p=1}^{Pi} \beta_{ip} h_{i,t-p}$ (19)

Univariate GARCH could be with a different order, which enables analysis of sets with different numbers of lags.

The Rt matrix is that of standardized residual conditional correlations ε_t and it is now dynamic:

$$\mathrm{Rt} = \begin{bmatrix} 1 & \rho 12, t\rho 13, t \cdots & \rho 1n, t \\ \rho 21, t \vdots & 1 \ddots & \rho 2n, t \vdots \\ \rho n1, t & \rho n2, t\rho n3, t \cdots \rho nn-1, t & 1 \end{bmatrix} \qquad (20)$$

The Ht matrix must be positive definite, because it is a variance-covariance matrix.

In order to ensure that Ht be positive definite, Dt must be positive definite. The matrix Rt is always positive because Dt= diag($\sqrt{h_{1,t}}$, $\sqrt{h_{2,t}}$, ….., $\sqrt{h_{N,t}}$) so these elements are always positives. We also have to ensure that R_t elements are smaller or equal to 1, because they are correlations.

Then in order to ensure that Rt is positive, it has to be decomposed in two matrixes:

$Rt = Q_t^{*-1} Q_t Q_t^{*-1}$ (21)

and $Q_t = (1 - \alpha_{DCC} - \beta_{DCC})\,\overline{Q} + \alpha_{DCC}\, \varepsilon_{t-1}\, \varepsilon'_{t-1} + \beta_{DCC}\, Q_{t-1}$ (22)

where

$$Q_t^* = \begin{bmatrix} \sqrt{q11, t} & 0\ 0\ 0 & 0 \cdots & 0 \\ 0 & & \sqrt{q22}, t \ddots & O \\ 0 & 0\ 0\ 0 & 0 \cdots & \sqrt{qNN, t} \end{bmatrix} \qquad (23)$$

and where $Qt = \begin{bmatrix} q11,t & \sqrt{q11},tq22,t \cdots & \sqrt{q11},tqNN,t \\ \sqrt{q11},tq22,t & q22,t \ddots & \sqrt{q22},tqNN,t \vdots \\ \sqrt{q11},tqNN,t & \sqrt{q11},tqNN,t \cdots & qNN,t \end{bmatrix}$ (24)

The Qt matrix must be positive definite to ensure that Dt is positive too.

Q = Cov $[\varepsilon_t\varepsilon'_t]$ =$E[\varepsilon_t\varepsilon'_t]$, presents the non-conditional covariance of the standardized residuals obtained by univariate GARCh. α_{DCC} and β_{DCC} are scalars. In order to ensure that His positive definite :

$\alpha_{DCC} \geq 0$,

$\beta_{DCC} \geq 0$

and $(\alpha_{DCC} + \beta_{DCC}) < 1$.

The general structure of DCC dynamic correlation (p, q) is as follows:

$$Q_t = (1- \sum^{P}_{i=1} \alpha_{DCC,i} - \sum^{Q}_{j=1}\beta_{DCC,j})\bar{Q} + \sum^{P}_{i=1} \alpha_{DCC,i}(\varepsilon_{t-i}\varepsilon'_{t-i}) + \sum^{Q}_{j=1}\beta_{DCC,j}Q_{t-j} \quad (25)$$

The DCC-GARCH (l,l) bivariate model is:

$$h_{11,t} = \alpha_{0,1} + \alpha_{11}\varepsilon^2_{1,t-1} + \beta_{11}h_{11,t-1} \quad (26)$$

$$h_{22,t} = \alpha_{0,2} + \alpha_{21}\varepsilon^2_{2,t-1} + \beta_{21}h_{22,t-1} \quad (27)$$

$$Rt = Q_t^{*-1} Q_t Q_t^{*-1} \quad (28)$$

$$Q_t = (1- \alpha_{DCC} - \beta_{DCC})\bar{Q} + \alpha_{DCC}\varepsilon_{t-1}\varepsilon'_{t-1} + \beta_{DCC} Q_{t-1} \quad (29)$$

where equations (33) and (34) are the conditional variance equations obtained from equation

$$H_t = \begin{bmatrix} h11,t & h12,t \\ h21,t & h22,t \end{bmatrix} \quad (30)$$

The advantages of the DCC-GARCH model are a direct modeling of the variance and covariance and thus its flexibility. DCC-GARCH model has been used by various researchers to detect the dynamic correlation between variables (Amrouk et al., 2020; Shiferaw, 2018 ; Ertuğrul and Seven, 2021 ; Bhebhe and Ndlovu, 2021; Shiferaw, 2019; Luo and Tanaka, 2021).

4.3. Justification of the use of the model

GARCH models provide statistical volatility prediction and data analysis. There are several multivariate GARCH models available. Making multivariate GARCH models parsimonious while maintaining flexibility is a key aim. Since the conditional covariance matrix uses square values, it is also necessary for it to be positive by definition..

The most famous is Bollers’ev's generalized ARCH (GARCH) model. Several volatility models have been proposed during the past few years. The autoregressive conditional heteroskedasticity (ARCH) model, which was later developed to the generalized ARCH (GARCH) model by Bollerslev, is the most resilient and appropriate model among them (1986).

The DCC-GARCH model is an extension of the CCC-GARCH model that permits the correlation matrix to be time dependent. The DCC-GARCH model offers obvious computing advantages because the number of parameters to estimate in the correlation process is independent of the number of series to be correlated.

In the parameter estimation of conditional cross-moments, the multivariate GARCH and its numerous extensions have been frequently used. MGARCH models in many forms have been introduced. They vary in how they characterize a stochastic vector process' conditional variance matrix.

Since, the volatility of a time series changes over time, multivariate GARCH models are one of the most efficient instruments for understanding and forecasting it. The GARCH requirement has the advantage of allowing for time-dependent conditional variances and leptokurtosis in the unconditional distribution of price fluctuations using very simple assumptions about the conditional density of commodity price changes (e.g. the normal and t distribution)

Because we are interested in the correlation between two level of price series, the bivariate GARCH model seems to be the most adequate model. There are three conditional variance equations in bivariate GARCH models, one for each variance and one for conditional covariance. Volatility and correlations are the two most important aspects to consider when analyzing product price. Since En’el's development of the autoregressive conditional heteroskedasticity (ARCH) model in 1982, univariate fluctuation forecasting has gained a lot of attention.

4.4. Food security index forecast

Food security measures have changed in recent decades from bridging the dietary energy gap through greater staples production to making diets more economically feasible (World Health Organization, 2017). To estimate the food security index, the gap of supply of different staple food has been used. The daily food allocation for a person is considered based on the eat lancet commission in 2019 (EAT-Lancet commission, 2019 and Verkerk, 2019)).They introduced the recommended macronutrient intake in grams per day per person. The following table present the amount of each food category that should be consumed.

Table 3. Macronutrient Intake (grams/ day) where, when? (I responded below)

Food categories	Required quantity in grams/ person/day/
Vegetables	300
Fruits	200
Whole grain	232
Nuts	50
Dairy products	250
Fish and sea products	28
Legumes	75

Source: Eat lancet commission (2019)

On January 16, 2019, the EAT-Lancet Commission released its initial evidence-based recommendations for a diet that promotes both ecological sustainability and healthfulness.

DALYs (disability-adjusted life year) are defined as the sum of “years of life lost due to premature mortality and years lived with disability” (Murray et al., 2012). DALYs measures are included from food deficiencies (Sulser et al., 2021). Dalys have been used to measure the hunger and highlight the linked trends (Gödecke et al., 2018). In our study, DALYs for food subcategories have been employed.

The difference of the supplied food and the recommended amount has been used to quantify the food security. The weight of each items is based on the DALY indicator given by the Global burden of disease. DALY indicator involved in our study considers the dietary risks. The dietary risks included in our thesis are; diet low in fruits, vegetables, nuts, milk, fish and sea food, cereals, and legumes. the DALY indicator weight of each item has employed to measure its magnitude in the estimated food security index.

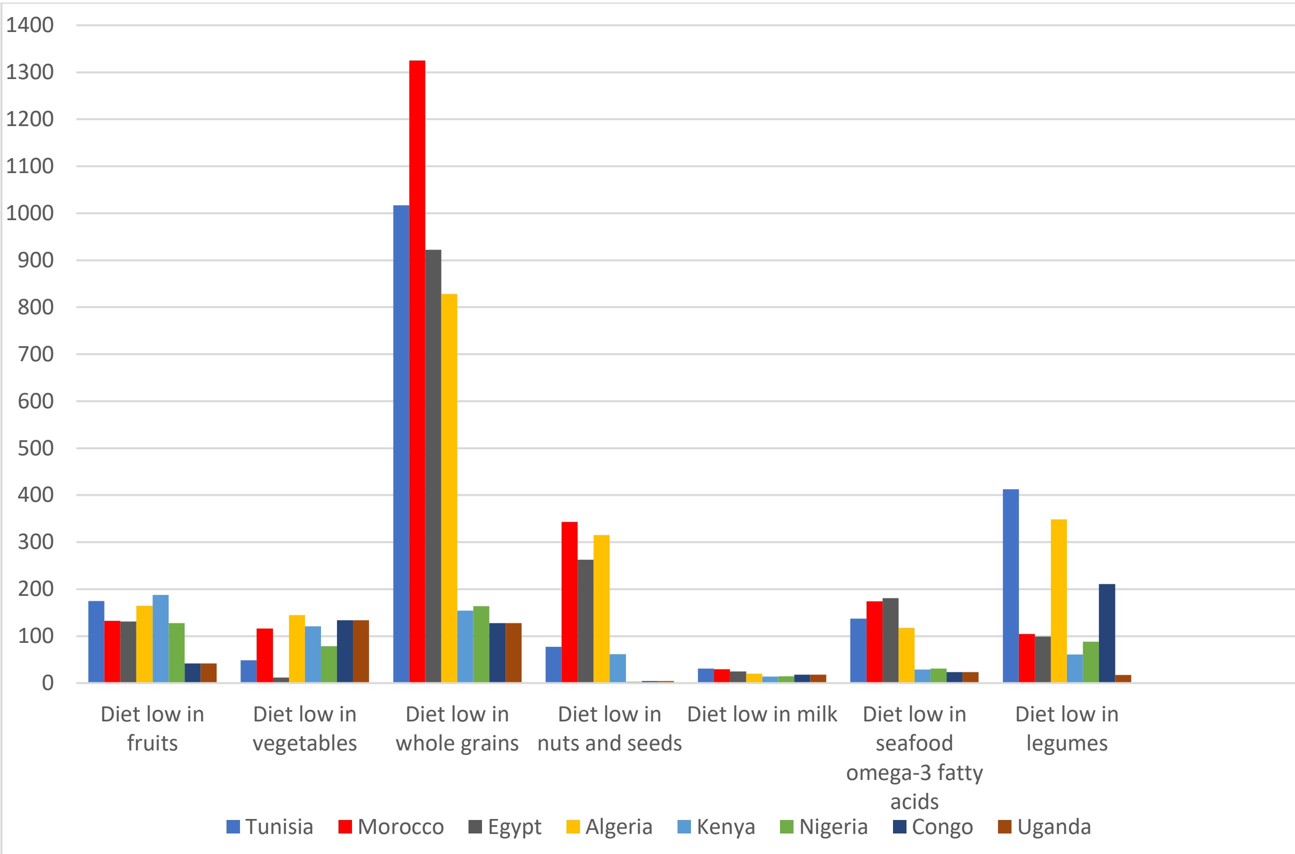

Figure 19. DALY rates presenting the diet low in food subcategories (fruits, vegetables, milk, seafood, legumes, whole grains, and nuts and seeds)

Source: Author's own work based on Global Burden Disease Database

DALYs for a specific cause are calculated as the sum of the years of life lost due to premature mortality (YLLs) from that cause and the years of healthy life lost due to disability (YLDs) for people living in states of less than good health resulting from the specific cause.
After the determination of the weight. Figure 21 shows the DALYs of the selected African countries. The disability life lost due to the deficit diet in cereals has the highest rate for all countries, except Congo, where the shortage of legumes has the highest rate.

4.5. PANEL data analysis: GMM approach

The composite food security, agricultural producer price, and macroeconomic factors relationship is estimated applying a two-step system GMM approach.in order to avoid the endogeneity, the difference GMM, suggested by Arellano and Bond in 1991, has been utilized. It uses the first differences of the variables, and considers the lagged value of regressors as instruments to remove the country specific effect.

Different studies have been used GMM approach to examine panel data, because it is the fitted and efficient model comparing others in performing the biases unlike the regression methods (Ogunniyi et al., 2018; Manap and Ismail,, 2019; Osabohien et al., 2021; John et al., 2019; Mahmah and Amar, 2021; Wardhani and Haryanto, 20267anadiser et al., 2021; Kwaw-Nimeson et al., 2021; Ogunlesi et al., 2018).

But to eliminate the specific fixed effect of the country is not always correct, it could affect the model estimators and weaken the instruments. Thus, the system GMM model proposed by Arellano and Bover in 1995, and Blundell and Bond in 1998, resolves the issue of the instruments. They suggested the two systems equation; the first equation takes the first difference of variables and the second equation uses the level variables. In the second equation, at level, also the first variable difference is taken in consideration, that ameliorates the model efficiency. The combination of the conditional moment at their level and their differences improves the model performance (Roodman, 2009).

