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Review

Factors Affecting Crop Prices in the Context of Climate Change—A Review

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Abstract: Food security has become a concerning issue because of global climate change and increasing populations. Agricultural production is considered one of the key factors that affects food security. The changing climate has negatively affected agricultural production, which accelerates food shortages. The supply of agricultural commodities can be heavily influenced by climate change, which leads to climate-induced agricultural productivity shocks impacting crop prices. This paper systematically reviews publications over the past ten years on the factors affecting the prices of a wide range of crops across the globe. This review presents a critical view of these factors in the context of climate change. This paper applies a systematic approach by determining the appropriate works to review with defined inclusion criteria. From this, groups of key factors affecting crop prices are found. This study finds evidence that crop prices have been both positively and negatively affected by a range of factors such as elements of climate change, biofuel, and economic factors. However, the general trend is towards increasing crop prices due to deceasing yields over time. This is the first systematic literature review which provides a comprehensive view of the factors affecting the prices of crops across the world under climate change.

Keywords: crop price determinants; economic drivers; impacts of climate change; yield change

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1. Introduction

Climate change and food security are currently two of the greatest challenges to the entire world and are highly interlinked [1]. Food security is defined as a state in which "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life." by the United Nations' Committee in World Food Security [2]. Clapp et al. [3] discussed two food security approaches: (i) the traditional approach with four main dimensions (food availability, food access, utilisation, and stability) and (ii) a recent six-dimensional approach with two additional dimensions (agency and sustainability). Climate change may have an impact on food availability, stability, and sustainability via its impact on the productivity of agricultural systems.

Global agriculture has recently been impacted greatly by climate change [4–8]. Its impact is changing how production can be sustainably planned for in the long term. Crop production is sensitive to climate change, which has been accelerating food shortage, a notable challenge to the world [9]. Climate change has an impact on agriculture worldwide and has caused yield losses [10–13] and undermined food security [11]. Given increasing population sizes and climate change, analysing the stability of food security is crucial to identify priority interventions and policy initiatives to adapt agriculture to climate change [11,14–16]. Di Falco et al. [17] found that the adaptation of farming to climate change increased food productivity.

However, there exists a limited number of studies on climate-induced changes in crop yields, which then affects crop price. Existing studies have found significant effects of climate change on crop yield [4,8]. Adverse climate conditions are mainly caused a decline in agricultural output [10–13]. Recent studies have also found climate change-induced agricultural productivity changes and the influence of climate change on fluctuations of crop prices [5,18,19]. The higher crop prices caused by climate change will increase input prices for food production and then affect food prices and food security. Rising food prices decrease the purchasing power of fixed incomes and result in a lower quantity of food being consumed, which may lead to food insecurity, particularly for low-income populations in developing and underdeveloped countries.

Recent studies using climate models and optimisation approaches for crop planning have been instrumental in laying the foundations of appropriate optimisation models and frameworks to help find solutions that maximise revenue, a product of crop price and yield, and minimise water use [20–22]. Crop price is a key input in these optimisation models, but agronomic models to forecast crop prices including multiple variables related to market forces and climate elements are few. The economic and agronomic effects of the previous and proposed models are extremely important to understand fully, but they have not incorporated the climate elements affecting crop prices via yield changes or market factors affecting prices. New agronomic models integrated in optimisation models are expected to guide and inform crop planning and adaptation responses in the context of climate change. A forecasting model for crop prices which includes adequate factors affecting crop prices in the context of climate change will make the optimisation models more robust and applicable to informed decision making in crop planning.

Crop prices are changing in response to changing climatic conditions and other factors. Thus, crop price forecasting plays a crucial role in predicting crop revenue and farmers' profits, which then affects long-term crop planning. The highly accurate prediction of agricultural crop price may support the cropping decisions made by agribusinesses at all scales, from family-run farms to large commercial ventures.

In light of the importance of food security and the economic impact of climate change on crop prices, there is a need for a comprehensive study reviewing the factors affecting crop prices under climate change. Therefore, this systematic review aims to highlight the determinants of crop prices and determine whether these factors are potentially affected by changes in climatic conditions.

2. Methodology

For this review, a systematic approach was used. Firstly, the field of enquiry was defined by a set of terms describing and constraining its extent. These then became the "search terms" for a database query. A comprehensive database was selected to give a reasonable assurance that no contributions of significance had been overlooked. Among the available sources such as Scopus, Education Resources Information Center, and Bielefeld Academic Search Engine, Google Scholar currently produces the broadest range of relevant results. According to Tsai [23], the Google Scholar database covers approximately 200 million indexed articles and was thus chosen for the purposes of this review. The set of search keywords that define the factors affecting crop prices with a particular emphasis on climate change are as follows:

- "factors influencing crop price" OR "factors affecting crop price" OR "determinants of crop price" OR "factors influencing crop prices" OR "factors affecting crop prices" OR "determinants of crop prices".
- "impacts of climate change on crop prices" OR "effects of climate change on crop prices" OR "impact of climate change on crop prices" OR "effect of climate change on crop prices".
- "driver of crop price OR "drivers of crop prices" OR "driver of crop prices" OR "drivers of crop price".

The key terms "driver of crop price" OR "drivers of crop prices" OR "driver of crop prices" OR "drivers of crop price" are used to find the economic drivers of crop prices or economic theories on the determinants of prices. Three searches using these sets of key terms on 20 May 2023 returned a total of 29 works including journal articles, book chapters, papers from conference proceedings, and three review articles. After the screening process, there were four irrelevant and four duplicate papers which were removed from the review. Of the three review papers included in this systematic review, one was published in 2014 and presented findings of new key factors affecting crop prices in recent years, in comparison to those found up to 2013.

