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Review

COVID-19 Pandemic, Climate Change, and Conflicts on Agriculture: A Trio of Challenges to Global Food Security

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Abstract: Global food security is a worldwide concern. Food insecurity is a significant threat to poverty and hunger eradication goals. Agriculture is one of the focal points in the global policy agenda. Increases in agricultural productivity through the incorporation of technological advances or expansion of cultivable land areas have been pushed forward. However, production growth has slowed in many parts of the world due to various endemic challenges, such as decreased investment in agricultural research, lack of infrastructure in rural areas, and increasing water scarcity. Climate change adversities in agriculture and food security are increasing. Recently, the COVID-19 pandemic has severely affected global food supply chains. Economic and social instability from the pandemic contribute to long-term disturbances. Additionally, conflicts such as war directly affect agriculture by environmental degradation, violence, and breaches of national and international trade agreements. A combination of food security and climate change challenges along with increased conflicts among nations and post-COVID-19 social and economic issues bring bigger and more serious threats to agriculture. This necessitates the strategic design of policies through multifaceted fields regarding food systems. In this comprehensive review, we explore how these three challenging factors, COVID-19, climate change, and conflicts, are interrelated, and how they affect food security. We discuss the impact of these issues on the agricultural sector, plus possible ways of preventing or overcoming such adverse effects.

Keywords: agriculture; pandemic; climate change; conflict; global; food security; zero hunger; policies

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1. Introduction

Food security is commonly understood as the availability of food in the household or the community, or on national and global levels [1]. The World Food Summit of 1996 stated that "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life" [2]. Food insecurity has many negative consequences on the health, nutritional status, and behavior of both children [3] and adults [4,5]. One of the joint reports from the FAO, IFAD, UNICEF, WFP, and the WHO reported that 702–828 million people faced acute food insecurity in 2021, almost 150 million more than in the pre-pandemic period [6]. In the context of the US, a report from USDA Economic Research Service (ERS) showed that around 14.3% of American households are food insecure, and 5.6% of these can be classed as highly food insecure households [7]. In the current scenario of increasing population growth and the increasing average life span of individuals, producing more food to ensure food security is a necessary condition in order to combat both poverty and hunger. Given the inextricable tie of food to agriculture, an increase in productivity and growth of the agriculture sector as well as sustainable expansion at the global level through cutting-edge advancements is essential in this context [8]. However, to achieve food security, we should consider its broader, multi-faceted dimensions, bringing the depth and breadth of scope of multiple disciplines to this issue as well as the challenges surrounding it.

Agriculture is the major source for food and many livelihoods, and it is one of the major components that can enable the mitigation of both poverty and food insecurity issues. However, agriculture alone cannot fill the gaps related to food insecurity, but, rather, needs simultaneous institutional and industrial development [9]. Still, without addressing ways to increase agricultural production efficiency and outcome, food security cannot be achieved at a global scale. Improvements in agriculture can help farmers enhance or maximize outcomes at the same level of resources by increasing productivity [9]. Achieving sustainable global food security requires the combined integrated efforts on physical, social, economic, political, health, nutritional, and environmental levels as well as adequate policies and trade balance, both nationally and globally [10]. Therefore, addressing global food security with a sustainable approach is a multi-faceted issue. Among many factors, there are a few major issues around the world that need to be central concerns of nations. In the current context, these issues include the interface of pandemic issues and post-pandemic situations, climate change, and related conflicts that directly affect food and agricultural systems. Without a consensus on these issues, purposeful policy actions and their effective implementation seem daunting, and make the challenge to end hunger seem unachievable.

This comprehensive review focuses on the challenges in sustainable agriculture and food security, the interrelationship between these factors, and potential resolutions and opportunities underlying the current influence of climate change, post-pandemic situations, and conflicts.