To find out the effect of the price dynamic and some selected macroeconomic variables on the estimated food security index, GMM approach has been used to investigate the determinants of food security in 8 African countries. It is an econometric method for panel data analysis.

$$\text{Log}\,(FSI_{it}) = \mu + \alpha \log(FSI_{it-1}) + \beta \log(X_{it}) + \tau_i + \varepsilon_i \quad (31)$$

We introduced the natural logarithms to the variables considered in our model, in order to reduce the occurrence of heteroscedasticity Where FSI_{it} is the dependent variable of country i for period t, X_{it} t is the matrix of explanatory (independent) variables that detect the effect of the macroeconomic characteristics of countries. μ is a constant, α and β are the coefficients of the lag value of food security index and the independents variables respectively. τ_i presents the fixed effect of the country (country control), ε_i is the error terms.

4.6. Data sources and description

To examine the price volatility time series database has been used. For the examination of the price volatility between the global food price and crude oil price, a monthly price index of food and food subcategories have been taken from FAOSTAT and mundi index from January 1992 till October 2021.

To calculate the gap in food supply, we used the database from FAOSTAT. It has a yearly value of the quantity supplied of food subcategories from 1995 till 2018.

The used variables are illustrated in table 10.

Table 4: Description of the data series used in the empirical analysis, 1995-2018

Variables	Description	Source
Fuel Price (oil)	Monthly price index of the crude oil price, base year 2016	Mundi Index
Food Price	Monthly food price index base year 2016	FAOSTAT
Agricultural producer price (APPI)	Yearly agricultural producer price index (2014-2016=100)	FAOSTAT
Food supply	The quantity of food supplied in gram/person/day	FAOSTAT
Trade openness (TO)	Trade openness: exports plus imports as percent of GDP	The Global Economy
Interest rate (IR)	Real interest rate: Bank lending rate minus inflation,	The Global Economy
Exchange rate (EXG)	Official exchange rate (local currency unit per US$, period average)	World Bank database
Inflation (INF)	the rate of increase in prices over a given period of time	World Bank database
Employment (EMP)	Number of persons engaged (in millions)	Pen World database

Retail milk price in Tunisia	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail beef price in Tunisia	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail lamb price in Tunisia	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail chicken price in Tunisia	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail durum wheat in Morocco	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail soft wheat in Morocco	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail chicken price in Algeria	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail milk price in Algeria	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)
Retail lamb price in Algeria	Retail monthly price in Dollars	GIEWS FPMA Tool (FAO)

Source: Author's own work

We employed a panel data of eight selected African countries covering the period between 1995 and 2018. The choice of the variables and time frame, employed in our dissertation, is based on previous research works and data availability. Data used in the study are taken mainly from the Word Bank database and FAO's FAOSTAT.

The retail monthly prices of Tunisia, Morocco, and Algeria of the different commodities are retrieved from Food Price and Monitoring Analysis (FPMA) provided by FAO, which contains time series of agricultural commodity retail prices. Based on the data availability, we illustrate the data frame used in our research. For Tunisia, we used monthly retail prices from January 1994 till February 2018 for milk price, monthly data from January 1994 till March 2022 for chicken and beef meat, and for lamb meat price is from January 1994 till October 2021. For Algeria, price series are from January 2005 till April 2018. And for Morocco, retail prices are between January 2010 and June 2020.

5. RESULTS AND DISCUSSIONS

Data analysis is the part of presenting research findings. This section describes the specific analyses realized to respond the research problem and decide whether to support or reject the hypotheses. The used software for all findings is R studio version 4.1.2 (2021-11-01) (R Core team,, 2013).

5.1. Analysis of global crude oil, global food prices volatility and their dynamic correlations

To understand the movement of global food price index and the staple food prices (i.e. meat, dairy, and cereal), the price volatility of each price series has been analyzed. A univariate GARCH model has been employed to measure the magnitude of the past effect (shocks and volatility) of each own price series.

Table 11 presents the descriptive statistics of the variables. It points out the value of minimum, maximum, average, median, and the standard deviation. It gives an image about the price range of each item. Crude oil price has registered the highest standard deviation that explains its important fluctuation around the average price.

Table 5. Descriptive statistics of the variables

	Min	**mean**	**Median**	**Standard deviation**	**Max**
Food Price Index	50.47	85.06	80.42	24.34	137.62
Meat Price Index	51.10	83.14	81.77	16.63	119.17
Dairy Price Index	40.08	84.90	77.12	31.19	156.49
Cereal Price Index	48.62	86.49	86.21	29.59	163.33
Crude oil price index	24.09	110.54	103.81	63.57	264.61

Source: Author’s own work based on R studio results

Prior to estimate the GARCH model, it is mandatory to determine the optimal lag number of the variables. For this purpose, as indicated in table 12, the optimal lag number determined using “Varselect” command from Vars package in R studio software. The optimal lag is equal to 1 for our variables.

Based Schwartz Information Criteria (SIC), Lag 1 is considered the optimal lag length for all test and the model estimation.

Table 6. Optimal lag number selection

	Food price index	**Meat price index**	**Dairy price index**	**Cereal price index**	**Crude oil price index**
Optimal lag (SIC)	1	1	1	1	1

Source: Author’s own work based on R studio results

5.1.1. Unit root tests

Unit roots in non-stationarity in price series are investigated using two alternative unit root tests. Said and Dickey (1984) established the Augmented Dickey-Fuller (ADF) test, while Phillips and Perron (PP) established the Phillips-Perron (PP) test (Phillips and Peron, 1988).

The acceptance of the null hypothesis in these tests means that the price series are non-stationary,as they do not have a unit root. The results of the tests show that all price series have a unit root, indicating that they are all stationary at first level.

Table 7. Unit root tests (ADF test values with p-values in parentheses)

	Level of price indices

Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude oil price index
Value	-1.14(0.915)	-1.56 (0.764)	-1.69 (0.709)	-1.7 (0.701)	-2.46 (0.381)
	First difference of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude oil price index
Value	-10.5(0.01)	-14.1 (0.01)	-10.7 (0.01)	-12 (0.01)	-7.08 (0.01)

Source: Author's own work based on R studio results

Firstly, we performed the ADF test for unit roots, as presented in table 13, to determine if the price series are non-stationary. The test has been applied on price series and first difference price series. Our data are stationary at first level.

Table 8. Phillips Perron unit root test results (test values, and p-values in parentheses)

	Level of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude price index
Value	-9.26 (0.491)	-9.07 (0.5)	-15.4 (0.217)	-13.5 (0.301)	-13.98 (0.327)
	First difference of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Oil price index
Value	-181 (0.01)	-265 (0.01)	-189 (0.01)	-218 (0.01)	-227 (0.01)

Source: Author's own work based on R studio results

Phillips Perron (PP) proposed another theory of unit root non-stationarity, as seen in Table 14. The tests are similar to ADF tests, except they include an automated DF process adjustment to account for autocorrelated residuals.

Table 9. ARCH test result: aTSA package- A better title can be: ARCH LM test for heteroscedasticity (p-values in parentheses)

	Porte-manteau	**Lagrange Multiplier**
Crude Oil	99.7 (0.0000)	137.4 (0.0000)
Cereal	26.5 (0.00002)	419.9 (0.0000)
Dairy	77.3 (0.00000)	210.3 (0.0000)
Meat	10.4 (0.033581)	165.8 (0.0000)
Food price index	50.5 (0.00000)	234.7 (0.0000)

Source: Author's own work based on R studio results

The residuals should perform an autoregressive conditional heteroscedasticity to support the use of the GARCH model. The ARCH LM test for conditional heteroscedasticity, as mentioned in Table 15, reveals a high existence of the ARCH structure across the different price series, confirming the feasibility of using GARCH models to study volatility dynamics.

5.1.2. GARCH model estimation

Firstly, we estimated the own price volatility for the price series using the univariate GARCH model to determine the level of own price volatility.

Table 10. Univariate GARCH model

	Mu	**Ar1**	**Omega**	**Alpha**	**Beta**

Food Price Index	0.001680 (0.27446)	0.367212 (0.0000)	0.000024 (0.16397)	0.100105 (0.01165)	0.834572 (0.00000)
Meat	0.001982 (0.228913)	0.305901 (0.00000)	0.000027 (0.255688)	0.089728 (0.046113)	0.867663 (0.000000)
Dairy	0.001898 (0.4408)	0.528247 (0.00000)	0.000055 (0.080907)	0.220968 (0.004070)	0.751703 (0.00000)
Cereal	0.000531 (0.831952)	0.368369 (0.0000)	0.000060 (0.144872)	0.042833 (0.084801)	0.9066022 (0.00000)
Crude Oil	0.002845 (0.361235)	0.292031 (0.00000)	0.000150 (0.095180)	0.119925 (0.005180)	0.823627 (0.000000)

Source: Author's own work based on R studio results

The univariate GARCH model captures the own ARCH and GARCH of each price series, as presented in table 16. Own shocks spillovers of each price series are significant, we can affirm the presence of the own volatility effect for the employed price series. The global dairy price registered the highest ARCH value (0.22), that means 22% of the past shocks are transmitted to the present value.

The lagged volatility spillover effects for all price series are significant. This suggests that previous price volatility shocks have a significant impact on future volatility. The GARCH impact is measured by beta values, which suggests that price series are heavily influenced by previous volatility.

We prove that the cereal price has a high volatility persistence of 0.90, which implies that 90% of the previous'day's volatility endures the next day. The meat price has a Beta value of 0.86, which means 86% of past volatility is spilled over the present value, which is considered also high.

Table 17 shows the magnitude of interdepended relationship between the crude oil price and the food price.

Table 11. The time-varying volatility spillover between crude oil price and global food price index (what model??)

Variables	Coefficient	Standard Error	T value	Probability
Mu (fuel)	0.0113	0.0044	2.526	0.0115
Omega (fuel)	0.0041	0.0015	2.630	0.0085
Alpha (fuel)	0.4264	0.1490	2.8613	0.0042
Beta(fuel)	0.0000	0.2591	0.0000	1.0000
Mu (food price index)	0.0014	0.0010	1.3865	0.1655
Omega (food price index)	0.00003	0.00002	1.0801	1.2801
Alpha (food price index)	0.18970	0.07523	2.5216	0.0116
Beta (food price index)	0.76037	0.1179	6.4460	0.0000
Alpha DCC	**0.1037**	**0.0300**	**3.4549**	**0.0005**
Beta DCC	**0.8151**	**0.0644**	**12.6420**	**0.0000**

Source: Author's own work based on R studio results

To examine the strength and direction of the spillover effect of oil price fluctuation. The data used for the estimation is monthly price index from January 1992 till October 2021. The DCC model (Engle, 2002) is estimated. The GARCH (1,1) process accounts for serial correlation in squared residuals.

DCC (1, 1)-GARCH (1, 1) is adopted to examine the time varying conditional correlation between crude oil price and the food price index. The estimation results for the DCC (1, 1) model is highlighted in table 17. At first sight, Alpha DCC and Beta DCC are significant, their sums is close to 1, indicating rather high persistence in conditional variances.

The β coefficient indicates that the conditional correlation between the residuals. 0.8151 is the value of Beta DCC, that means the food price index and the fuel price are 81% conditionally correlated. The results approve the stronger positive dependence between these two prices.

This relationship is explained by reallocation of the farmer land to produce energy products instead other products, mainly cereals, which by itself will aggravate the food insecurity.

5.2. Volatility investigation between global food price index and the national food price index in 8 African countries (i.e. Tunisia, Algeria, Morocco, Egypt, Uganda, Kenya, Congo, and Nigeria)

The continent of Africa is considered a high importing continent. They import 85% of their needs in food between 2016 and 2018. A sudden increase of international food price could worsen the status, where an unexpected increase affects the amount of imported food, which may decrease.

An empirical econometric model has been estimated to quantify the magnitude of the volatility spillovers between the global food price index and the food price index of some selected African countries (i.e. Algeria, Tunisia, Morocco, Egypt, Congo, Uganda, Nigeria, and Kenya). Monthly price series have been used from January 2000 till June 2021.

Table 12. Optimal lag number according to SIC

	Optimal lag (SIC)
Food price index in Algeria	1
Food price index in Tunisia	1
Food price index in Egypt	1
Food price index in Congo	1
Food price index in Uganda	2
Food price index in Nigeria	1
Food price index in Morocco	4
Food price index in Kenya	1
Retail milk price in Tunisia	1
Retail beef price in Tunisia	2
Retail lamb price in Tunisia	1
Retail chicken price in Tunisia	1
Retail durum wheat in Morocco	2
Retail soft wheat in Morocco	1

Retail chicken price in Algeria	1
Retail milk price in Algeria	2
Retail lamb price in Algeria	1

Source: Author's own work based on R studio results

Table 18 indicates the optimal lag number for the model estimation. The lag number should be respected for the GARCH model estimation.