Figure 1 shows the number of publications which examined each group of factors affecting crop prices. The effects of climate change on crop prices have been attracting more researchers' attentions. Out of the 21 publications in this review, 11 works directly investigated the impact of climate elements on crop prices and three works indirectly mentioned the effects of climate change on water supply, impacting water scarcity and irrigation—a supply side factor affecting agricultural commodity prices. So, two thirds of the works in this review considered the fact that climate change impacted crop prices.

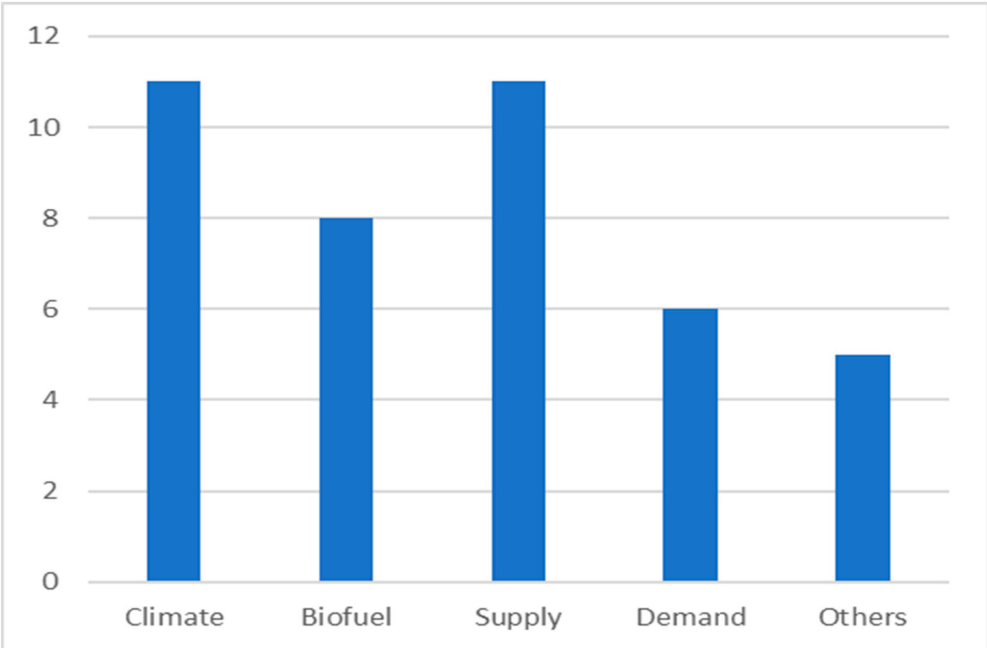

Figure 1. Number of studies on each group of determinants of crop price.

Figure 2 illustrates the locations of the studies included in our review. They investigated the changes of crop prices in countries all over the world but there seem to be more specific case studies for the USA (24%) and India (14%). Additionally, among five studies at the global level, two focussed on the USA and one on India. According to the US Department of Agriculture [24], U.S. agricultural exports were approximately USD 196 billion in 2022 and the leading US exports are soybeans, corn, and wheat. India is one of the largest producers of rice, wheat, cotton, sugarcane, fruit, vegetables, and tea [25].

This paper is structured as follows. Section 2 discusses our methodology. Sections 3–7 provide reviews for the papers and organise these into identified themes. These parts discuss the patterns and trends that are present within this body of literature to determine how prices and yields are changing over time, and the economic effects of this. The sections review five groups of factors affecting crop prices, which are climate change, biofuel, demand-side factors, supply side factors, and other factors. These sections also discuss the influencing factors that have not been included in the reviewed papers. Finally, Section 8 provides the conclusions as well as the future research directions that come from this paper.

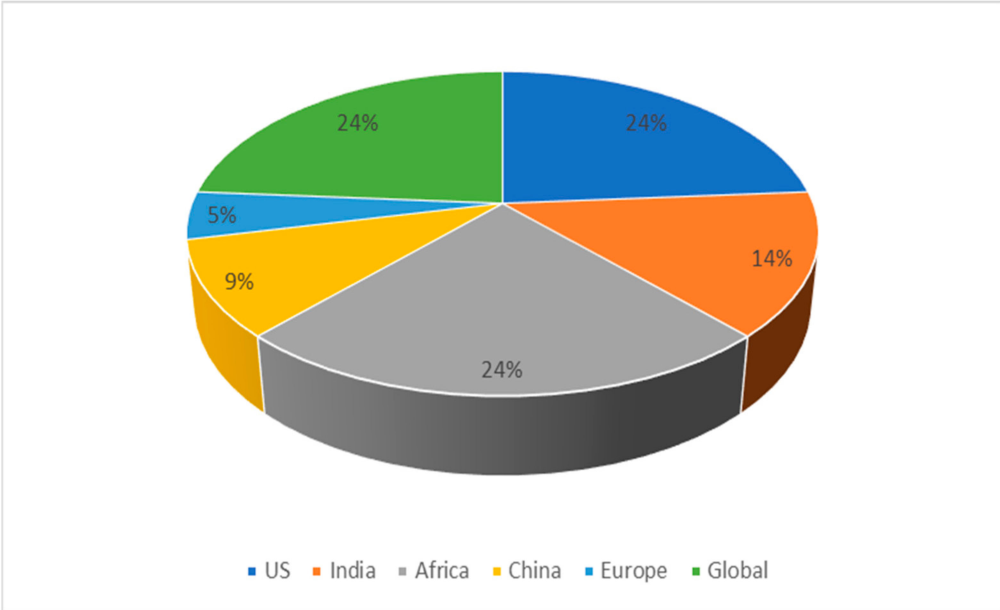

Figure 2. Locations of studies.