2. Methodology

Figure 1 shows the outline of the methodological steps we followed in our comprehensive literature review. The five main steps include the literature identification or the sources/resources lookup, their selection and screening, the development of a conceptual framework, discussion of the problem and its resolution, and the derivation of a synopsis and inferences. We conducted a thorough review of related research through various sources such as Pubmed, Scopus, Web of Science, and Google Scholar. We considered several studies, systematic reviews, and meta-analyses published after the year 2000. We specified a set of important keywords and combinations of them, including "food security", "climate change", "COVID-19", "pandemic", "conflict", "agriculture", "sustainability", etc. in order to identify the breadth and the depth of relevant studies. The search allowed us to gather literature on global food security, climate change, and food and agricultural systems in the past two decades, to screen the relevant studies, and to build connections to the recent food and agricultural studies as well as the reports related to the COVID-19 pandemic and various conflicts in the world. Building a conceptual framework, we assess and elaborate how the trio of the challenges of climate change, the pandemic, and conflicts have interacted to affect the global agricultural systems and food security. We then present a discussion and elaboration of the challenges and potential resolutions based on our synopsis of the literature and the inferences we have drawn from it. We restricted our review to the studies published in the English language, and we took into consideration the relatedness of the studies and the reliability of the sources.

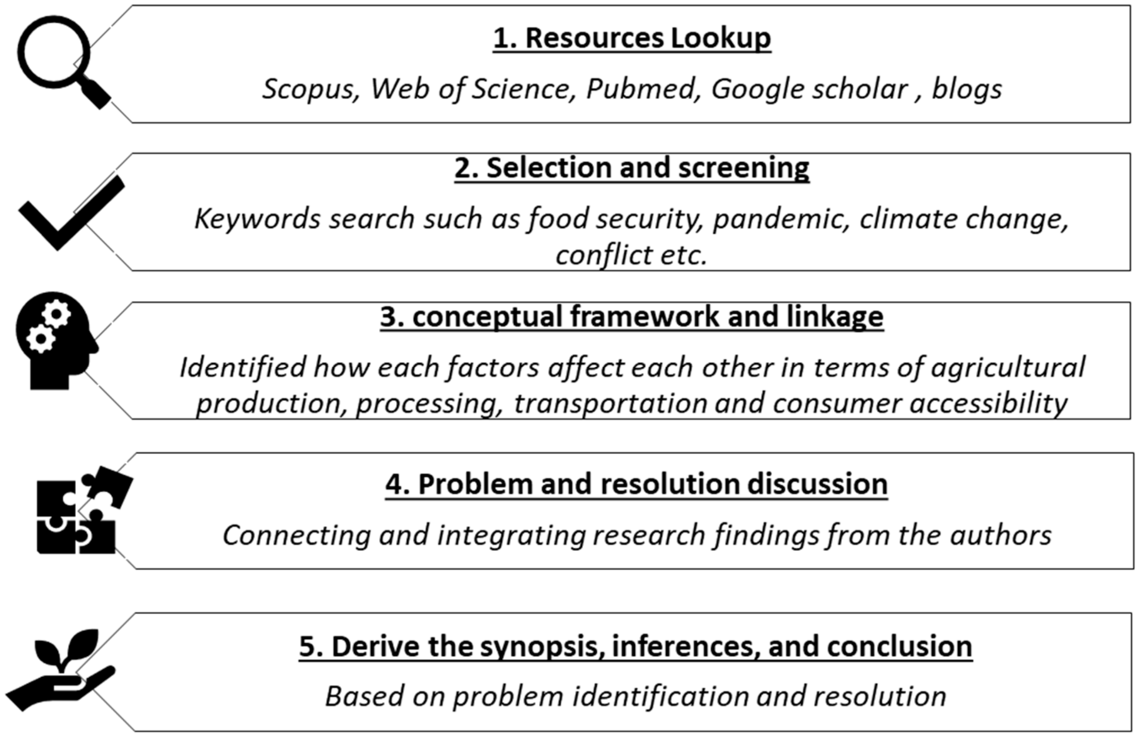

Figure 1. Outline of the methodological framework followed in this study for comprehensive review.