Table 13. ARCH-LM test results for heteroskedascity

	Portmanteau	**Lagrange Multiplier**
Food price index in Algeria	30.89 (0.003)	79.39 (0.0000)
Food price index in Tunisia	16.0 (0.003)	70.34 (0.0000)
Food price index in Egypt	46.4 (0.0000)	70.55 (0.0000)
Food price index in Congo	52.4 (0.0000)	124.4 (0.0000)
Food price index in Uganda	47.6 (0.0000)	226.3 (0.0000)
Food price index in Nigeria	15.8 (0.003)	408.8 (0.0000)
Food price index in Morocco	55.0 (0.0000)	102.00 (0.0000)
Food price index in Kenya	38.7 (0.0000)	79.10 (0.0000)
Retail milk price in Tunisia	20.8 (0.0000)	203.6 (0.0000)
Retail beef price in Tunisia	42.4 (0.0000)	158.3 (0.0000)
Retail lamb price in Tunisia	38.9 (0.0000)	126.9 (0.0000)
Retail chicken price in Tunisia	26.5 (0.0000)	118.5 (0.0000)
Retail durum wheat in Morocco	27.1 (0.0000)	98.1 (0.0000)
Retail soft wheat in Morocco	37.4 (0.0000)	93.7 (0.0000)
Retail chicken price in Algeria	19.6 (0.0000)	89.78 (0.0000)
Retail milk price in Algeria	26.8(0.0000)	187(0.0000)
Retail lamb price in Algeria	27.34(0.0000)	345(0.0000)

Source: Author's own work based on R studio results

ARCH E'gle's Test for Residual Heteroscedasticity has been employed using ARCH test function from aTSA package in R studio. This test helps to detect the heteroskedasticity of residuals, the, the use of GARCH model. As shown in table 19, all variables exhibit heteroscedasticity. In other words, conditional variance of the error terms is non constant, it varies over time.

5.2.1. Unit root tests

To check the stationarity of the variables, two tests have been employed. The first one is the Augment Dickey-Fuller (ADF) test suggested by Said and Dickey (1984), the second test is the Phillips-Perron (PP) test suggested by Phillips and Perron (1988). The null hypothesis says that variables are non-stationary, which means that they have unit root. Test results indicate that all price series contain a unit root, i.e. price series are I(1). The ADF results are illustrated in table 20 and 21.

Table 14. Unit root te–ts - ADF test results of the food price index, with p values in parentheses

	Level of price indices							
Variables	Algeria	Tunisia	Egypt	Congo	Uganda	Nigeria	Morocco	Kenya
Value	0.19 (0.733)	-0.108 (0.99)	-1.540 (0.769)	-2.442 (0.389)	-2.329 (0.437)	4.326 (0.99)	-0.993 (0.938)	-2.480 (0.373)
	First difference of price indices							
Variables	Algeria	Tunisia	Egypt	Congo	Uganda	Nigeria	Morocco	Kenya
Value	-215 (0.01)	-6.687 (0.01)	-5.276 (0.01)	-7.039 (0.01)	-4.716 (0.01)	-6.357 (0.01)	-6.517 (0.01)	-4.881 (0.01)

Source: Author's own work based on R studio results

Table 15. Unit root te–ts - ADF test results of the domestic retail agricultural commodity prices with p-values in parentheses

Level of price indices

Variables	Retail milk price in Tunisia	Retail beef price in Tunisia	Retail lamb price in Tunisia	Retail chicken price in Tunisia	Retail durum wheat in Morocco	Retail soft wheat in Morocco	Retail chicken price in Algeria	Retail milk price in Algeria	Retail lamb price in Algeria
Value	0.19 (0.733)	-0.7859 (0.963)	-1.357 (0.847)	-2.3219 (0.4409)	0.1447 (0.684)	2.46 (0.1499)	-2.8782 (0.210)	1.68 (0.977)	1.87 (0.984)

First difference of price indices

Variables	Retail milk price in Tunisia	Retail beef price in Tunisia	Retail lamb price in Tunisia	Retail chicken price in Tunisia	Retail durum wheat in Morocco	Retail soft wheat in Morocco	Retail chicken price in Algeria	Retail milk price in Algeria	Retail lamb price in Algeria
Value	-7.033 (0.01)	-7.697 (0.01)	-7.348 (0.01)	-9.122 (0.01)	-9.18 ‘0.01(	-11.00 (0.01)	-8.44 (0.01)	-16.76 (0.01)	-5.77 (0.01)

Source: Author’s own work based on R studio results

Table 20 and 21 highlight the ADF for unit root results. At level price series, the P-value is higher than 10%, the result is not significant that means we can nor reject the null hypothesis of the unit root presence. While, the first difference price series have a P-value is 0.01 which means the rejection of null hypothesis of the presence of unit root. Thus, the variables are stationary at first level difference.

A second unit root test has been employed to check the variable stationarity. Phillips Perron test is able also to detect the unit root of the variables. In tables 22 and 23, we illustrated the findings.

Table 16. Philips Perron unit root test results of food price index

	Level of price indices							
Variables	Algeria	Tunisia	Egypt	Congo	Uganda	Nigeria	Morocco	Kenya
Value	-2.635 (0.3084)	-2.221 (0.482)	-2.633 (0.309)	-3.004 (0.152)	-1.316 (0.863)	-1.917 (0.610)	-1.546 (0.766)	-0.619 (0.976)
	First difference of price indices							
Variables	Algeria	Tunisia	Egypt	Congo	Uganda	Nigeria	Morocco	Kenya
Value	-17.239 (0.01)	-14.414 (0.01)	-10.228 (0.01)	-18.244 (0.01)	-11.577 (0.01)	-10.241 (0.01)	-14.423 (0.01)	-8.060 (0.01)

Source: Author's own work based on R studio results

Table 22 and 23 highlight the PP for unit root results. At level price series, the P-value is higher than 10%, the result is not significant that means we can nor reject the null hypothesis of the unit root presence. While, the first difference price series have a P-value is 0.01 which means the rejection of null hypothesis of the presence of unit root. Thus, the variables are stationary at first level difference.

Table 17. Philips Perron test results of domestic retail prices

	Level of price indices								
Variables	Retail milk price in Tunisia	Retail beef price in Tunisia	Retail lamb price in Tunisia	Retail chicken price in Tunisia	Retail durum wheat in Morocco	Retail soft wheat in Morocco	Retail chicken price in Algeria	Retail milk price in Algeria	Retail lamb price in Algeria
Value	8.153 (0.653)	-2.1463 (0.964)	-7.187 (0.707)	-3.1463 (0.897)	0.111 (0.714)	0.126 (0.717)	-22.11 (0.0401)	0.503 (0.802)	0.518 (0.805)
	First difference of price indices								
Variables	Retail milk	Retail beef	Retail lamb	Retail chicken	Retail durum	Retail soft	Retail chicken	Retail milk	Retail lamb

	price in Tunisia	price in Tunisia	price in Tunisia	price in Tunisia	wheat in Morocco	wheat in Morocco	price in Algeria	price in Algeria	price in Algeria
Value	-336.46 (0.01)	-319.56 (0.01)	-315.3 (0.01)	-372.03 (0.01)	-88.9 (0.01)	-101 (0.01)	-89.316 (0.01)	-178 (0.01)	-115 (0.01)

Source: Author's own work based on R studio results

5.2.2. DCC-GARCH estimation

The two rows; alpha DCC and beta DCC measure the dynamic volatility transmission from the global food price index to every country (i.e. Algeria, Tunisia, Morocco, Nigeria, Egypt, Kenya, Congo, and Uganda). Mu, Omega, Alpha and Beta of each price series measure the own price volatility. Mu is a constant.

The sums of the GARCH estimates α and β are close to one and it is significant for all price series. This implies a high volatility persistency (compounded shocks to the prices) as the sum α and β and defines the decay factor of the exponentially declining autocorrelation function. A high β coefficient indicates a strong impact of the own-variance on volatility development.

Tables 24 and 25 highlight the forecasted conditional correlations of the DCC model between African food price and the international food price. Table 26 and 27 presents the conditional correlation between the crude oil price and the food price in the selected African countries. All variables have a significant β coefficient that indicates that the conditional correlation between the residuals is highly persistent. It means the existence of the conditional correlation between the two-price series.

Table 18. volatility spillovers between national food price index of selected African countries and the global food price (DCC-GARCH model)

Coefficients	GFPI	FPI Algeria	FPI Tunisia	FPI Morocco	FPI Nigeria
Mu	0.00275(0.017)	0.0017(0.200)	0.003(0.00000)	0.0011(0.000)	0.0095(0.000)
Omega	0.000036(0.34)	0.000003(0.021)	0.0000(0.9924)	0.0000(0.988)	0.000(0.0000)
Alpha	0.3154(0.040)	0.1999(0.0000)	0.2428(0.0000)	0.3299(0.0000)	0.635(0.000)
Beta	0.6511(0.0009)	0.7990(0.0000)	0.7561(0.0000)	0.6687(0.0000)	0.363(0.002)
Alpha DCC	-	**0.000(0.99)**	**0.000(0.99)**	**0.0000(0.9976)**	**0.009(0.551)**
Beta DCC	-	**0.901(0.0000)**	**0.909(0.000)**	**0.9142(0.0000)**	**0.978(0.000)**

Source: Author's own work based on R studio results

As highlighted in two tables 24 and 25, the highest conditional correlation of 0.978 is registered between the Nigerian food price and the global food price. 97.8% of the global food price volatility is transmitted to the Nigerian food price. Food price in Nigeria is highly sensitive to the perturbation of the global food price. Alpha DCC is not significant. It means that in short term a shock of the global food price is not transmitted to the domestic food price of Algeria, Tunisia, Morocco, and Nigeria.

Table 19. Volatility spillovers between national food price index of selected African countries and the global food price (DCC-GARCH model) (continuous)

Coefficients	FPI Egypt	FPI Kenya	FPI Congo	FPI Uganda
Mu	0.0054(0.046)	0.0086(0.0000)	-0.002(0.0210)	0.0038(0.001)
Omega	0.000014(0.506)	0.000029(0.009)	0.0000(0.6714)	0.0000(0.223)
Alpha	0.307(0.103)	0.567(0.0004)	0.2564(0.0000)	0.151(0.049)
Beta	0.6913(0.0000)	0.274 (0.035)	0.7425(0.0000)	0.78(0.00)
Alpha DCC	**0.168(0.035)**	**0.119(0.086)**	**0.015(0.67)**	**0.116(0.061)**
Beta DCC	**0.0000(0.999)**	**0.296(0.645)**	**0.799(0.0000)**	**0.629(0.000)**

Source: Author's own work based on R studio results

To examine the linkage between energy price and food prices over the period 2000–2021 by using DCC-GARCH model in the case of 8 African countries. Monthly prices of crude oil and food price from January 2000 till June 2021 have been used. Tables 26 and 27 present the results of the econometric model. Table 26 and 27 provide the model results.

Table 20. Volatility spillovers between national food price index of selected African countries and the crude oil price (DCC-GARCH model)

Coefficients	FUEL	FPI Algeria	FPI Tunisia	FPI Morocco	FPI Nigeria
Mu	0.013(0.010)	0.0017(0.200)	0.003(0.0000)	0.0011(0.000)	0.0095(0.000)
Omega	0.004(0.002)	0.0000(0.021)	0.0000(0.992)	0.0000(0.988)	0.000(0.000)
Alpha	0.479(0.007)	0.1999(0.000)	0.242(0.000)	0.3299(0.000)	0.635(0.000)
Beta	0.000(0.99)	0.7990(0.000)	0.756(0.000)	0.6687(0.000)	0.363(0.002)
Alpha DCC	**-**	**0.000(0.99)**	**0.045(0.02)**	**0.058(0.051)**	**0.008(0.74)**
Beta DCC	**-**	**0.924(0.000)**	**0.870(0.000)**	**0.722(0.000)**	**0.78(0.000)**

Source: Author's own work based on R studio results

We notice that all Beta DCC are significant at 1%. It explains the significance of the volatility transmission between the crude oil and food price of the eight African countries. Our results demonstrate that energy price has a significant impact on food prices.

Table 21. Volatility spillovers between national food price index of selected African countries and the crude oil price (DCC-GARCH model) (continuous)

Coefficients	FPI Egypt	FPI Kenya	FPI Congo	FPI Uganda
Mu	0.0054(0.046)	0.0086(0.0000)	-0.002(0.0210)	0.0038(0.001)
Omega	0.000014(0.506)	0.000029(0.009)	0.0000(0.6714)	0.0000(0.223)
Alpha	0.307(0.103)	0.567(0.0004)	0.2564(0.0000)	0.151(0.049)
Beta	0.6913(0.0000)	0.274 (0.035)	0.7425(0.0000)	0.78(0.00)
Alpha DCC	**0.033(0.371)**	**0.005(0.908)**	**0.037(0.31)**	**0.00 (0.99)**
Beta DCC	**0.755 (0.000)**	**0.852(0.000)**	**0.827(0.001)**	**0.925(0.000)**

Source: Author’s own work based on R studio results

According to the results, food prices respond positively, with different magnitude, to any shock from oil prices. Thus, our results show that there is a connection between energy and food security as a consequence of price volatility. The DCC-GARCH findings prove the evidence of volatility spillovers between all price series. The highest level of conditional correlation has been registered in Algeria and Uganda. They record 0.925 and 0.924. It measures the magnitude of the dynamic coefficient of the correlation between the crude oil and food price, that translates the persistence correlation feature.

An examination of price volatility between Ihe international agricultural commodity and retail prices has been realized. Based on data availability and the selected Africa countrie, I analyzed the spatial price volatility transmission across meat, wheat, and milk products in Tunisia, Algeria, and Morocco. Tables 28, 29, 30, 31, and 32 illustrate the results of the model estimation.

Table 28 exhibits the volatility spillovers across the international dairy price and the retail milk price in Tunisia and Algeria.