3. Climate Change and Its Effects on Crop Yields and Prices

As defined by Beck [26], climate change includes changes in the expected patterns of climatic parameters in a region or globally. The Earth has witnessed climatic change related to precipitation, temperature, relative humidity, and carbon dioxide (CO_2) over the last few decades [15,27–29]. The effects of climate change on the agricultural sector, which is dependent on climatic conditions [28], have been studied in recent research. The effects of climate conditions on crop prices often result from the impacts of the climate on crop yields. A large part of the literature has focussed on the effects of climate change mainly because of changes in rainfall, drought, temperature, and CO_2, which in turn impact crop quantity and price. Many studies [30–39] have discussed these effects on the prices of a broad range of crops including maize, rice, wheat, soy, cassava, cowpea and (mung) beans, tomatoes, sorghum, cotton, hay, oats, barley, oilseeds and sugar, yam, millet, and groundnut, but there is also a focus on key crops for food such as maize/corn, rice, and wheat. They have investigated the changes of crop prices in the USA, China, India, Nigeria, Madagascar, and Morocco, but there seem to be more case studies for the USA and India.

These studies used a variety of methods to analyse the effects of climate change on prices, notably a non-linear partial equilibrium trade model [36]. The Autoregressive Integrated Moving Average (ARIMA), Seasonal Autoregressive Integrated Moving Average (SARIMA), and Prophet [33] were applied to a pooled model which is a reduced empirical form drawing from a seasonal competitive storage model [31]; a linear panel model with panel-corrected standard errors (PCSE) [32]; the computable general equilibrium (CGE) model from the Global Trade Analysis Project (GTAP), called GTAP-BIO-W [34]; a generalised method of moments (GMM) approach [37]; General Circulation Models (GCMs) and an Environmental Policy-Integrated Climate model (EPIC); Regional Environment and Agriculture Programming Model (REAP) [39]; Captive Simulation (CAPSiM) model [30]; and three-stage least square regression [35]. They discussed the changes of distinct types of prices from weekly and monthly to yearly ones. Generally, they found upward trends in crop prices in the context of climate change.

3.1. Temperature

Buschmann et al. [36] analysed the effects of heat stress or waves in ten world regions (sub-Saharan Africa, Centrally Planned Asia, Europe, the Former Soviet Union, Latin America, the Middle East and North Africa, North America, Pacific member states of the

Organisation for Economic Co-operation and Development, Pacific Asia, and South Asia) with a 30-year baseline period (1971–2000) and a 30-year future period (2071–2100) under the A1B emissions scenario (a balance between fossil and non-fossil fuel-based technologies). Maize and rice faced dramatic price increases while soy had a lower increase which was still quite considerable. Wheat had a slight decrease or significant increase in price depending on the scenarios of heat stress or wave. For maize and rice, the 75th percentile of results increased nine and eleven times, respectively, in the main scenario, while in the other scenario it was two and five times, respectively. For soy, the increase was lower in both scenarios but still 2.6 and 1.7 times, respectively. Wheat price volatility slightly decreased in the main scenario, but it increased significantly in the other scenarios, more than double for the 75th percentile of results.

Aye and Haruna [35] applied three-stage least square regression to examine the effects of rainfall and temperature on the prices of maize, rice, sorghum, yam, millet, groundnut, beans, and cassava in Benue State, Nigeria. They found that climate change had a significant impact on the productivity of millet, sorghum, cassava, and groundnut, while it had significant impact only on the price of maize. A remarkable change in temperature in 1997 caused a rapid decline in the productivity of maize, which led to a price increase of about 40% between 1996 and 1998.

3.2. Rainfall and Drought

Rainfall and drought have affected crop and food prices across the globe [30–35,38]. Most of the studies revealed an increasing trend in prices.

Drought conditions significantly increased (monthly) prices of maize and rice during the growing period in India [31]. Neudert et al. [32] studied rainfall and its impact on the weekly prices of maize, cassava, cowpea, and mung beans in the Mahafaly Plateau region, south-western Madagascar. They found that the prices increased due to rainfall events in the lean season and a strong demand for seeds during these periods. Jain et al. [33] investigated climate change and its effects on the prices of tomatoes and maize in Karnataka state in India and highlighted that drought conditions significantly increase (monthly) food prices during the growing period. Changes in rain also had a small negative impact on the productivity of cassava, but a positive effect on groundnuts. The change in cassava yield indirectly affected its prices [35].

3.3. Carbon Dioxide

Several publications in this systematic review identified the effects of carbon dioxide on crop quality and then crop price. Hertel et al. [40] studied the effects of CO_2 on crop prices and found that the beneficial effects of elevated CO_2 on crop growth were absent; yields were lower and crop prices higher. These results emphasise the importance of better understanding the impact of climate change on crop yields. Marshall et al. [39] acknowledged that changes in carbon dioxide concentration were expected to affect crop yields through their impact on the efficiency of (i) the photosynthetic pathway (radiation use efficiency), and (ii) crop respiration, or transpiration. They revealed that increased CO_2 could positively affect crop yields by stimulating plant photosynthesis and improving the water use efficiency of crops, which was likely to promote dryland and irrigated yields. The study documented that the carbon dioxide fertilisation effect was relatively greater for crops with the C3 photosynthetic pathway (wheat, barley, soybeans, and alfalfa hay) than those with the C4 photosynthetic pathway (corn and sorghum).

3.4. Other Elements of Climate

Rude and An [37] examined the effects of the Southern Oscillation Index (SOI), which measures global weather patterns caused by shifts in Pacific Ocean atmospheric pressures. They considered monthly prices of maize, wheat, rice, and soy in the USA and documented that weather events (SOI) could affect wheat and rice crop production, and increase their price volatility, but not maize production or its price volatility.