3. Conceptual Framework of Interrelation between Pandemics, Climate Change, and Conflicts

Usually, pandemics, because of the risk of negative health consequences and even death, create restrictions in the work system, limiting the operation of agriculture, industries, trade, and business, inevitably causing a plateau (or decline) in economic growth. Threats from pandemics are multidimensional and interconnected. From the social perspective, to a certain extent, the COVID-19 pandemic has changed our behavior, social attitudes, and lifestyles, such as working from home, fewer face-to-face interactions, etc. [11]. It has also slowed the responses of different countries that were acting against environmental issues, threatening our ability to respond to climate change in time, including delays in international negotiations for biological diversity, weakened climate policies, interruption of environment-related scientific research, the higher use of plastic-made consumables like gloves and masks as well as plexiglass and other disposable plastic items, and increasing litter resulting from such disposables in the big cities [12]. It has been reported that greenhouse gas (GHGs) emissions and air pollutants have been lower during the pandemic due to less demand for global energy use, such as flying, driving, etc. However, these results are temporary with short-term outcomes that will not have a significant impact on the overall reduction in GHGs. Instead, more negative and long-term impacts on climate change are expected because of negative secondary effects and their interactions [13], and, moreover, saving energy is negatively counterbalanced by the behavioral and systemic responses to the preventative measures during the pandemic, such as depression and other mental health problems. Moreover, the reduction of GHG emissions and pollutants during the pandemic was counterbalanced by the "rebound effect" [11], where emissions and pollutants increase during the rebuilding period when life starts to return to normal in order to make up for lost time and save the economy. These anthropogenic activities could well exacerbate climate change in the long run. Although pandemics do not have a decisive effect on existing conflicts or the evolution of new ones, they can have some transformative effects on international politics due to changing social and economic dynamics [14]. This effect could worsen the pre-existing conflicts among nations or spark the emergence of new ones.

Climate change is one of the most challenging environmental issues of the twenty-first century. The US National Climate Assessment in 2018 noted that the climate on earth is changing more rapidly than at any point in modern history because of human-related activities [15]. Climate change generally includes shifts in weather patterns, changes in long-term patterns or average weather parameters, and the occurrence of unexpected extreme environmental events that are primarily due to greenhouse gas emissions [16]. Interactions between these changes and COVID-19 have also been studied, and it has been found that high temperatures combined with high humidity might suppress COVID-19, causing virus transmission and seasonal patterns alternating between the northern and southern hemisphere, which have, indeed, shown differences in COVID-19 transmission [17]. Due to the impact of climate change on various weather parameters such as precipitation, temperature, and humidity, which are directly or indirectly proportional to virus transmission, it could complicate the pandemic and post-pandemic situation by creating an environment for the future spread of such diseases. Furthermore, climate change can reshape the geographic range in which certain animals live, especially in the tropical regions, which harbor many types of infectious diseases, and this adds adversity to conditions that are already often precarious [18].

Some studies have reported that climate change could drive the risk of violent conflicts, although this finding is highly contested among researchers. It has been estimated that about 3–20% of conflicts over the past century are somehow associated with climate change. Mach et al. (2019) suggested that an increase in global temperature by approximately 2 °C is estimated to increase conflict-related risks by 13%. The reduced opportunities produced by responses to a pandemic can increase violence (in other words, people whose livelihoods are affected may find violence to be an alternative), and the decrease in agricultural productivity, the increased price of commodities, and uneven socioeconomic development are just some of the other mechanisms by which climate change could increase the risk of conflict [19]. Indeed, warming caused by climate change is one of the factors influencing the risk of civil war in countries in Africa due to the socio-economic effects of disrupted climate patterns [20].

Conflict can simply be defined as a disagreement due to actual or perceived opposition of needs, values, and interests [21]. International conflict can be referred to as the conflicts between nations around the world or between people and organizations of different countries [22]. Conflicts among nations, especially violent conflicts and outright wars, undermine systems and devastate the economy, social balance, developmental plans, and policies. Imbalances in these contexts could impact climate change. For instance, the current conflict between Russia and Ukraine could change mitigation policies as territorial and political decisions override climate ones, and they could also detrimentally affect the proper execution of existing climate policies due to the limited supply of global energy transition given that both of these countries are big manufacturers of the supplies needed for green technologies, which include solar panels, electric vehicle batteries, and wind turbines [23]. Moreover, conflicts might have negative effects on the pandemic situation, too. Social and economic instability that result from conflict between nations provide shocks that oblige people to migrate from one place or country to another. This migration further complicates pandemic mitigation efforts due to the logistics and pressures of migrating populations, which can only yield a variety of complications and difficulties. Conflicts also create distress to people as they cause death and long-term injuries in families and communities, and they can also cause resource crises due to draining resources such as food and medicine. Due to these reasons, people are forced to migrate [24], and due to larger contact among people or crowds from the flow of people during migration, this could increase the transmission of disease, adversely affecting recovery efforts during pandemic, and detrimentally impacting the health of migrants [25]. Figure 2 provides a summary and outline of the linkage and interrelation between a pandemic, climate change, and conflicts.