Table 22. Volatility spillovers between the global dairy price and the retail milk prices in Tunisia and Algeria

Variables	International dairy price	Retail milk price in Tunisia	Retail milk price in Algeria
Mu	-0.0011(0.813)	0.0032(0.736)	0.003(0.000)
Omega	0.0005(0.000)	0.0000(0.009)	0.000(0.718)
Alpha	0.3711(0.517)	0.348(0.000)	0.000(0.99)
Beta	0.571(0.001)	0.610(0.000)	0.998(0.000)
Alpha DCC		**0.257(0.000)**	**0.04(0.000)**
Beta DCC		**0.5561(0.000)**	**0.925(0.000)**

Source: Author's own work based on R studio results

As indicated in table 28, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. The sum for Algeria is closer to 1 (0.965), it signifies the existence of continuous linkage between the global dairy price and the retail milk price. However, the beta coefficient of Algerian retail milk price is greater than Beta DCC. It indicates that the retail milk price is highly affected by its own previous value. The magnitude of the conditional volatility in Tunisia is lower, Beta DCC is 0.55, that means the retail milk price is more resistant to international dairy price fluctuation than the retail milk price in Algeria.

Table 29 summarizes the DCC-GARCH output for beef meat in Tunisia. It shows the significance of Beta values. Beta DCC is equal to 0.917, this result proves a positive long run volatility persistence that transmitted from the international price shocks.

Table 23. Volatility spillovers between the global beef and retail beef prices in Tunisia

Variables	International beef price	Retail beef price
Mu	-0.000720(0.917)	0.047(0.0006)
Omega	0.0007(0.311)	0.0023(0.156)
Alpha	0.386(0.035)	0.179(0.001)
Beta	0.612(0.0003)	0.819(0.000)
Alpha DCC	**0.000(0.99)**	
Beta DCC	**0.917(0.000)**	

Source: Author's own work based on R studio results

The significance values of alpha in both meat price (international and domestic) prove that both prices show a significance sensitively impact of their previous own shock. The significance of Beta DCC, which is high value, 0.917, indicates the persistence of volatility that transmitted from the international beef price to the retail beef price in Tunisia. It demonstrates the strong conditional correlation between two markets.

Table 30 illustrates the volatility spillovers of the chicken price in Tunisia and Algeria. It indicates the level of the conditional correlation between the global and the domestic chicken prices in these two countries.

Table 24. Volatility spillovers between the global chicken and retail chicken prices in Tunisia and Algeria

Variables	**International chicken price**	**Retail chicken price in Tunisia**	**Retail chicken price in Algeria**
Mu	-0.003(0.218)	0.006(0.0792)	0.847(0.710)
Omega	0.0001(0.339)	0.0007(0.267)	0.000(0.786)
Alpha	0.156(0.002)	0.237(0.000)	0.0176(0.223)
Beta	0.842(0.0000)	0.761(0.000)	0.981(0.000)
Alpha DCC		**0.000(0.99)**	**0.000(0.99)**
Beta DCC		**0.898(0.000)**	**0.9300 (0.000)**

Source: Author’s own work based on R studio results

The international chicken price shows a significant alpha and beta coefficients. It means that the international chicken price is sensitive to its own previous shock and is persistent to previous volatility. The sum of alpha and beta is highly close to 1, it reflects the high volatility persistence. Beta DCC for both national markets are significant. It justifies the high volatility persistence between the international chicken price and the retail chicken price in Tunisia and Algeria. Own and across volatility persistence is justified for the chicken meat price.

Table 31 illustrates the volatility spillovers of the lamb price in Tunisia and Algeria. It indicates the level of the conditional correlation between the global and the domestic lamb prices in these two countries. The sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. The sum for Tunisia is closer to 1 (0.911), it signifies the existence of continuous linkage between the global lamb price and the retail lamb price. However, for Algeria Beta DCC is non-significant, it indicates that the retail lamb price is not persistent to an international volatility of lamb price. Retail lamb price in Algeria is sensitive to international lamb price shock. We observe the significant of Beta value for Algeria, it indicates the own volatility persistence of retail lamb price.

Table 25. Volatility spillovers between the global lamb and retail lamb prices in Tunisia and Algeria

Variables	International lamb price	Retail lamb meat price in Tunisia	Retail lamb meat price in Algeria
Mu	0.010(0.329)	0.037(0.000)	0.003(0.295)
Omega	0.0000(0.830)	0.011(0.098)	0.000(0.797)
Alpha	0.015(0.061)	0.313(0.037)	0.089(0.288)
Beta	0.983(0.000)	0.626(0.000)	0.894(0.000)
Alpha DCC		**0.000(0.977)**	**0.161(0.042)**
Beta DCC		**0.911(0.000)**	**0.009(0.994)**

Source: Author's own work based on R studio results

Tunisian lamb meat shows a significant sensitivity and persistence to its own previous value. As indicated in table 31, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability.

Table 32 illustrates the wheat price volatility. It indicates the volatility spillovers between international wheat price and retail price in Morocco. Two kind of wheat, durum and soft wheat, are considered in our analysis.

The international wheat price has a significant beta value, that means that it is persistent to its previous shock. Retail durum wheat price has a significant alpha and beta values, it proves that it is sensitive to its own past price shocks, and has a persistent own volatility transmission from its previous price.

Table 26. Volatility spillovers between the global wheat price and the domestic wheat prices in Morocco

Variables	International wheat price	Retail durum wheat price	Retail soft wheat price
Mu	-0.000(0.927)	0.002(0.661)	0.001(0.000)
Omega	0.0000(0.999)	0.0006(0.138)	0.000009 (0.0264)
Alpha	0.000(0.99)	0.127(0.05)	0.000(0.99)
Beta	0.996(0.000)	0.638(0.003)	0.99(0.000)
Alpha DCC		**0.000(0.99)**	**0.000(0.99)**
Beta DCC		**0.924(0.000)**	**0.913(0.000)**

Source: Author's own work based on R studio results

As indicated in table 32, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. It signifies the existence of continuous linkage between the global wheat price and the retail durum and soft wheat prices. However, the beta coefficient of soft wheat price is higher than Beta DCC (0.99> 0.913). It indicates that the retail soft wheat price is highly affected by its own previous price. The magnitude of the conditional volatility in Morocco of both kind of wheat, Beta DCC, are high, that means the retail wheat price is persistent to international dairy price shocks.

Give a brief summary of your findings by country and product – maybe a summary table with: which product, what country, what relationship identified.

5.3. Food security index forecast

In this part, we describe the followed steps to estimate to unique food security index. The weight has been calculated based on DALYs values. DALYs values are retrieved from the Global Burden disease website. The coefficient indicates the rate of the DALY resulted from deficiency of the food. Table 33 illustrates these rates.

Table 27. The weight of the dietary composition

	Diet low in fruits	Diet low in vegetables	Diet low in whole grains	Diet low in nuts and seeds	Diet low in milk	Diet low in seafood omega-3 fatty acids	Diet low in legumes	Total
Tunisia	9%	2.5%	53.5%	4.1%	1.6%	7.2%	21.7%	100%
Algeria	8.5%	7.5%	42.7%	16.3%	1%	6%	18%	100%
Congo	24.4%	23%	25.6%	1%	3.4%	5 %	17.6%	100%
Morocco	6%	5.2%	59.6%	15.4%	1.3%	7.8%	4.7%	100%
Kenya	299%	19.2%	24.6%	9.8%1	2.2%	4.6%	9.7%	100%
Egypt	8%	0.7%	56.5%	16.1%	1.5%	11.1%	6.1%	100%
Uganda	11.4%	36.5%	34.8%	1.2%	5%	6.4%	4.7%	100%
Nigeria	25.2%	15.6%	32.3%	0.6%	2.8%	6.1%	17.4%	100%

Source: Author's own work based on Global Burden Disease database (https://www.healthdata.org/gbd/2019)

Table 33 shows the percentage of the diet low of the different food category (i.e. fruits, vegetables, whole grains, nuts, milk, seafood, and legumes). the weight of each item describes the importance of each food category.

$$FSI_{y,t} = \sum a_{x,t} \times \text{dietary supply deficit}_{(x,y,t)} \quad (32)$$

FSI designs the forecasted food security index for a country "y", at a "t" year. $a_{x,t}$ is the weight of each food subcategory "x" at the time "t". The coefficient "$a_{x,t}$" is retrieved from the global burden disease database. It presents the percentage of DALY caused by dietary insufficiency. It is the aggregated value of the weighted food subcategories.

We notice clearly that every country has a different weight of each food subcategory diet deficit. For Tunisia, the weight of cereal supply has the highest percentage, 53%, among other items. The diet low in cereal has the topmost percentage for all countries, except Kenya, where the fruit supply deficit has the highest percentage.

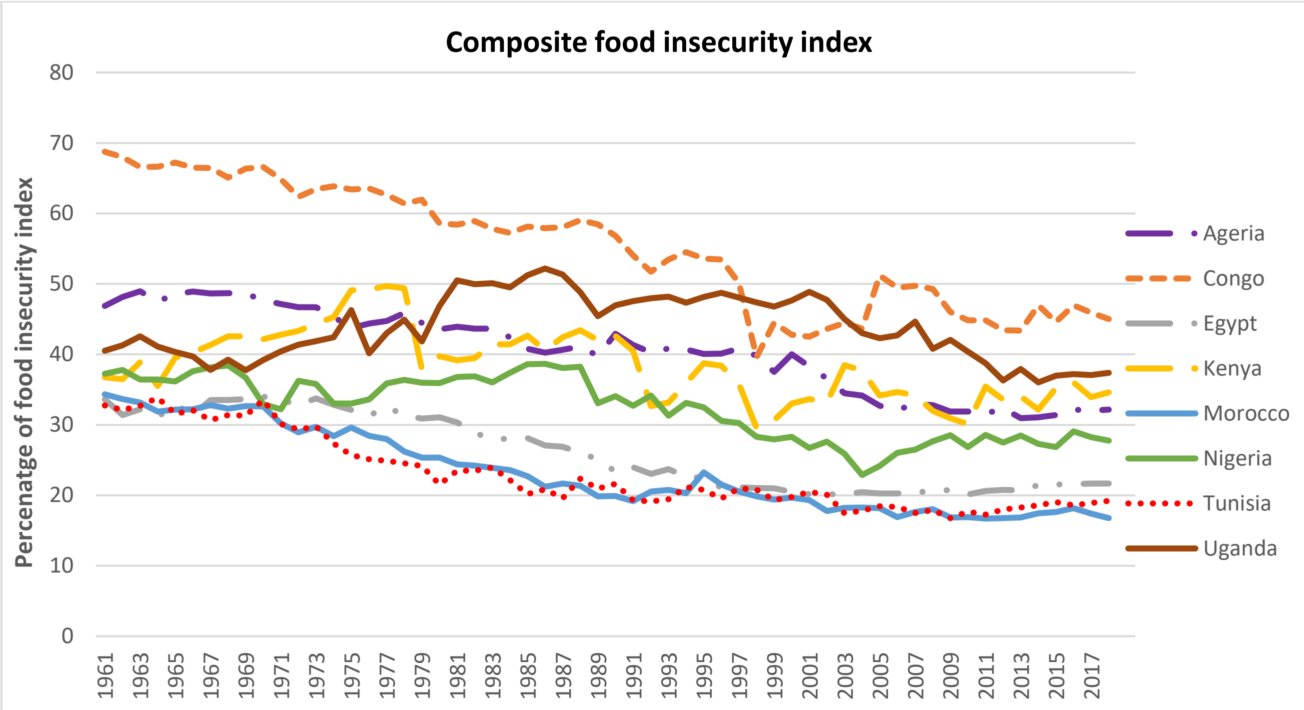

Figure 20. The forecasted food insecurity index

Source: Author’s own calculation

We illustrate the forecasted food security index from 1961 till 2018 in figure 22. The highest percentage describes the highest food insecurity level, that means the decrease of the percentage signifies an improvement of the food security index value. A fluctuation has been registered in all countries; it is translated by the perturbation in the food supply. Congo has the highest food insecurity along the years that reflects the serious concern of food supply.

Tunisia and Morocco, has almost, the lowest food insecurity index, followed by Egypt. The northern African countries have an ameliorated food security index comparing the other African countries. Their location could be among the reasons that explains the easiness of the trade.

5.4. Empirical results of food security determinants

The link between the explanatory variables (i.e. macroeconomic variables and agricultural producer price) and the food security index was examined through the two-step system GMM method.

Two step GMM model has been selected instead of the one step GMM, because of its robustness to the autocorrelation and heteroscedasticity characteristics. Table 34 provides the two-step dynamic GMM model results.

Table 28. Two-step dynamic GMM model results

variables	Coefficients	Standard error	T-Stat	Probability
Lag (FSI)	1.27300	0.0109	$116.7^{8}1$	<2e-16 ***
APPI	-0.05748	0.0073490	$-7.8^{2}1$	<2e-16 ***
IR	1.093	0.002511	-435.329	<2e-16 ***
EXG	0.0006034	0.00007102	8.496	<2e-16 ***
TO	0.06148	0.002659	23.119	<2e-16 ***
Oil	0.01330	0.005794	2.296	0.0217 **
INF	0.31470	0.007264	$43.3^{2}9$	<2e-16 ***
EMP	0.10320	0.01508	$-6.8^{4}5$	<2e-16 ***

Significance level: *** 0.001 and ** 0.05

The F-statistic of the overall model is equal to 51156255 with a significance level <0.001. It justifies the suitability of the model to fit our data. The system GMM estimator's statistical tests proved the model's stability using F-statistics, as the model is empirically stable at the 1% level of confidence range.