3.5. Joint Impacts of the Elements of Climate Change

Cui et al. [30] investigated the impacts of climate change on the annual prices of 21 agricultural commodities (rice, wheat, maize, soybean, oilseeds, sugar, and cotton and other crops) under the worst (RCP 8.5) and best (RCP 2.6) climate change scenarios in China. They found evidence of significant disparity among different crops due to the uncertainty of climate change impacts on their production and then on their prices, with the largest uncertainty seen for wheat. For example, the wheat yield would decline significantly in 2050, by 5.79% under RCP2.6 and 9.39% under RCP 8.5, while the rice yield would drop moderately, by 1.51% under RCP 2.6 and 2.62% under RCP 8.5 in 2050. The prices of crops adversely affected by climate change would rise by 2030 and 2050. Wheat, with the highest yield loss, would have the highest level of price increase (6.83% under RCP 2.6 and 17.53% under RCP 8.5), whereas the price of rice would have a moderate increase of approximately 2.66% under RCP 2.6 and 5.29% under RCP 8.5. Cotton would have a drop in price resulting from the positive effect of climate change on its yield under RCP 2.6 (0.27%) and RCP 8.5 (1.37%).

Marshall et al. [39] explored the impacts of temperature and precipitation on the annual prices of corn, sorghum, soybeans, cotton, rice, hay, wheat, oats, and barley in the USA and acknowledged that changes in temperature and precipitation resulted in significant increases in a production-weighted price index calculated across the ten field crop commodities. In 2080, the price impacts of climate change could range from a decline in indexed price levels of 7% for the CGCM_A1B scenario to a predicted increase of 41% under the MIROC_A2 scenario. The prices of corn, sorghum, soybeans, cotton, and rice increased relative to the reference price due to yield drop across regions. However, hay and wheat prices decreased due to higher yields under the climate change projections. Jain et al. [33] analysed weather parameters such as average humidity, total rainfall, and daily average temperature to forecast the prices of tomatoes and maize in India. Bhardwaj et al. [41] included climate conditions (namely rainfall, temperature, surface net solar radiation, and humidity) in their crop price forecasting model.

Taheripour et al. [34] used a computable general equilibrium (CGE) model from the Global Trade Analysis Project (GTAP), called GTAP-BIO-W, to investigate water supply and different water scarcity scenarios and their effects on the annual prices of rainfed and irrigated crops. This included 12 categories in Morocco. The study revealed that:

- Without the impacts of climate change, a 25% reduction in water supply caused the producer and consumer price indexes to grow by 10.3% and 5.7%, respectively.
- With the impacts of climate change, the growths were 15.9% and 8.7%, respectively, as climate change would penalise rainfed crops, increasing the price impacts sharply.
- Water scarcity and yield changes jointly increased all crop (producer) prices but at different levels, for instance, by 11.5%, 13.6%, 20.1%, and 15.9% for wheat, coarse grains, oilseeds, and vegetables and fruits, respectively.

3.6. Previous Review Articles in the Area

Chen and Hsu [38] reviewed the effects of climate change on maize, rice, soy, and wheat in China in different studies by Xiong et al. [42,43] and Wei et al. [44]. Xiong et al. [42] estimated the impacts of climate change on the yields of China's three major crops to range from +6.2% to −13.6% for rice, from +18.4% to −22.8% for maize, and from +25.1% to −20.4% for wheat by 2050. Wheat yields will both increase the most under relatively advantageous climate change scenarios, which account for CO_2 fertilisation—the phenomena that the increase in carbon dioxide in the atmosphere increases the rate of photosynthesis in plants—and decrease for the least under disadvantageous climate change scenarios, which do not account for CO_2 fertilisation. Additionally, rain-fed crops will be much more vulnerable to the adverse effects of climate change than irrigated crops will be. The effects of climate change on yield are different in different Chinese regions. Higher temperatures increased agricultural output in the China's northeast region but decreased crop yield in the North China Plain. The predicted increasing precipitation will decrease average yields in southeastern China while helping increase yield in the northwest region.

Xiong et al. [43] and Wei et al. [44] found that CO_2 fertilisation would largely determine future production outcomes. Nelson et al. [45] noted that world maize prices will increase most among cereals by 61% from 2010 to 2050 under a scenario of perfect mitigation, and from 93% to 123% across a range of climate change scenarios. It is expected that rice will increase from 34% (perfect mitigation scenario) to between 53% and 56% under climate change scenarios by 2050. Wheat price increases were similar across the different perfect mitigation (31%) and climate change scenarios (from 47% to 64%). Soybean price increases under the climate change scenarios (50–61%) are triple that for the scenario of perfect mitigation (19%).

3.7. Discussion about Climate Change and Its Effects on Crop Prices

The reviewed studies used various methods to analyse the effects of climate change on crop prices, which range from weekly and monthly to yearly prices in a wide time-frame. The literature investigated the prices of a variety of crops but focussed more on the important crops providing main food staples (maize, rice, and wheat) grown all over the world, especially in the USA and India. Changes in temperature and rainfall were the key elements of climate change that had strong effects on crop yield and price. The changes in the prices of crops were varied among crops and in different locations, but the general trend was an increase in prices due to a decrease in quantity under the effects of climate change. Additionally, the joint effects of the elements of the climate were evident from a moderate to strong level. However, changes in carbon dioxide concentration and their effects on the quality of crops, which may impact crop prices, and the contributions of climate change to the changes in crop prices, were not discussed in the reviewed articles.

4. The Effects of Biofuel on Crop Prices

Crops are not only used for food consumption, but increasingly as a partial substitute for conventional fossil fuels. As seen in this section, this increases prices and decreases food availability.