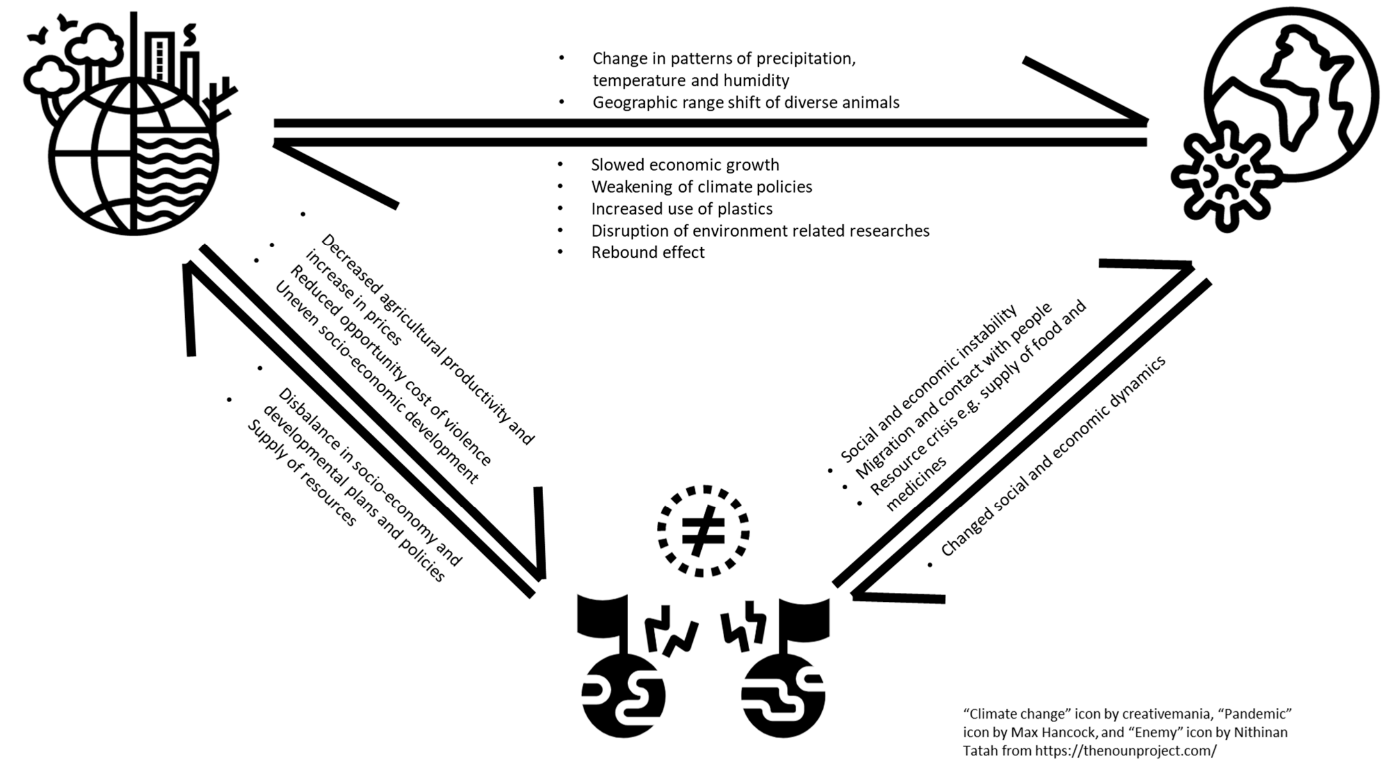

Figure 2. Conceptual framework of interrelation between climate change, pandemics, and conflicts.

4. Trio of Challenges

4.1. Climate Change: Challenge to Agriculture, Crops, and Food Supply

The concept of climate change includes both global warming caused by greenhouse gas emissions due to human activities as well as large-scale shifts in weather patterns resulting from global warming [26]. In recent decades, human activity has had unprecedented effects on the Earth's climate system and triggered massive global change. A large part of the warming is attributed to greenhouse gas emissions, of which carbon dioxide and methane account for more than 90% [27]. These emissions are mainly caused by fossil fuel burning (coal, oil, and natural gas), along with agriculture, livestock production, deforestation, and manufacturing. The resulting warmer temperatures cause evaporation to increase, resulting in more intense storms and extreme weather events. The WHO has stated that climate change is one of the greatest threats to global health as it might threaten people with food insecurity, flooding, infectious diseases, extreme heat, economic disbalance, and displacement. Agriculture contributes to 15% of all global emissions, primarily methane and nitrous oxide, with a significant contribution from the livestock production and management sector. Livestock emissions contribute about 8–10.8%, but life cycle analysis has shown that it can amount to over 18% of greenhouse gas emissions [28]. Enteric fermentation, liming, extensive use of fossil fuels, and fertilizer production for organic farming are the main sources of greenhouse gas emissions from the livestock industry.