As indicated in the Table 34 all variables are significant at 1% except crude oil price which is significant at 5%. That means the independent variables explain well the dependent variables which is the food insecurity index.

To measure the impact of the agricultural producer price on food security, macroeconomic variables have been employed as well. All variables show a positive dependence with the food insecurity index, a negative effect on food security, except the APPI which has a negative connection with the food insecurity index, thus a positive correlation with the food security. The food Insecurity index is affected by its past value.

APPI has a negative impact on food insecurity index. An increase of APPI will decrease the level of food insecurity, thus improves the food security index. It means that an increase of APPI enhances the food security level. This positive correlation is explained by the fact of increasing the investment in the agriculture field. An upward shift in the APPI encourages farmers to produce more, therefore the food production increases and the supply gap could be ameliorated by the availability of domestic agricultural products.

The interest rate shows a positive coefficient, that explains an increase of interest rate will increase the food insecurity index, which means it aggravate the food security status. An amplification of the interest rate lead to reinforce the credit restrictions. Small farmers are the most affected because they rely more on credit to insure their production. A growing interest rate will hamper the agricultural production, and as a consequence the food security level. The expanding of the interest rate will create an extra cost for the agricultural production, even for large scale farmers, which force them to reduce their production.

The exchange rate exhibits a positive effect on the forecasted food insecurity index. A higher exchange rate will amplify the food insecurity, deteriorate the food security level. An increase of the exchange rate will raise the cost of import, because of the depreciated local money. Thus, the imported food may get shortened, followed by a diminishing of food availability. Furthermore, it may affect the cost of production, where it increases the imported agricultural input.

Trade openness increases the insecurity index. A non-restricted trade policy implemented within a country, facilitate the trade activity and improve the logistical infrastructure to enhance the import activity. As a result, it decreases the self-sufficiency of the country and create a disequilibrium of the balance trade.

The used “employment” variable describes the number of employed people. The results suggest that an increase of employment depreciate the food security. This finding is explained by the fact that the employed people are in the industrial sector. That creates a lack of labor in agriculture field. It reflects as well the increasing urbanization. People prefer to move to urban area to get employed, which has a negative effect on farm activity, less workforce, and as a result, low productivity.

An increasing in the oil price promotes the increasing in the inflation rate. Both indicators create a disequilibrium of the food market price. They threaten the food security situation. An increase of the crude oil price leads to the increasing the agricultural inputs price from one side, and from the other side, farmers will allocate their land to produce biofuel products instead of others.

Accordingly, the agricultural products will decrease significantly, and the food security, too. Interest rate has the highest coefficient. This implies the importance of the agricultural investments, and financial depts needed by farmers to maintain and enhance the agricultural activities.

Table 35 summaries the hypothesis results.

Table 29. Summary of the hypothesis findings

Hypothesis	Results	Relevant table with supporting results
H1: Food prices are significantly impacted by its own past values: a past volatility is significantly transmitted to the present value in Africa	Accepted	
H2: Crude oil price is significantly impacted by its own past values: a past volatility is significantly transmitted to the present value in Africa	Accepted	
H3: Crude oil price has a significant volatility spillover on the global food price in Africa	Accepted	
H4: Highly perishable agricultural commodity price (meat price) has the highest own volatility among other commodities in Africa	Rejected	
H5: The global food price volatility is significantly transmitted the domestic food price in Africa	Accepted	
H6: The crude oil has a significant influence on the global and domestic food prices: energy and food price and highly interdependent in Africa	Accepted	

H7: The agricultural producer price has a significant negative effect on forecasted food insecurity index in Africa	Accepted
H8: Trade openness, exchange rate, inflation rate, interest rate, employment rate, and crude oil price have significant positive effects on the forecasted food insecurity index in Africa	Accepted

Source: Author's own work

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Volatility is a directionless measure of the extent of the variability of a price or quantity. Exorbitant price volatility has an impact on farmers, consumers, processors, and traders, as well as the political system. It has the potential to skew farmer's' and intermediaries'' output and investment decisions, resulting in inefficient resource allocation. Poor customers may be compelled to cut back on their food and non-food spending. If this trend continues, it may induce to political disequilibrium.

This dissertation measures the degree of interdependence, at the global scale between food and crude oil price, and between domestic and international food prices.

Research results applied from univariate GARCH indicate the significance of past volatility on the present value. A previous shock in price is transmitted to the present price.

A bivariate DCC-GARCH model detects the spatial interdependence between global and domestic food prices. We tried to evaluate the price volatility transmission across international food price and domestic food price, as well across energy price and food price employing for that the DCC-GARCH model. DCC-GARCH shows the characteristics of the correlation between the used variables. A volatility spillover has been found across crude oil price to food price, different magnitude of volatility has been registered which reveals the strength of its persistence. From these findings we understand the conditional correlation transmission. Furthermore, the results highlight the strong persistence of the volatility transmitted from crude oil price to food price. However, increased biofuel demand may raise concerns of the agricultural commodity prices, potentially jeopardizing food security, particularly in vulnerable nations. The global cereal price showed the highest price volatility, this fact can be explained by the importance of the cereal sector in African countries to provide the basic food. Roman et al, 2020 found that there is a significant volatility transmission from the crude oil and international meat prices. As well, Koirala et al, in 2015, confirm the significance of the conditional correlation between energy price and agricultural commodity prices.

Because of the oil price inflation is destructive to food security, it is important to expand energy consumption in this sector, moving away from a reliance on fossil fuels and toward an optimal mix of renewable and nonrenewable energy resources that will benefit both energy and food security.

In most of most of research papers the food security index is presented by different proxies (e.g. food production, Average protein supply, average energy supply, etc…) (Henchion et al., 2017). Given the efforts to achieve the United Nations; Sustainable Development Goals (SDGs) for food security by 2030, this research examines the impact of the agricultural producer price on the food insecurity index in African countries from 1995 to 2018.

We investigated a dynamic panel data model based on the one-step system using multiple regression approaches. The System- GMM estimator, proposed by Arellano and Bover (1995) and subsequently refined by Blundell and Bond (1998), was chosen over other techniques because of its efficiency in removing simultaneous biases associated with regression model estimations. Because of the efficiency of its optimal weighting matrices, the one-step System-GMM was favored over the two-step System-GMM for our estimation. The results confirm the existence of positive relationship between agricultural producer price and food security, that indicates the importance to develop the domestic production.

Africa continent has the lowest rate of the share of the public expenditure in agriculture comparing other continents. In accordance with our results of the dynamic GMM approach, the negative relationship detected between the food security index and agricultural price reflects the importance of the domestic production. That means these countries should rely more on their national agricultural production by encouraging the agricultural investments.

African countries should focus on agricultural investments and encourage farmers to expand their agricultural activities instead of releasing trade barriers to facilitate the food import.

To conclude, implementing trade policy, by policy makers is not enough to strengthen the food security, but they need to build monetary policy that protect the country from macroeconomic fluctuation to prevent the economic crisis.

6.2. Recommendations and managerial implications

The significant linkage between the crude oil and food price, justifies that any crude oil price perturbation may disturb the food market price, thus policy makers should carefully diversify the energy portfolio as an agricultural input.

The level of interdependence between the international and domestic food price can provide an image about the domestic food market resistance strength against global price fluctuation. It helps policy makers to implement the efficient policy to protect the food market from unexpected price increase.

According to our results, considering that public investments in agriculture raise producer prices, which has a long-term positive influence on food security, African countries should consider policy reforms that enhance total agricultural investment responsibilities.

6.3. Limitation

As any research work, we faced some limitations to elaborate the dissertation. Lack of data is the main imitation faced. At the beginning, we tried to collect producer price of some agricultural commodities, but we could not find enough data to run the model correctly. The African continent is suffering from difficulties of data availability. Not all data was successfully found. There is especially, lack of data for developing countries. We tried to contact the national statistic offices but unfortunately no feedbacks. For the reliability of our data sources, we are limited to trusted websites such as FAO, and World Bank database.

Our dissertation is limited to the crude oil price as energy, three retail commodity prices (wheat, meat, and milk), and eight countries are considered. Future research can consider more retail commodity prices, and producer price. Other countries as well can be examined to have a wider picture about the different markets.

7. NEW SCINTIFIC RESULTS

This study offers new scientific findings based on the collected data, findings, and analysis. These findings may serve a framework as for future research and to expand the model using the analytical technique utilized and new components in the model that were included in this study.

1- The research has proven the volatility spillovers between food and oil price. In this way the work gives an update that covers the Global Financial Disaster (GFC), European Sovereign Debt Crisis (ESDC), and the Covid-19 pandemic health and economic crisis which spans the years 2000-2021.
2- The research contributes to the current literature by using the generalized autoregressive heteroscedasticity model to measure the magnitude of the dynamic correlation, volatility spillovers, between crude oil and the food prices. The dynamic behavior of the spillover effect is critical since it provides point-in-time information on the effect. In other words, the dynamic approach shows how volatility spillover changes over time as a result of shocks absorbed by the market.
3- The work offers a synthetic overview on the movement of price volatility and the dynamic correlation between food price and global food price from one side, and from the other side, between retail commodity prices and global commodity prices.
4- My research work tackles the food security issue from the gap in the supply side in order to estimate a unique index. It is the first study research that suggested model assigns weights based on DALY indicators, avoiding the difficulties of subjective weighing, which is the novelty in our research. I was the first to develop a food insecurity index, based on the gap between the supplied and required of food sub-categories (i.e. milk, vegetables, fruits, cereals, legumes, nuts, and fish).
5- My dissertation is the first study that examines price volatility spillovers among international food- and local retail food prices in north African countries (Tunisia, Algeria, Morocco, and Egypt).
6- I have firstly proven a significant effect of macroeconomic variables on the unique forecasted food insecurity index in African countries through a panel approach.

8. SUMMARY

Our dissertation tackles three main parts. First of all, a bibliometric analysis was carried out. It highlights the importance of the link between food price and food security. It highlights the importance of the emerging studies that link the effect of agricultural price on the national food security status in African countries. From this point, we tried to focus on this gap to elaborate our research on examining the relationship between food security and agricultural price.

Prior, the investigation of the relation between agricultural price, food security index and macroeconomic indicators, an examination of price volatility spillovers among food and crude oil prices, and spatial volatility transmission between domestic food market and global food market prices has been carried out to get a clear idea how much the food domestic market is vulnerable to an international food price shocks. DCC-GARCH model has been employed to achieve the purpose, because of its suitability to catch the conditional variance. Price volatility, which is a common aspect of agricultural commodity prices presents a high uncertainty for the food market. Understanding the magnitude of volatility might assist in defining strategies to mitigate the negative effects of price instability. Our results justify the high conditional correlation between the crude oil and food price, the significance of this linkage explains the movement of food price followed by a crude oil price shock. The considered countries show a significant dynamic interdependence between the global food price and the domestic food price except Nigeria and Egypt, where an international food price shock is not persistent in these domestic food prices.

Crude oil price shows a significant linkage with the domestic food price, it highlights the degree of the connectedness of the agriculture sector to the energy price, crude oil price. It demonstrates the strong conditional dependence between the crude oil and the overall national food prices.

In contrast to one hypothesis that we have made (H3), the global cereal price shows the highest own price volatility magnitude, comparing meat and dairy products.

To tackle the food security challenges, we focused on food supply gap and food deficiency. To measure the food supply deficit, we introduced a novel weighting method to aggregate the food sub-categories (vegetables, fruits, nuts, cereals, milk, legumes, and seafood). The aggregated food insecurity index has been presented for 8 African countries; it shows the food supply deficit in these countries.

Dynamic two-step system GMM approach has been applied because of its robustness on the hidden heterogeneity and endogeneity potentiality of the key explanatory variables. The model is efficient to determine the effect of the explanatory variables. The GMM approach was found to gives significant results, it proves the model robustness. The agricultural producer price shows a negative effect on the forecasted food insecurity index, that means an increase of the agricultural price will improve the food security situation. The other macroeconomic indicators exhibit a positive and significant relation with the forecasted food insecurity index. Trade openness shows a positive significant effect on food insecurity, that could be explained by the inefficiency of the existed trade policies in supplying food.

The positive effect between agricultural producer price and food security, and the negative effect of interest rate and the food security raise the importance of the agricultural investment. In other words, the liberalization of the trade policy does not solve the issue of food insecurity. Policy makers should focus on the self-sufficiency and encourage farmers to expand their agricultural activities to enhance the domestic productivity. Trade liberalization may hamper national diversification and force nations into a non-sustainable development plan.