4.1. Biofuel Production and Its Direct Effect on Crop Prices

Many of the reviewed publications presented the short- to long-term effects of biofuel on crop prices through the direct effects of biofuel production or the indirect effect of biofuel policies [34,37,46–51].

Condon et al. [47] examined US corn crops and documented that (i) a billion-gallon expansion in ethanol production increased corn prices on average, across studies, by 2–3% and that (ii) the short-term impacts on corn prices per billion gallons of corn ethanol production in response to unexpected shocks were higher. Taheripour et al. [34,46] analysed the medium- and long-term price impacts of the biofuel production of coarse grains (corn), soybeans, rapeseed, and other oilseeds in the USA in the period of 2004–2016 and revealed that the medium- to long-term price impacts of biofuel production were not large. Real crop prices increased between 1.1% and 5.5% in 2004–11 while only one tenth of the price increases was associated with the Renewable Fuel Standard (RFS) [46]. A 20.8% increase in the supply of corn ethanol would cause a 5.3% increase in the price of this commodity [46].

Rude and An [37] investigated US ethanol production and found evidence of a positive relationship between ethanol production and the price volatility of maize and wheat. Zilberman et al. [51] reviewed the relationship between food and fuel prices and the impact of the introduction of a biofuel on food commodity prices. They documented that biofuel prices do not seem to affect food commodity prices, but that the introduction of biofuel did. Additionally, biofuels had not been the most dominant contributor to the recent price inflation of food, and different biofuels had different impacts.

Globally, during 2001 to 2011, biofuels contributed about 30% and 4% to the increase in the price of corn and soybean, respectively [48]. For example, corn prices would have been 9% lower without the increase in biofuel production, this study found.

Table 1 was compiled from the contributions of biofuels to the increase in crop prices in 2007 compared to 2001, determined in a study by Hochman et al. [48] (pp. 111–112). The contribution to the increase in corn (20%) was lower than that of income shock (30%) but higher than other shocks (16% and 11%). The contribution to the price change in soybean (7%) was less significant than that of income, exchange rate, and energy shocks (28%, 11%, and 10%, respectively). It is assumed that the prices of rice and wheat were not affected by biofuels mainly because rice and wheat were not used for biofuels in any significant quantities.

Table 1. Contributions of different factors to crop price changes.

Factor	Contribution to the Increase in Crop Price in 2007 Compared to 2001 (%)			
	Corn	**Soybean**	**Rice**	**Wheat**
Biofuel	20	7	NA	NA
Income shock	30	28	35	35
Exchange rate shock	16	11	20	20
Energy shock	11	10	9	9

Hochman et al. [49] also documented the contributions of biofuel shock to price increases using a counterfactual scenario (with inventory) in 2007, which were about 10% for corn and 3% for soybean.

4.2. Biofuel Policies and Their Indirect Effect on Crop Prices

Taheripour et al. [34,46] investigated biofuel policies and their findings include that (i) with no mandate on ethanol, US farmers produced fewer coarse grains (basically corn) by 1.2% and slightly more of other crops; (ii) with no mandates on both ethanol and biodiesel, the outputs of coarse grains, soybeans, rapeseed, and other oilseeds dropped by 1.4%, 1.6%, 12.4%, and 4.3%, respectively, while outputs of all other crop categories grew slightly, and (iii) biofuel production encouraged farmers to shift to produce more coarse grains (corn) and oilseeds.

Nuñez and Trujillo-Barrera [50] studied ethanol mandates—the Renewable Fuel Standard (RFS)—and emphasised the positive relationship between US ethanol mandates and world crop prices, specifically corn, soybeans, and wheat. One explanation for the observed price fluctuation in corn is that the consumption of corn for biofuel became significant around 2006, when the US federal government began implementing biofuel mandates [48]. The study suggested that mandates were the main cause for the recent increase in biofuel production, and the mandate of 2006 not only impacts current demand but also affects future supply due to its effect on inventories. Zilberman et al. [51] found that EU biodiesel mandates have a strong effect on agricultural commodity prices in their review article.

4.3. Discussion about the Effects of Biofuels on Crop Prices

Biofuel has been an increasingly concerning issue that affects crop prices. Biofuel policies had indirect effects on crop prices via changes in biofuel production. Biofuel production had both long- and short-term effects on crop prices, but the short-term impacts were greater. A positive relationship between biofuel production and the prices of the crops used to produce biofuel was found in our selected articles. It was evident that biofuel production increased the diversion from food production. The contribution of biofuels to the increases in crop prices was less significant than that of income shock, but might be greater or smaller than those of exchange rate and energy shocks depending on each type of crop. However, there appears to be no causal link between climate change and biofuel production. Climate change could put negative pressure on biofuel use in a zero-carbon economy and that link should be analysed in this scenario.

5. The Effects of Supply Side Factors on Crop Prices

Similarly to any commodity market, crop prices are affected by market-driven factors including demand-side and supply side factors. This section discusses the supply driven determinants of crop prices.

5.1. Historical Price and Supply

Jain et al. [33] included the market arrival quantity of crops in their crop price prediction model for tomatoes and maize in India. Rude and An [37] found that a lower stock-to-use ratio, which estimates final stocks and total use, was associated with tighter markets and increased price variability for wheat, rice, and maize, but not soybean. This relationship also holds for corn, rapeseed, rice, soybean, and wheat [48]. Hertel et al. [40] highlighted that a smaller global supply response leads to a rise in crop prices. Hochman et al. [48] incorporated an inventory demand function into the market-clearing condition and found that the prices of corn, soybean, rapeseed, rice, and wheat in 2017 would have been 38–52% lower than the observed prices in that year if inventory demand was not considered. They also emphasised that the impact of the inventory on prices increased as the level of inventory decreased, and more elastic inventory demand would lead to less fluctuation in prices. Historical price information was incorporated in the model forecasting crop prices by Jain et al. [33] and Bhardwaj et al. [41].