With the increase in global population, modern agriculture is going to face the challenge of meeting food supply considering worldwide sustainability goals. There is an urgent requirement to take measures to mitigate the negative effects of climate change and aid sustainable development goals (SDGs), specifically in the agricultural sector worldwide, with a specific focus on ensuring food security [29]. Changing climate could jeopardize agricultural production by making it increasingly vulnerable to yield losses and economic instability, as well as increasing pest infestations and invasive weeds [30–32]. The agricultural sector is extremely vulnerable to climate change because of its size and sensitivity to weather conditions. Climate change can severely impact crop production, as it depends on the combination of various environmental factors, such as precipitation, relative humidity and temperature, pollinating agents, and weather events [26]. Mostly, the effects of climate change are severe in tropical regions, since tropical crops are more susceptible to high-temperature stress during high temperatures rise. Increased temperatures alter climate patterns in complex ways. Temperature fluctuations, daytime and night-time high and low temperatures, duration and intensity of extreme cold or hot weather, and timing will all have different effects on crops, mostly during reproductive, grain-filling, or maturing stages. High temperatures during pollen development or during seed or grain production, in combination with drought, significantly reduce crop yields in cereal crops like maize [30]. In some other nutrient-dense crops, late frosts after early spring warming can reduce crop production, decreasing the chilling period (for example grapes, apples, and winter grain crops require a chilling period). Lobell et al. [33] found that a 1 °C increase in temperature can decrease yields of the major food and cash crops by 5% to 10%. It has been projected that climate change is likely to reduce wheat, corn, and rice yields in China by 18.26 ± 12.13%, 45.10 ± 11.55%, and 36.25 ± 10.75% by 2100, respectively [34]. This not only applies to field crops, as a study in Mexico also shows that coffee production may not be suitable for growers in the coming years if the temperature continues to rise—a 34% reduction in current production has been projected [35]. Furthermore, the plant–water relations are also likely to be impacted by extreme changes in these parameters [36].

Plant responses to each type of climatic alteration are species specific as they have specific response thresholds [37]. For instance, Fodor et al. [30] illustrated that photosynthesis in C3 plants is more sensitive to higher CO_2 levels than in C4 crops. A sensitivity analysis using CERES (Crop Estimation through Resources and Environmental Synthesis) also showed that wheat and rice yields in Northwest India will potentially increase by 28% and 15%, respectively, when levels of CO_2 are doubled (Malhi, G.S. et al., 2021). However, studies also suggest that the increased thermal stress due to the higher temperatures associated with high CO_2 overshadows the positive impact of yield gains. In the case of acute water shortage and thermal stress, the yield of rice and wheat is projected to decline even with raised CO_2 in the future [38].

Cropping systems, weather, and pests could have unpredictable interactions due to climate change. For example, the changing climate or weather pattern of an area can increase the susceptibility of crops to various pests, diseases, and weeds in that area. Climate change can enhance pest populations and their migration, negatively impacting agricultural yields, since pest populations depend largely on environmental factors such as humidity and temperature. In one of the studies [31], it is highlighted that the major ramification of climate change and globalization is due to unpredictability and uncertainty of interactions between the weather, cropping systems, and pests. Indeed, the yield losses due to insect pests account for more than 40% worldwide [39]. This will continue to increase as more aggressive pests and diseases are likely to invade and threaten food security on a global scale. Different research relates how a milder climate shift toward the colder poles will improve the potential of crop production [40,41], and, in contrast, hotter and drier conditions in semi-arid areas of the world will have limited agricultural production [42]. Studies like Ma et al. (2023) [43] also predict that global warming of 2 °C or more is likely to change the structure of agricultural production, which may result in a continued decline of grain planting areas and the continued growth of cash crop planting areas in ecologically vulnerable regions, making grain security more difficult.