9. REFERENCES

1. Abrhám, J., Vošta, M., Čajka, P., & Rubáček, F. (2021). The specifics of selected agricultural commodities in international trade. Agricultural and Resource Economics: International Scientific E-Journal, 7(2), 5-19
2. Acosta, A., & Valdés, A. (2014). Vertical price transmission of milk prices: are small dairy producers efficiently integrated into markets?. Agribusiness, 30(1), 56-63.
3. Adam P., Rianse U., HarafahL´. M., Cahyono E., & Rafiy M. (2016). A model of the dynamics of the effect of world crude oil price and world rice price on Indonesia's inflation rate. Agris On-Line Papers in Economics and Informatics, 8(665-2016-45110), 3–12. Economics and Informatics, 8(665-2016-45110), 3–12.
4. Ahmadi, M., Behmiri, N. B., & Manera, M. (2016). How is volatility in commodity markets linked to oil price s hocks?. *Energy Economics*, *59*, 11-23.
5. Ahn, D. H., Boudoukh, J., Richardson, M., & Whitelaw, R. F. (2002). Partial adjustment or stale prices? Implications from stock index and futures return autocorrelations. The Review of Financial Studies, 15(2), 655-689.
6. Akinboade, O. A., & Adeyefa, S. A. (2018). An analysis of variance of food security by its main determinants among the urban poor in the city of Tshwane, South Africa. Social Indicators Research, 137(1), 61-82.
7. Alem Y, Söderbom M. Household-level consumption in urban Ethiopia: the effects of a large food price shock. World development. 2012 Jan 1;40(1):146-62.
8. Alexandri, C. (2011). Analysis of price transmission along the agri-food chains in Romania. Agricultural Economics and Rural Development, 8(2), 171-189.
9. Allee, A., Lynd, L. R., & Vaze, V. (2021). Cross-national analysis of food security drivers: comparing results based on the Food Insecurity Experience Scale and Global Food Security Index. *Food Security*, *13*(5), 1245-1261.
10. Amolegbe, K. B., Upton, J., Bageant, E., & Blom, S. (2021). Food price volatility and household food security: Evidence from Nigeria. *Food Policy*, *102*, 102061.
11. Amrouk, E. M., Grosche, S. C., & Heckelei, T. (2020). Interdependence between cash crop and staple food international prices across periods of varying financial market stress. *Applied Economics*, *52*(4), 345-101anadiAnser, M. K., Osabohien, R., Olonade, O.,

Karakara, A. A., Olalekan, I. B., Ashraf, J., & Igbinoba, A. (2021). Impact of ICT adoption and governance interaction on food security in West Africa. *Sustainability*, *13*(10), 5570.

12. Apergis, N., & Rezitis, A. (2003a). An examination of'Okun's law: evidence from regional areas in Greece. Applied Economics, 35(10), 1147-1151.
13. Apergis, N., & Rezitis, A. (2003b). Agricultural price volatility spillover effects: the case of Greece. European Review of Agricultural Economics, 30(3), 389-406.
14. Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The review of economic studies*, *58*(2), 277-297.
15. Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics*, *68*(1), 29-51
16. Arouna, A., Soullier, G., Del Villar, P. M., & Demont, M. (2020). Policy options for mitigating impacts of COVID-19 on domestic rice value chains and food security in West Africa. *Global Food Security*, *26*, 100405.
17. Arndt, C., Davies, R., Gabriel, S., Harris, L., Makrelov, K., Robinson,I, ... & Anderson, L. (2020). Covid-19 lockdowns, income distribution, and food security: An analysis for South Africa. *Global Food Security*, *26*, 100410.
18. Assouto, A. B., Houensou, D. A., & Semedo, G. (2020). Price risk and farmers' decisions: A case study from Benin. Scientific African, 8, e00311.
19. Awokuse, T. O., & Wang, X. (2009). Threshold effects and asymmetric price adjustments in US dairy markets. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 57(2), 269-286.
20. Baek, J., & Koo, W. W. (2014). On the upsurge of US food prices revisited. *Economic modelling*, *42*, 272-276.
21. Bakucs, L. Z., Brümmer, B., von Cramon-Taubadel, S., & Fertő, I. (2012). Wheat market integration between Hungary and Germany. Applied Economics Letters, 19(8), 785-788.
22. Bakucs, Z., Benedek, Z., & Fertö, I. (2019). Spatial price transmission and trade in the European dairy sector. AGRIS on-line Papers in Economics and Informatics, 11(665-2019-4001), 13-20.

23. Barrett, C. B., Reardon, T., Swinnen, J., & Zilberman, D. (2022). Agri-food value chain revolutions in low-and middle-income countries. Journal of Economic Literature, 60(4), 1316-1377.
24. Beghin, J. C., & Schweizer, H. (2021). Agricultural trade costs. Applied Economic Perspectives and Policy, 43(2), 500-530.
25. Ben Abdallah, M., Fekete-Farkas, M., & Lakner, Z. (2020a). Analysis of meat price volatility and volatility spillovers in Finland. *Agricultural Economics*, *66*(2), 84-91
26. Ben Abdallah, M., Fekete Farkas, M., & Lakner, Z. (2020b). Analysis of dairy product price transmission in Hungary: A nonlinear ARDL model. *Agriculture*, *10*(6), 217.
27. Ben Abdallah, M., Fekete-Farkas, M., & Lakner, Z. (2021). Exploring the Link between Food Security and Food Price Dynamics: A Bibliometric Analysis. *Agriculture*, *11*(3), 263.
28. Béné, C. (2020). Resilience of local food systems and links to food security–A review of some important concepts in the context of COVID-19 and other shocks. *Food Security*, 1-18.
29. Bhat, J. A., Ganaie, A. A., & Sharma, N. K. (2018). Macroeconomic response to oil and food pric e shocks: A structural var approach to the Indian economy. *International Economic Journal*, *32*(1), 66-90
30. Bhebhe, S., & Ndlovu, I. (2021). The impact of world oil and food price shocks on the interdependence of Brazil and Russia: SVAR-DCC-GARCH model. *BRICS Journal of Economics*, *2*(4), 47-76.
31. Blekking, J., Waldman, K., Tuholske, C., & Evans, T. (2020). Formal/informal employment and urban food security in Sub-Saharan Africa. Applied Geography, 114, 102131.
32. Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics*, *87*(1), 115-143.
33. Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. Journal of econometrics, 31(3), 307-327.
34. Bollerslev, T. (1990). Modelling the coherence in short-run nominal exchange rates: a multivariate generalized ARCH model. *The review of economics and statistics*, 498-505.

35. Bor, Ö., Ismihan, M., & Bayaner, A. (2014). Asymmetry in farm-retail price transmission in the Turkish fluid milk market. New Medit, 13(2), 2-8.
36. Borawski P., Guth M., Truszkowski W., Zuzek D., Beldycka-Borawska A., Mickiewicz B., Szymanska E., Harper J.K., Dunn J.W. (2020): Milk price changes in Poland in the context of the Common Agricultural Policy. Agric. Econ. – Czech, 66: 19–26.
37. Bouis H. Rising food prices will result in severe declines in mineral and vitamin intakes of the poor. Washington DC: HarvestPlus. 2008 Sep.
38. Bouzembrak Y, Klüche M, Gavai A, Marvin HJ. Internet of Things in food safety: Literature review and a bibliometric analysis. Trends in Food Science & Technology. 2019 Dec 1;94:54-64.
39. Brown MT, Ulgiati S. Understanding the global economic crisis: A biophysical perspective. Ecological Modelling 2011; 223:4-13.
40. Buguk, C., Hudson, D., & Hanson, T. (2003). Price volatility spillover in agricultural markets: an examination of US catfish markets. Journal of Agricultural and Resource Economics, 86-99.
41. De Bakker FG, Groenewegen P, Den Hond F. A bibliometric analysis of 30 years of research and theory on corporate social responsibility and corporate social performance. Business & society. 2005 Sep;44(3):283-317.
42. Caccavale, O. M., & Giuffrida, V. (2020). The Proteus composite index: Towards a better metric for global food security. World Development, 126, 104709.
43. Cardwell, R., & Ghazalian, P. L. (2020). COVID-19 and International Food Assistance: Policy proposals to keep food flowing. *World Development*, *135*, 105059
44. Chen, S. T., Kuo, H. I., & Chen, C. C. (2010). Modeling the relationship between the oil price and global food prices. *Applied Energy*, *87*(8), 2517-2525.
45. Chen, P. C., Yu, M. M., Shih, J. C., Chang, C. C., & Hsu, S. H. (2019a). A reassessment of the Global Food Security Index by using a hierarchical data envelopment analysis approach. *European Journal of Operational Research*, *272*(2), 687-698.
46. Chen D, Zhang P, Luo Z, Zhang D, Bi B, Cao X. (2019b)Recent progress on the water–energy–food nexus using bibliometric analysis. Curr. Sci. Aug 25;117(4).
47. Ciaian, P. (2011). Food, energy and environment: is bioenergy the missing link?. *Food Policy*, *36*(5), 571-580.

48. Clapp, J., & Moseley, W. G. (2020). This food crisis is different: COVID-19 and the fragility of the neoliberal food security order. *The Journal of Peasant Studies*, *47*(7), 1393-1417.
49. Climate & Development Knowledge Network. *(*2019*)*. The IPCC's special report on climate change and land: What's in it for Africa? *Retrieved from* https://cdkn.org/wp-content/uploads/2019/10/IPCC-Land_Africa_WEB_03Oct2019.pdf
50. Coghlan, C. M., & Bhagwat, S. A. (2019). Going beyond hunger: Linking food supplies to global malnutrition. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, *73*(2), 128-134.
51. Cooper, M. W., Brown, M. E., Niles, M. T., & ElQadi, M. M. (2020). Text mining the food security literature reveals substantial spatial bias and thematic broadening over time. *Global Food Security*, *26*, 100392.
52. Davies, A. (2006). Testing for international equity market integration using regime switching cointegration techniques. Review of Financial Economics, 15(4), 305-321.
53. De Paulo Farias De Nicola, F., De Pace, P., & Hernandez, M. A. (2016). Co-movement of major energy, agricultural, and food commodity price returns: A time-series assessment. *Energy Economics*, *57*, 28-41.
54. Devereux, S., Béné, C., & Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Security*, *12*(4), 769-772.
55. Diao, X., & Sarpong, D. B. (2011). Poverty implications of agricultural land degradation in Ghana: an economy-wide, multimarket model assessment. *African Development Review*, *23*(3), 263-275.
56. Dong, X., Brown, C., Waldron, S., & Zhang, J. (2018). Asymmetric price transmission in the Chinese pork and pig market. British Food Journal.
57. EAT-Lancet Commission. "The EAT-Lancet Commission on Food, Planet, Health." EAT https://eatforum. org/eat-lancet-commission. Accessed 16 (2019).
58. EIU (The Economist Intelligence Unit). (2015). Global food security index 2015. An annual measure of the state of global food security. London: The Economist Intelligence Unit Limited.

59. EIU. (2016). The Global Food Security Index 2016: An annual measure of the state of global food security. Economist Intelligence Unit Limited. https://foodsecurityindex.eiu.com/
60. EIU. (2019). The global food security index 2019: Strengthening food systems and the environment through innovation and investment. Economist Intelligence Unit. https://foodsecurityindex.eiu.com/.
61. Engle, R. F. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. Econometrica: Journal of the Econometric Society, 987-1007.
62. Engle, R. F., Lilien, D. M., & Robins, R. P. (1987). Estimating time varying risk premia in the term structure: The ARCH-M model. Econometrica: journal of the Econometric Society, 391-407.
63. Engle, R. F., & Kroner, K. F. (1995). Multivariate simultaneous generalized ARCH. Econometric theory, 11(1), 122-150.
64. Erokhin, V. (2017). Factors influencing food markets in developing countries: An approach to assess sustainability of the food supply in Russia. *Sustainability*, *9*(8), 1313.
65. Erokhin, V. (Ed.). (2018). *Establishing Food Security and Alternatives to International Trade in Emerging Economies*. IGI Global. https://doi.org/10.4018/978-1-5225-2733-6
66. Erokhin, V., & Gao, T. (2020). Impacts of COVID-19 on trade and economic aspects of food security: Evidence from 45 developing countries. *International journal of environmental research and public health*, *17*(16), 5775.
67. Erokhin, V., Diao, L., Gao, T., Andrei, J. V., Ivolga, A., & Zong, Y. (2021). The Supply of Calories, Proteins, and Fats in Low-Income Countries: A Four-Decade Retrospective Study. *International Journal of Environmental Research and Public Health*, *18*(14), 7356.
68. Ertuğrul, H. M., & Seven, Ü. (2021). Dynamic spillover analysis of international and Turkish food prices. *International Journal of Finance & Economics*.
69. Fan, S. (2019). Food policy in 2018–2019: Growing urgency to address the SDGs. *International Food Policy Research Institute (IFPRI), 2019 global food policy report*, 6-15.
70. Fan, S., Si, W., & Zhang, Y. (2020). How to prevent a global food and nutrition security crisis under COVID-19?. *China Agricultural Economic Review*.

71. FAO, IFAD, UNICEF, WFP, WHO. (2020). The State of Food Security and Nutrition in the World. Transforming Food Systems to Deliver Affordable Healthy Diets for All. FAO, Rome

72. FAO (1996) Rome declaration on world food security and world food summit plan of action. FAO, Rome.

73. FAO. (2011). The state of food insecurity in the world: How does international price volatility affect domestic economies and food security? Rome; Italy: Food and Agriculture Organisation of the United Nations.

74. FAO (2015) The state of food insecurity in the world. Food and Agriculture Organization of the United Nations (FAO), Rome.

75. FAO, IFAD, UNICEF, WFP and WHO. (2021). The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO. https://doi.org/10.4060/cb4474en

76. Fasanya, I., & Akinbowale, S. (2019). Modelling the return and volatility spillovers of crude oil and food prices in Nigeria. *Energy*, *169*, 186-205

77. Fernández-Amador, O., Baumgartner, J., & Crespo-Cuaresma, J. (2010). Milking the prices: the role of asymmetries in the price transmission mechanism for milk products in Austria (No. 2010-21). Working Papers in Economics and Statistics.

78. Fousekis P, Katrakilidis C, Trachanas E.(2016) Vertical price transmission in the US beef sector: Evidence from the nonlinear ARDL model. Economic ModellingJan 1;52:499-506.