5.2. Energy and Oil Prices

The variability of crude oil prices was one of the crucial factors affecting crop price variability in the reviewed studies, with the rise of biofuels enhancing the linkage between oil and agricultural production. Increased crude oil price volatility is likely to increase crop price volatility, as crude oil prices affect crop production inputs and biofuel markets [37]. Hochman et al. [48] documented the contribution of energy shocks to the increase in the prices of corn (11%), soybean (10%), and rice (7%) at the global level in 2007 relative to 2001. However, their contribution was less important than that of income and exchange rate shocks (see Table 1). Hochman et al. [49] also found positive effects of energy shocks on the prices of corn, soybean, rice, and wheat. Crude oil price volatility positively affected the volatility of grain (wheat, rice, maize, and soybean) and oilseed prices in the USA [37].

5.3. Water Supply and Irrigation

Climate change, especially precipitation, can affect water supply/scarcity and thus irrigation demand. Taheripour et al. [34] highlighted that water scarcity was one source of the increase in crop prices and the negative relationship between water supply and crop prices, which is caused by the positive relationship between water supply and yield. It was evident that a 25% decrease in water supply was associated with a 10.3% and 5.7% increase in the producer and consumer price indexes, respectively, when the impacts of climate change on crop prices were not taken into consideration.

Marshall et al. [39] found that the marginal impacts of irrigation shortages are insignificant compared with the impacts of changes in temperature and precipitation on crop prices. The effects of surface water irrigation shortages attributable to climate change are smaller than the direct biophysical impacts of climate change on yield on the national level. Anderson et al. [52] indicated that the vines in Oliver-Manera et al. [53] and olives in Ahumada-Orellana et al. [54] showed great sensitivity to deficit irrigation in their yields, in their review paper.

5.4. Total Factor Productivity (TFP) and Technology

Total factor productivity, which is the ratio of an output to the inputs such as labour and capital, can capture the effects of innovation, technology, and other factors on productivity. Hertel et al. [40] illustrated that the strong historical growth of TFP was associated with the falling trend of crop prices in the 1961–2006 period and predicted that future prices would depend critically on future TFP growth. This could be explained by the close relationship between productivity and agricultural output, which has a negative relationship with crop/food price. The improvement of technology is a key driver of changes in productivity. Hertel et al. [55] applied a quantitative, partial equilibrium trade model, augmented by a temporal relationship between research and development (R&D) investments, knowledge capital, and agricultural productivity, and revealed that direct R&D investments were the dominant drivers that lowered food prices in sub-Saharan Africa in the historical period 1991–2011. They also forecast the important contribution of technological change to the reduction in consumers' crop prices in sub-Saharan Africa in the period 2006–2050.

5.5. Discussion about the Effects of Supply Side Factors on Crop Prices

There was evidence that a series of supply side factors, notably energy/oil prices, water supply, technology, and stock-to-use ratio, affected crop prices in different directions. All the above-mentioned factors, except technology, had negative effects on crop prices. However, the impacts varied in different crops and depended on each factor. Notably, the contributions of energy shocks to the increase in crop prices were smaller than those of demand-side factors (income and exchange rate shocks). It was found that the works did not discuss water prices or irrigation costs and fertiliser costs, which are crucial input prices for agricultural production. Agricultural crops are seasonal and climate change can have an indirect impact on seasonal water supply, which is associated with changes in yield. As a result, climate change affects the supply side factors of crop prices and indirectly changes agricultural commodity prices. Bhardwaj et al. (2023) [41] also considered soil type and location as key determinants of crop prices when forecasting crop prices.

6. The Effects of Demand-Side Factors

Demand-related factors are also crucial determinants of crop prices. These factors include population, income, inflation, and exchange rate.

6.1. Population

As documented in economic theories, population is one of the determinants of food/crop demand which has a positive relationship with crop price. Hertel et al. [55] documented that global food prices were expected to continue their long-term decline (falling by another 39% from 2006 levels) with an average annual growth of 2.6% in 1961–2006 and 0.8% in 2006–2050 due to the anticipated slowdown in demand growth contributed to by global population stabilisation. According to Hertel et al. [40], population, not income, was the main driver of the historical growth in crop demand which led to the rise in crop prices.

6.2. Income

While population has been the most important demand-side driver of crop prices historically, income growth could be another crucial vehicle and even surpass population, as the population growth rate could be lower in the coming decades [40,55]. Hochman et al. [48] found that income shock contributed 30%, 35%, 30%, and 14% to the price increases in 2007 relative to 2001 of corn, wheat, soybean, and rice, respectively, and emphasised that income shock was the main contributor to increases in wheat prices. This study considered income to be a more significant factor in the increase in crop prices than biofuels, exchange rate, and energy shocks (see Table 1). Income shock contributed to 15% to 20% of price increases from the counterfactual scenario (with inventory) in 2007 for soybean, corn, rice, and wheat [49].

6.3. Inflation

Neudert et al. [32] acknowledged the positive relationship between the Consumer Price Index (CPI) and crop prices, except that of cassava. Rude and An [34] also included an inflation rate in the model used in their study to calculate the real interest rate by deflating the US Treasury's 3-month bill using the US CPI inflation rate.