As climatic change intensifies, it also invites new pest threats to that region, and agricultural production is increasingly vulnerable to yield losses and economic instability from these growing pest populations. In addition to geographical distribution and the growth rate of insect pest populations, climate change also affects insect phenology by increasing the number of generations. The earlier onset and increased duration of the growing season due to changing climate has favored insect species to have more generations, leading to higher population levels at the end of the season. This also increases the risk of migrant pest invasion and pest outbreak. For example, the three common insect species of Africa, *Tuta absoluta*, *Ceratitis cosyra*, and *Bactrocera invadens*, have increased their habitat suitability across the mainland and continent, particularly in regions close to its most suitable habitat [44]. Similarly, a study on potato tuber moth (*Phthorimaea operculella*) revealed that the insect pest's damage potential would be greater in warmer regions with its prevalence, and is expected to spread to temperate areas with increased damage potential [45]. Pest infestations of several crops are predicted to worsen with climate change, but will vary from one region to another, and will also depend on pests' adaptability to climate change. Climate change also affects the development and survival of pathogens. Increasing temperatures are projected to limit the growth of certain pathogens, such as *Puccinia striiformis*, while increasing atmospheric CO_2 concentrations could provide favorable growing conditions for *Fusarium pseudograminearum* [46]. These studies suggest that climate change has contributed to the occurrence of recent pest and disease outbreaks. This indicates that with the projected increase in global temperatures, the frequency of pest outbreaks in agricultural fields may also increase.

Equally important as the climate continues to change is that it can both directly and indirectly impact the growth, development, and reproduction of weeds, making them more competitive, and potentially leading to increased weed infestations. Additionally, changes in land use and agricultural practices driven by climate change can indirectly create more favorable conditions for weed growth, further exacerbating the issue. This can have negative consequences for agricultural productivity, biodiversity, and ecosystem functioning. For instance, weeds compete with the main crops for water and nutrients, as they show higher nutrient requirements than crop plants [32], and they negatively impact crop yields. Weeds that are C3 are more sensitive to increased CO_2 concentrations as they can increase their leaf area and biomass with this. While C3 weeds pose a major threat to C4 plants, C4 weeds in C3 crops become less invasive [47]. Changes in climate patterns such as sudden shifts in weather influences the dynamics of crop–weed competition and can impact the mode of action of herbicides [48]. Climate change is projected to have a favorable influence on the weeds of wheat crops, which are vital to world food security [49]. The loss of crop yields and agricultural production due to climate change can increase food prices, and it can have detrimental effects on agricultural welfare—a study estimates around 0.3% annual loss of Global GDP by 2100, for example [50]. An increase of 1 °C in mean surface temperature can cause a yield loss by 10% to 25% in three major cereal grains: rice, maize, and wheat [51]. This could have massive worldwide economic repercussions, especially given that developing countries are projected to face severe negative consequences of climate change [52]. In India, agriculture is going to be severely affected by changing climate, for example, as the temperature is predicted to rise between 2.33 °C and 4.78 °C along with a doubling of CO_2 concentration [53]. In Africa, one of the most vulnerable areas to climate change, the yield of major crops in drought-prone areas is expected to decline by more than 50% by 2050 and 90% by 2100 [54].

4.2. COVID-19 Food Crises: A Unique and Complex Crisis

History shows that epidemics and pandemics have often resulted in food shortages and even famine, primarily due to disrupted food production and distribution chains. Food production and distribution are disrupted due to the loss of humans and the labor directly associated with the food systems. The Justinian plague led to the decimation of 25% of Constantinople's population, for example, and this caused the extinction of farming settlements and food shortages [55]. Likewise, the bubonic plague killed 25–30% of the population in Europe. This disease unevenly affected and killed the families of millers, bakers, and other food producers, disrupting food production and processing [56].