79. Frey, G., & Manera, M. (2007). Econometric models of asymmetric price transmission. Journal of Economic surveys, 21(2), 349-415.

80. Fróna D, Szenderák J, Harangi-Rákos M. The challenge of feeding the world. Sustainability. 2019 Jan;11(20):5816.

81. Fusco, G., Coluccia, B., & De Leo, F. (2020). Effect of trade openness on food security in the EU: A dynamic panel analysis. *International Journal of Environmental Research and Public Health*, *17*(12), 4311.

82. Galtier F. Managing food price instability: Critical assessment of the dominant doctrine. Global Food Security. 2013 Jul 1;2(2):72-81.

83. Giller, K. E. (2020). The food security conundrum of sub-Saharan Africa. Global Food Security, 26, 100431.
84. Glauber, J., Laborde Debucquet, D., Martin, W., & Vos, R. (2020). COVID-19: Trade restrictions are worst possible response to safeguard food security. *IFPRI book chapters*, 66-68.
85. Gödecke, T., Stein, A. J., & Qaim, M. (2018). The global burden of chronic and hidden hunger: trends and determinants. Global food security, 17, 21-29
86. Gouel C. Agricultural price instability: a survey of competing explanations and remedies. Journal of economic surveys. 2012 Feb;26(1):129-56.
87. Grace, K., Brown, M., & McNally, A. (2014). Examining the link between food prices and food insecurity: A multi-level analysis of maize price and birthweight in Kenya. Food Policy, 46, 56-65.
88. Grau A, Hockmann H. (2018). Market power in the German dairy value chain. Agribusiness. Dec;34(1):93-111
89. Grimaccia, E., & Naccarato, A. (2019). Food Insecurity Individual Experience: A Comparison of Economic and Social Characteristics of the Most Vulnerable Groups in the World. Social Indicators Research, 143(1), 391-410.Guo, Jin, and Tetsuji Tanaka. "Dynamic transmissions and volatility spillovers between global price and US producer price in agricultural markets." Journal of Risk and Financial Management 13, no. 4 (2020): 83Gupta, B. M., & Bhattacharya, S. (2004). Bibliometric approach towards mapping the dynamics of science and technology. DESIDOC Journal of Library & Information Technology, 24(1)Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste. FAO, Rome Italy
90. Harzing AW, Alakangas S. Google Scholar, Scopus and the Web of Science: a longitudinal and cross-disciplinary comparison. Scientometrics. 2016 Feb;106(2):787-804.
91. Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M., & Tiwari, B. (2017). Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. Foods, 6(7), 53
92. Hillen, J. (2021). Vertical price transmission in Swiss dairy and cheese value chains. Agricultural and Food Economics, 9(1), 13.

93. Hernandez, M. A., Ibarra, R., & Trupkin, D. R. (2014). How far do shocks move across borders? Examining volatility transmission in major agricultural futures markets. *European Review of Agricultural Economics*, *41*(2), 301-325.

94. Hirsch, J. (2005). An index to quantify an individual's scientific research output. PNAS. 105 (46): 16569-165.

95. HLPE, (2011). Price volatility and food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome 2011.

96. HLPE. (2020). Impacts of COVID-19 on food security and nutrition: developing effective policy responses to address the hunger and malnutrition pandemic. Rome. https://doi.org/10.4060/cb1000en.

97. Horn, B., Ferreira, C., & Kalantari, Z. (2022). Links between food trade, climate change and food security in developed countries: A case study of Sweden. *Ambio*, *51*(4), 943-954

98. Huang, J.K. and Hu, R.F. (2000) Government-Major Funding Source of Agricultural S&T. Forum on Science and Technology in China, 20, 59-62.

99. Ibok, O. W., Osbahr, H., & Srinivasan, C. (2019). Advancing a new index for measuring household vulnerability to food insecurity. Food policy, 84, 10-20.

100. IMF. (2011). Rising Prices on the Menu. Finance & Development, March 2011, Vol. 48, No. 1, P 24:27.

101. Intergovernmental Panel on Climate Change. *(*2020*)*. Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, summary for policymakers. Geneva*: Author. Retrieved from* https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

102. Ira.M and Kohler.S, (2014), Urbanization and Food Security. World risk report.

103. Ivanic, M., & Martin, W. (2008). Implications of higher global food prices for poverty in low-income countries. The World Bank. Agricultural Economics 39 (2008) supplement 405–416.

104. Ivanic, M., W. Martin and H. Zaman (2011) ‘Estimating the Short-run Poverty Impacts of the 2010–2011 Surge in Food Prices’, World Bank Policy Research Working Paper No.5633 (Washington, DC: World Bank Development Research Group).

105. Izraelov, M., & Silber, J. (2019). An assessment of the global food security index. Food Security, 11(5), 1135-1152.

106. Jeremić, M., Zekić, S., Matkovski, B., & Kleut, Ž. (2019). Spatial price transmission in pork market in Serbia. Custos e Agronegocio.

107. John, J., Bhatt, A., & Varma, P. (2019). Impact of minimum support price policy and national food security mission on the production of pulses in India.

108. Kalkuhl, M., Von Braun, J., & Torero, M. (2016). *Food price volatility and its implications for food security and policy* (p. 626). Springer Nature.

109. Karolyi, G. A. (1995). A multivariate GARCH model of international transmissions of stock returns and volatility: The case of the United States and Canada. Journal of Business & Economic Statistics, 13(1), 11-25.

110. Khan, M. A., & Helmers, G. A. (1997). Causality, Input Price Variability, and Structural Changes in the US Livestock-Meat Industry (No. 1839-2016-152205).

111. Kharin, S. (2015). Vertical price transmission along the diary supply chain in Russia. Studies in Agricultural Economics, 117(2), 80-85.

112. Khorsandi, P.(2020). WFP chief warns of ‘hunger pandemic’ as Global Food Crises Report launched. World food Programme Insight, April 22. https://www.wfp.org/stories/wfp-chief-warns-hunger-pandemic-global-food-crises-report-launched.

113. Klassen, S., & Murphy, S. (2020). Equity as both a means and an end: lessons for resilient food systems from COVID-19. *World Development*, *136*, 105104.

114. Koirala, K. H., Mishra, A. K., D'Antoni, J. M., & Mehlhorn, J. E. (2015). Energy prices and agricultural commodity prices: Testing correlation using copulas method. *Energy*, *81*, 430-436.

115. Kolodina, N. Criteria of the food market potential evaluation. (2013). Bull. Orenbg. State Agrar. Univ. 1,157–159.

116. Kostrova, Y. (2014). Analysis of Food Market of Russia. *Saint-Petersburg University of Management and Economics: Saint Petersburg, Russia*..

117. Kumar, B., Sharma, A., Vatavwala, S., & Kumar, P. (2020). Digital mediation in business-to-business marketing: A bibliometric analysis. *Industrial Marketing Management*, *85*, 126-140.

118. Kwaw-Nimeson, E., & Tian, Z. (2021). The impact of agricultural producer price on sustainable food security in Africa–a system GMM approach. *Agricultural and Resource* Economics: International Scientific E-Journal, 7(1868-2021-1454), 60-76.
119. Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, *369*(6503), 500-502.
120. Letta, M., Montalbano, P., & Pierre, G. (2022). Weather shocks, traders' expectations, and food prices. American Journal of Agricultural Economics, 104(3), 1100-1119
121. Liu W. Accuracy of funding information in Scopus: a comparative case study. Scientometrics. 2020 Jul;124(1):803-11.
122. Lotka AJ. The frequency distribution of scientific productivity. Journal of the Washington academy of sciences. 1926 Jun 19;16(12):317-23.
123. Lu, Y., Yang, L., & Liu, L. (2019). Volatility spillovers between crude oil and agricultural commodity markets since the financial crisis. Sustainability, 11(2), 396.
124. Luo, P., & Tanaka, T. (2021). Food import dependency and national food security: A price transmission analysis for the wheat sector. *Foods*, *10*(8), 1715.
125. Lv, F., Deng, L., Zhang, Z., Wang, Z., Wu, Q., & Qiao, J. (2021). Multiscale analysis of factors affecting food security in China, 1980–2017. *Environmental Science and Pollution Research*, 1-15.
126. Mahmah, A. E., & Amar, A. (2021). Food Security in the MENA Region: Does Agriculture Performance Matter?. In *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa* (pp. 101-125). Springer, Cham.
127. Manap, N. M. A., & Ismail, N. W. (2019). Food security and economic growth. *Int. J. Mod. Trends Soc. Sci*, *2*, 108-118.
128. Matz, J. A., Kalkuhl, M., & Abegaz, G. A. (2015). The short-term impact of price shocks on food security-Evidence from urban and rural Ethiopia. *Food Security*, *7*(3), 657-679.
129. McKenzie, F. C., & Williams, J. (2015). Sustainable food production: constraints, challenges and choices by 2050. *Food Security*, *7*(2), 221-233.
130. Meyer, J., & von Cramon-Taubadel, S. (2004). Asymmetric price transmission: a survey. Journal of agricultural economics, 55(3), 581-611.

131. Meyer, D. F., Sanusi, K. A., & Hassan, A. (2018). Analysis of the asymmetric impacts of oil prices on food prices in oil-exporting developing countries. Journal of International Studies, 11(3), 82-94.

132. Mkhawani, K., Motadi, S. A., Mabapa, N. S., Mbhenyane, X. G., &Blaauw, R. (2016). Effects of risingfoodprices on household foodsecurity on femaleheadedhouseholds in RunnymedeVillage, MopaniDistrict, South Africa. South African Journal of ClinicalNutrition, 29(2), 69-74.

133. Monasterolo I, Pasqualino R, Janetos AC, Jones A. Sustainable and inclusive food systems through the lenses of a complex system thinking approach—a bibliometric review. Agriculture. 2016 Sep;6(3):44.

134. Mouloudj, K., Bouarar, A. C., & Fechit, H. (2020). The impact of COVID-19 pandemic on food security. *Les cahiers du CREAD*, *36*(3), 159-184

135. Muflikh, Y. N., Smith, C., Brown, C., & Aziz, A. A. (2021). Analysing price volatility in agricultural value chains using systems thinking: A case study of the Indonesian chilli value chain. Agricultural Systems, 192, 103179.

136. Muñoz-Leiva F, Viedma-del-Jesús MI, Sánchez-Fernández J, López-Herrera AG. An application of co-word analysis and bibliometric maps for detecting the most highlighting themes in the consumer behaviour research from a longitudinal perspective. Quality & Quantity. 2012 Jun;46(4):1077-95.

137. Murray, C. J., Vos, T., Lozano, R., Naghavi, M., Flaxman, A. D., Michaud, C., ... & Haring, D. (2012). Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet*, *380*(9859), 2197-2223.

138. Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. *(*2010*)*. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science, 130*(*1–3*)*, 57–69.

139. Natcher, W. C., & Weaver, R. D. (1999). The transmission of price volatility in the beef markets (No. 371-2016-19168).

140. Nazlioglu, S., & Soytas, U. (2012). Oil price, agricultural commodity prices, and the dollar: A panel cointegration and causality analysis. *Energy Economics*, *34*(4), 1098-1104.

141. Nehrey, M., & Voronenko, I. GLOBAL FOOD SECURITY: ASSESSMENT AND TRENDS. *European Journal of Molecular & Clinical Medicine*, *7*(8), 2020.

142. Novickytė L. Risk in agriculture: An overview of the theoretical insights and recent development trends during last decade–A review. Agricultural Economics. 2019 Sep 25;65(9):435-44.

143. Nuryartono, N., Rifai, M. A., Anggraenie, T., & Setiawan, B. I. (2021). Determining factors of regional food resilience in Java-Indonesia. *Journal of Social and Economic Development*, *23*(3), 491-504.

144. Ogunniyi, A., Mavrotas, G., Olagunju, K., Fadare, O., & Rufai, A. M. (2018). *The Paradigm of Governance Quality, Migration and its Implication on Food and Nutritional Security in Sub-Saharan Africa: What does Dynamic Generalized Method of Moments estimation reveal?* (No. 2058-2018-5302).

145. Okumus, B., Koseoglu, M. A., & Ma, F. (2018). Food and gastronomy research in tourism and hospitality: A bibliometric analysis. *International Journal of Hospitality Management*, *73*, 64-74.

146. Omidvar, N., Ahmadi, D., Sinclair, K., & Melgar-Quiñonez, H. (2019). Food security in selected Middle East and North Africa (MENA) countries: an inter-country comparison. Food Security, 11(3), 531-540.

147. Onumah, E. E., Addey Owusu, P., Mensah-Bonsu, A., & Acquah Degraft, H. (2022). Rice price volatility and transmission: implications for food security in Ghana. *Cogent Economics & Finance*, *10*(1), 2085605.

148. Onegina, V., Megits, N., Kravchenko, O., & Kravchenko, Y. (2022). Price transmission in milk supply chain in Ukraine. Agricultural and Resource Economics: International Scientific E-Journal, 8(1), 152-170.

149. Osabohien, R., Ashraf, J., De Alwis, T., Ufua, D. E., Osabuohien, E., Odularu, G., ... & Augustine, D. (2021). Social protection and food security nexus in the Global South: empirical evidence from West Africa. *Contemporary Social Science*, 1-14

150. Özkaya, G., & Özkaya, G. U. (2022). Evaluation of Global Food Security Index Indicators with 2020 COVID-19 Data and Country Comparisons with Multi-Criteria Decision Making Methods. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, *11*(1), 249-268.