6.4. Exchange Rate

The exchange rate is likely to affect crop prices by changing the demands for crops. Exchange rate shocks contributed 16%, 20%, 11%, and 13% to increases in the prices of corn, wheat, soybean, and rice in 2007 compared to 2001, respectively, but that contribution was less important than that of income and exchange rate shocks [48]. Hochman et al. [48] showed that exchange rate shock contributed to 5% to 11% of price increases using a counterfactual scenario (with inventory) in 2007 for soybean, rice, corn, and wheat, of which wheat was most affected. The study by Rude and An [37] showed that the effects of the exchange rate on crop prices were statistically significant in all cases except for wheat, but that the exchange rate had a small contribution to changes in crop prices. They found the sign of the coefficient was negative for rice and maize and explained that a weaker dollar made grain purchases more affordable and contributed to a price surge.

6.5. Discussion about the Effects of Demand-Side Factors on Crop Prices

From the demand-side, population, income, inflation, and exchange rate were documented to have impacts on crop prices at different magnitudes. Population was still a strong driving force for crop prices, with a less significant impact due to a lower population growth rate, while income had a growing impact. The contribution of income to increases in crop prices was found to be more crucial than that of biofuels, exchange rates, and energy shocks. Changes in exchange rates had effects on foreign demand and then agricultural commodity prices. A lower exchange rate or lower value of the domestic currency would promote foreign demand for crops and then increase crop prices. For the current global economy and integration, international influences such as global commodity prices have played a key role in local food prices by affecting both demand and supply, but world crop prices were not considered in our selected publications.

7. Other Factors Affecting Crop Prices

The works included in this systematic review also discussed the other factors that had an impact on crop prices. These factors consist of international trade and trade restrictions, market participants, and interest rates.

7.1. International Trade and Trade Barriers

Rude and An [37] concluded that export restrictions including export taxes and quantitative restrictions (2011–2016) increased the price volatility of wheat and rice but not of maize and soybean. The contribution of export restrictions to price volatility was the same as key macroeconomic variables. However, important trade distortions and other factors related to trade shocks or policies were not included in the model in this research. Another study by Hertel et al. [55] highlighted the crucial role of international trade in lowering food prices and ensuring food security for the African population. Hochman et al. [48] also suggested that trade policy might be responsible for contributing to increases in the global prices of corn, rapeseed, rice, soybean, and wheat.

7.2. Market Participants

One of the key findings of Neudert et al. [32] was a significant relationship between crop prices and market centrality, except in the case of maize, and that the presence of national and international retailers might boost prices in a central market. Sindi [56] highlighted that wealthier farmers were more likely to market their produce through traders and were able to negotiate higher prices due to the quantity they produce, when studying the pigeon pea and groundnut markets.

7.3. Interest Rate

The US Treasury Bill rate had a positive and statistically significant relationship to all four commodities, maize, wheat, rice, and soy, in the USA, according to Rude and An [37]. The relationship was explained by the fact that as the interest rate was considered an opportunity cost for holding stocks and a macroeconomic tool, the crop price may respond to interest rate volatility.

7.4. Discussion about the Effects of Other Factors on Crop Prices

Other factors affecting crop prices include international trade and trade restrictions, market participants, and interest rates. Import flows, which had a positive relationship with trade barriers, had a negative impact on all crop prices in our selected publications. The interest rate of the Treasury Bill in the USA also had a positive effect on crop prices. Participating in a larger market with more buyers and a greater marketing capability was likely to be associated with higher crop prices. However, global agricultural commodity prices were not included in the analysis of the reviewed studies.

8. Summary of Key Findings

The focus of this article is on how climate change affects the factors that are determinants of crop prices. This is the first systematic literature review which provides a comprehensive view on the factors affecting the prices of crops across the world under climate change. Most of the works included in this systematic review are journal articles. These articles are considered to be high quality, as 70% of them are from Quantile 1 journals and 30% from Quantile 2 journals (according to Scimago [57]). There were more case studies for the USA and India, leading producers/exporters of soybeans, corn, wheat, and rice, which are key food crops. A wide range of methods was used to analyse the effects of climate change, and other factors, on crop prices.

According to the publications reviewed, agricultural commodity prices were mainly affected by groups of factors including climate elements, biofuel, and market-based factors related to demand and supply sides. These groups of factors are shown in Table 2. The effects of climate change on crop prices were a key focus of these studies.

Table 2. Summary of the determinants of crop price potentially affected by climate change.

Determinants of Crop Prices		Potentially Affected by Climate Change
Climate elements	Temperature	YES
	Rainfall	YES
	Drought	YES
	Carbon dioxide	YES
	Southern Oscillation Index	YES
Biofuels	Biofuel production	INDIRECTLY
	Biofuel policies	INDIRECTLY
Supply	Historical price	YES
	Supply	YES
	Energy and oil prices	NO
	Water supply	YES
	Irrigation	YES
	Total factor productivity and technology	NO
Demand	Population	NO
	Income	NO
	Inflation	NO
	Exchange rate	NO
Others	International trade and trade barriers	NO
	Market participants	NO
	Interest rates	NO

As illustrated in Table 2, all climate elements and most supply side factors are potentially affected by climate change, while demand-side factors (population, income, inflation, and exchange rate) and other factors related to trade, the market structure, and interest rates are unlikely to be affected by changes in the climate. The findings show that climate change must be thoroughly considered in relation to changes in crop prices and incorporated into models forecasting agricultural commodity prices (see Figure 3).