151. Pal, D., & Mitra, S. K. (2017). Diesel and soybean price relationship in the USA: evidence from a quantile autoregressive distributed lag model. *Empirical Economics*, *52*(4), 1609-1626

152. Pal, D., & Mitra, S. K. (2018). Interdependence between crude oil and world food prices: A detrended cross correlation analysis. *Physica A: Statistical Mechanics and its Applications*, *492*, 1032-1044.

153. Park, J. Y., Saint Ville, A., Schwinghamer, T., & Melgar-Quiñonez, H. (2019). Heterogeneous factors predict food insecurity among the elderly in developed countries: insights from a multi-national analysis of 48 countries. Food Security, 11(3), 541-552.

154. Pérez-Escamilla, R., Gubert, M. B., Rogers, B., & Hromi-Fiedler, A. (2017). Food security measurement and governance: Assessment of the usefulness of diverse food insecurity indicators for policy makers. Global Food Security, 14, 96-104.

155. Pesaran, M. H., & Shin, Y. (1998). An autoregressive distributed-lag modelling approach to cointegration analysis. Econometric Society Monographs, 31, 371-413.

156. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of applied econometrics, 16(3), 289-326.

157. Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.

158. Piot-Lepetit, I., & M'Barek, R. (2011). Methods to analyse agricultural commodity price volatility. In Methods to analyse agricultural commodity price volatility (pp. 1-11). Springer, New York, NY.

159. Popp, J., Oláh, J., Kiss, A., & Lakner, Z. (2019). Food Security Perspectives in Sub-Saharan Africa. Amfiteatru Economic, 21(51), 361-676.

160. Popp, J., Balogh, P., Oláh, J., Kot, S., Harangi Rákos, M., & Lengyel, P. (2018). Social network analysis of scientific articles published by food policy. *Sustainability*, *10*(3), 577.

161. Prabhakar, A. C., Kaur, G., & Erokhin, V. (Eds.). (2020). *Regional Trade and Development Strategies in the Era of Globalization*. IGI Global. https://doi.org/10.4018/978-1-7998-1730-7

162. Pritchard A. Statistical bibliography or bibliometrics. Journal of documentation. 1969 Dec 25;25(4):348-9.

163. Pu, M., & Zhong, Y. (2020). Rising concerns over agricultural production as COVID-19 spreads: Lessons from China. *Global food security*, *26*, 100409.

164. Rabobank. (2011). Rethinking the food and agribusiness supply chain; impact of agricultural price volatility on sourcing strategies.

165. Rafiq S., Salim R., & Bloch H. (2009). Impact of crude oil price volatility on economic activities: An empirical investigation in the Thai economy. Resources Policy, 34(3), 121–132.

166. R Core Team, R. (2013). R: A language and environment for statistical computing.

167. Rezitis AN, Stavropoulos KS. Modeling pork supply response and price volatility: the case of Greece. Journal of Agricultural and Applied Economics. 2009 Apr;41(1):1-8.

168. Rezitis, A.N. (2012). Modelling and decomposing price volatility in the Greek meat market. International Journal of Computational Economics and Econometrics, 2(3-4), 1757-1189.

169. Rezitis, A. N., & Tsionas, M. (2019). Modeling asymmetric price transmission in the European food market. Economic Modelling, 76, 216-230.

170. Ritchie, H., & Roser, M. (2018). Urbanization. *Our world in data*. *Published online at OurWorldInData.org.* Retrieved from: 'https://ourworldindata.org/urbanization' [Online Resource]

171. Roman, M., Górecka, A., & Domagała, J. (2020). The linkages between crude oil and food prices. *Energies*, *13*(24), 6545.

172. Ronto, R., Wu, J. H., & Singh, G. M. (2018). The global nutrition transition: trends, disease burdens and policy interventions. *Public health nutrition*, *21*(12), 2267-2270.

173. Roodman, D. (2009). A note on the theme of too many instruments. *Oxford Bulletin of Economics and statistics*, *71*(1), 135-158.

174. Sam, A. S., Abbas, A., Padmaja, S. S., Sathyan, A. R., Vijayan, D., Kächele, H., ... & Müller, K. (2021). Flood vulnerability and food security in eastern India: A threat to the achievement of the Sustainable Development Goals. *International Journal of Disaster Risk Reduction*, *66*, 102589

175. Sarkodie SA, Owusu PA. Bibliometric analysis of water–energy–food nexus: Sustainability assessment of renewable energy. Current Opinion in Environmental Science & Health. 2020 Feb 1;13:29-34.

176. Satterthwaite, D., McGranahan, G., & Tacoli, C. (2010). Urbanization and its implications for food and farming. *Philosophical transactions of the royal society B: biological sciences*, *365*(1554), 2809-2820
177. Schnepf, R. D., & Resources, Science, and Industry Division. (2005, December). Price determination in agricultural commodity markets: a primer. Congressional Research Service, Library of Congress.
178. Sen A. Poverty and famines: an essay on entitlement and deprivation. Oxford university press; 1982.
179. Serra, T., & Goodwin, B. K. (2003). Price transmission and asymmetric adjustment in the Spanish dairy sector. Applied economics, 35(18), 1889-1899.
180. Serra, T. (2011). Food scare crises and price volatility: The case of the BSE in Spain. Food policy, 36(2), 179-185.
181. Shiferaw, Y. A. (2018, December). Analysis of interdependence between agricultural and energy commodity price dynamics with Bayesian multivariate DCC GARCH approach. In *Annual Proceedings of the South African Statistical Association Conference* (Vol. 2018, No. Congress 1, pp. 41-48). South African Statistical Association (SASA).
182. Shiferaw, Y. A. (2019). Time-varying correlation between agricultural commodity and energy price dynamics with Bayesian multivariate DCC-GARCH models. *Physica A: Statistical Mechanics and Its Applications*, *526*, 120807.
183. Shin Y, Yu B, Greenwood-Nimmo M (2011) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. Mimeo.
184. Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In Festschrift in honor of Peter Schmidt (pp. 281-314). Springer, New York, NY.
185. Silvennoinen, A., & Terasvirta, T. (2008). Multivariate garch models. SSE (No. 669). EFI Working paper series in economics and finance.
186. Skaf, L., Buonocore, E., Dumontet, S., Capone, R., & Franzese, P. P. (2020). Applying network analysis to explore the global scientific literature on food security.Ecological Informatics,56, 101062
187. Smith, M. E. (1990). *World food security: The effect of US farm policy* (No. 600). US Department of Agriculture, Economic Research Service.

188. Smith, V. H., & Glauber, J. W. (2020). Trade, policy, and food security. *Agricultural Economics*, *51*(1), 159-171.

189. Sulser, T. B., Beach, R. H., Wiebe, K. D., Dunston, S., & Fukagawa, N. K. (2021). Disability-adjusted life years due to chronic and hidden hunger under food system evolution with climate change and adaptation to 2050. The American Journal of Clinical Nutrition, 114(2), 550-563.

190. Sun, T. T., Su, C. W., Mirza, N., & Umar, M. (2021). How does trade policy uncertainty affect agriculture commodity prices?. Pacific-Basin Finance Journal, 66, 101514.

191. Sweileh WM. Bibliometric analysis of peer-reviewed literature on climate change and human health with an emphasis on infectious diseases. Globalization and health. 2020 Dec;16:1-7.

192. Taya, S. (2012). Stochastic model development and price volatility analysis (OECD food, agricultural and fisheries working papers No. 57). OECD publishing.

193. Taghizadeh-Hesary, F., Rasoulinezhad, E., & Yoshino, N. (2019). Energy and food security: Linkages through price volatility. *Energy Policy*, *128*, 796-806

194. Tanaka, T., & Hosoe, N. (2011). Does agricultural trade liberalization increase risks of supply-side uncertainty?: Effects of productivity shocks and export restrictions on welfare and food supply in Japan. Food policy, 36(3), 368-377.

195. Tripathi (M). (2018). Occurrence of author keywords and keywords plus in social sciences and humanities research: A preliminary study. COLLNET Journal of Scientometrics and Information Management. 12(2): 215-232.

196. Tyner, W. E. (2010). The integration of energy and agricultural markets. Agricultural Economics, 41, 193-201

197. Uchezuba, I. D., Jooste, A., & Willemse, J. (2010). Measuring asymmetric price and volatility spillover in the South African broiler market (No. 308-2016-5023, pp. 1-26).

198. Ulezko, A., & Pashina, L. (2014). Market of Food Resources in the Food Security System of the Far East. *Voronezh State Agricultural University: Voronezh, Russia*.

199. United Nations. (2017). World Population Prospects: the 2017 Revision. *Department of Economic and Social Affairs, Population Division, United Nations, New York*.

200. United NationsThe sustainable development goals. UN. 2018.

201. United Nations. (2019). World Population Prospects: the 2019 Revision. *Department of Economic and Social Affairs, Population Division, United Nations, New York*
202. United Nations. Sustainable Development Goals. Available online: https://www.un.org/sustainabledevelopment/ (accessed on 07 December 2021).
203. Van Eck NJ, Waltman L. Visualizing bibliometric networks. InMeasuring scholarly impact 2014 (pp. 285-320). Springer, Cham.
204. Van Ittersum, M.K., Van Bussel, L.G., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., Claessens, L., De Groot, H., Wiebe, K., Mason-D'Croz, D. and Yang, H. (2016). Can sub-Saharan Africa feed itself?. Proceedings of the National Academy of Sciences, 113(52), 14964-14969.
205. Verkerk, R. (2019). EAT-Lancet–is there such a thing as 'one-size-fits-all'sustainability. J. Holist. Healthc, 16, 15.
206. Vollset, S. E., Goren, E., Yuan, C. W., Cao, J., Smith, A. E., Hsiao, T., ... & Murray, C. J. (2020). Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. The Lancet, 396(10258), 1285-1306.
207. Vochozka, M., Rowland, Z., Suler, P., & Marousek, J. (2020). THE INFLUENCE OF THE INTERNATIONAL PRICE OF OIL ON THE VALUE OF THE EUR/USD EXCHANGE RATE. Journal of Competitiveness, (2)
208. Vos, R., & Bellù, L. G. (2019). Global trends and challenges to food and agriculture into the 21st century. *Sustainable food and agriculture*, 11-30
209. Wahyuni H, Vanany I, Ciptomulyono U. Food safety and halal food in the supply chain: Review and bibliometric analysis. Journal of industrial engineering and management. 2019 Jul 25;12(2):373-91.
210. Wang, Y., Wu, C., & Yang, L. (2014). Oil price shocks and agricultural commodity prices. *Energy Economics*, *44*, 22-35.
211. Wardhani, F. S., & Haryanto, T. (2020). Foreign Direct Investment in Agriculture and Food Security in Developing Countries. Contemporary Economics, *14*(4), 510-521.
212. Weldesenbet, T. (2013). Asymmetric price transmission in the Slovak liquid milk market. Agricultural Economics, 59(11), 512-524.

213. Wolfe, W. S., & Frongillo, E. A. (2001). Building household food-security measurement tools from the ground up. *Food and Nutrition Bulletin*, *22*(1), 5-12.
214. Wood, S. A., Smith, M. R., Fanzo, J., Remans, R., & DeFries, R. S. (2018). Trade and the equitability of global food nutrient distribution. *Nature Sustainability*, *1*(1), 34-3
215. Workie, E., Mackolil, J., Nyika, J., & Ramadas, S. (2020). Deciphering the impact of COVID-19 pandemic on food security, agriculture, and livelihoods: A review of the evidence from developing countries. *Current Research in Environmental Sustainability*, 100014.
216. World Health Organization (WHO). (2020 a). The Global health observatory. Global health estimates: leading causes of death. Available from: https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death;WHO methods and data sources for global burden of disease estimates 2000–2019. Available from: https://cdn.who.int/media/docs/default-source/gho-documents/global-health-estimates/ghe2019_daly-methods.pdf?sfvrsn=31b25009_7
217. World Health Organization. (2020b). The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets (Vol. 2020). Food & Agriculture Org.
218. World Bank. Agriculture and Food, World Bank Group, Washington DC, USA. 2020. Available online: https://www.worldbank.org/en/topic/agriculture/overview (accessed on 30 September 2020).
219. World Health Organization. (2017). Double-duty actions for nutrition: policy brief (No. WHO/NMH/NHD/17.2). World Health Organization.
220. Wossen, T., Berger, T., Haile, M. G., & Troost, C. (2018). Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa. Agricultural systems,163, 7-15.
221. Zivot, E., & Wang, J. (2006). Efficient Method of Moments. Modeling Financial Time Series with S-PLUS®, 923-990

Acknowledgement

My PhD career has taught me different lessons which made me a better person in different aspects.

As I move towards its completion, I would like to say big thank to my supervisors, ***Prof. Dr. Maria Fekete-Farkas****, and* ***Prof.Dr. Zoltan Lakner*** *for providing guidance and feedback throughout this journey. From the bottom of my heart, express my sincere gratitude to them. They are always present to give me the right advice and guide whenever I need.*

Prof. Maria is not only my supervisor, but also, she is my stepmom since I arrived in Hungary.

I have to thank ***my parents****,* ***my husband****,* ***my brother****, and* ***my sister*** *for their love and support throughout my life. Thank you for giving me the main and ultimate meaning of life. I would like to dedicate this research to them without whom it was almost impossible for me to complete my PhD career.*

Last but not the least, I wish to extend my special thanks to ***my colleagues*** *and* ***university coordinators*** *who have been a great source in conducting my research.*