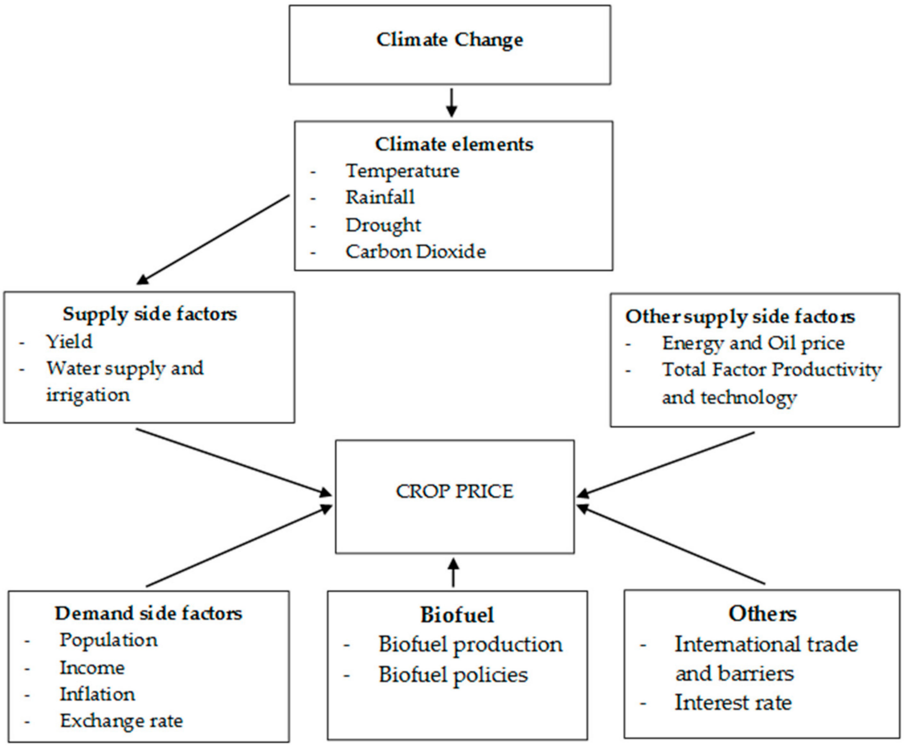

Figure 3. Factors affecting crop prices in the context of climate change.

The supply of agricultural commodities can be heavily influenced by climate change, and these studies reveal that output and climate-induced agricultural productivity shocks have impacted crop prices. Generally, the prices of a broad range of crops increased due to the decrease in quantity under the effects of climate change, especially changes in temperature and rainfall. For example, temperature had a strong effect on the price of maize. Water scarcity had significant effects on the prices of rainfed and irrigated crops. Additionally, there is evidence of a carbon dioxide fertilisation effect and significant joint effects of the elements of the climate on crop yields. The different climate-induced effects were evident in different crop prices.

Biofuel policy and production had both long-term and short-term effects on crop prices, but the latter effect was stronger. A positive relationship between biofuel production and the prices of crops used to produce biofuel was found in the selected articles. However, no causal relationship between climate change and biofuel production was shown.

Market-driven factors including both demand- and supply related elements were found to be determinants of crop prices. Regarding supply side factors, energy/oil prices, water supply, and technology were found to be key determinants of crop prices. While the negative relationships between inputs such as energy/oil prices, the water supply, and the stock-to-use ratio were evident, technology had a positive impact on the crop prices. On the demand-side, socio-demographic and socio-economic factors (such as income and population), exchange rate, and inflation were likely to become important drivers of crop prices. However, income was found to have a greater contribution to the increases in crop prices than biofuels and other economic determinants, including energy prices and exchange rate shocks. Income also has a more important effect on crop prices than population due to the stabilisation of population growth. Factors related to international trade such as trade policies and barriers played a key role in local food prices.

The findings of the empirical studies included in this review suggest that the impacts of climate change and other factors on agricultural commodity prices were different for different locations, crops, and lengths of the study period. Notably, this systematic review reveals that climate elements including temperature, precipitation, and carbon dioxide concentration were drivers of crop yields, which impacted crop prices. Climate change also affected the water supply, which was associated with changes in yield that determined the changes in agricultural commodity prices.

9. Conclusions

It must be acknowledged that a systematic review can miss a small number of relevant articles if they are not captured by the keywords used in the search. However, if carefully constructed (such as in this article) they generally gather highly relevant articles, and it can be confidently assumed that the keywords present the key concepts and trends. On this basis, the following conclusions are drawn. Climate change may affect 55% of the total specific factors considered in this review that determine crop prices. In general, the prices of a variety of crops rose due to decreases in their yields under the effects of climate change, notably changes in temperature and rainfall. One of the key findings of this systematic review is that climate elements (temperature, precipitation, and carbon dioxide concentration) were the determinants of crop yields which led to changes in crop prices. Additionally, demand- and supply side factors were found to be drivers of crop prices, but demand factors were largely unaffected by climate change.

However, the contributions of climate change or each climate element to changes in crop prices were not examined. Additionally, many factors such as water price or irrigation cost, fertiliser cost, and global crop prices were not incorporated in the key influences on crop prices. Changes in carbon dioxide concentration and their effects on the quality of crops, which may impact crop prices, were also not included in the reviewed articles. It is noted that the three review articles by Zilberman et al. [51], Chen and Hsu [38], and Anderson et al. [52] did not consider the economic factors affecting crop prices.

Crop price forecasting should take into account the effects of climate change on crop prices. Government policies should respond to the link between climate change and food security. Given the importance of food security and the potential impact of climate change, there exist too few articles about this issue. It is deserving of more attention and research.

It is evident that agricultural commodity price forecasting models which incorporate changing climate conditions and market-based factors to improve their forecasting accuracy are needed. Future research may focus on how economic factors influence decision making at various levels in response to changing climate conditions. These responses should ensure yield quantity and quality and avoid costly adaptation measures. The factors in changing climates that impact crop yield and yield quality should be thoroughly analysed. From all these considerations, quantifiable changes in crop yield and quality can be incorporated into the predicted changes in crop prices. A project covering research on different crops grown across the globe may improve the generalisation of these findings.

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