The COVID-19 pandemic has compounded the adverse effects on the highly vulnerable populations that are already grappling with poverty and hunger. The pandemic has been devastating for the global system on multiple levels. Though COVID-19 is a human health issue, its implications are diverse and profound. An estimated 113 million people worldwide were already living in food-insecure conditions before the COVID-19 crisis [57]. The World Food Program (WFP) predicted that an additional 130 million people could be pushed into hunger because of the pandemic [58]. Unlike food crises in the past, the COVID-19 food crisis is different and complex as it has many interconnecting dynamics with food systems (Figure 3). More specifically, the pandemic perturbed every component of the food system, from production to consumption. First, there were major disruptions in the supply chains because of multiple factors, such as lockdowns and the illness of food system workers, to name just two. Second, the slowdown of economic activities triggered by the pandemic resulted in greater unemployment and had a severe impact on food accessibility and affordability. Third, multiple complex factors caused uneven food prices at a local and global level, which led to increased hunger in the developing world [59]. Examples of food supply chain disruption and its impact are listed below:

a. The airline industry is a critical component of the global supply chain. However, the airline industry was short-staffed with approximately 4.8 million people as a result of SARS-CoV-2 virus containment measures. This reduced the air cargo capacity by 7.7% [60].
b. According to a study conducted across 143 countries, it was reported that inflation rose by 7% in 2021. This increase in inflation was attributed to supply chain disruptions triggered by the COVID-19 pandemic [61].

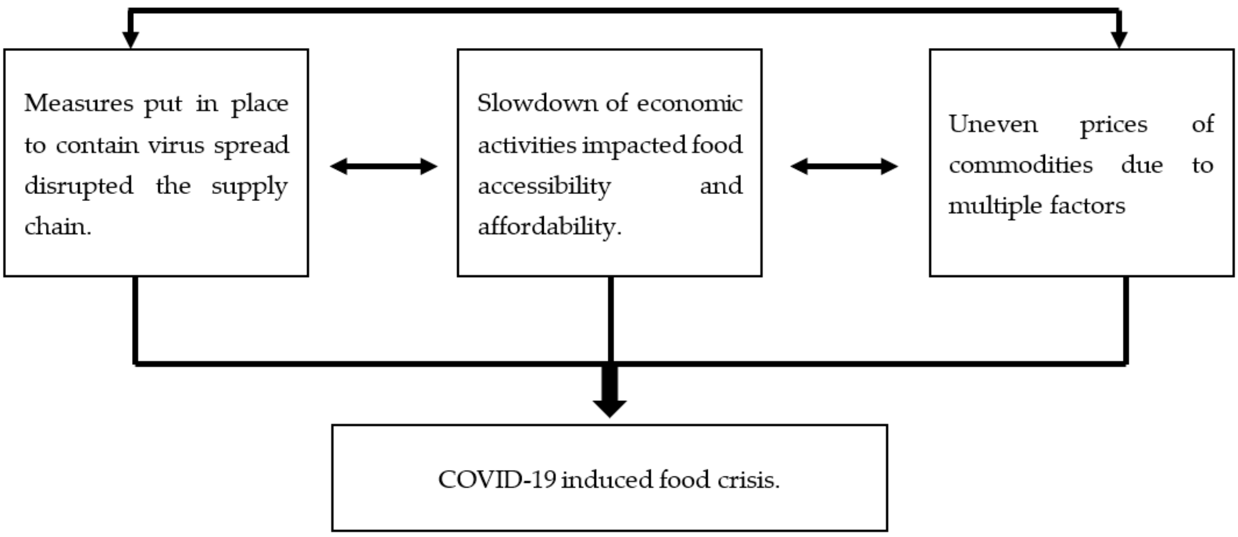

Figure 3. The impact of COVID-19 on the food system during the early phase of the pandemic.

From a production perspective, the pandemic affected producers in diverse ways. Growers faced a shortage of workers during the harvesting and planting season. Vyas et al. (2021) [62] reported that the lockdown measures during the early phase of the pandemic greatly impacted India's labor and input availability. Labor-supply shocks heavily hit labor-intensive enterprises such as fruit and vegetable production. Ridley and Devadoss (2021) [63] estimated a loss of over $12 million (conservative scenario) in fruits and vegetables due to labor-supply shocks during the initial phase of the COVID-19 outbreak in the US. These losses were incurred in essential commodities such as lettuce, onions, grapes, and apples, primarily concentrated in states like California, Arizona, and Washington. Moreover, growers faced challenges in procuring agricultural inputs such as seeds and agrochemicals during the early phase of COVID-pandemic [64]. Additionally, the pandemic made it harder for growers to sell their crops and livestock products [65].

From the consumers' side, food availability was heavily affected due to the limited mobility of food that resulted from lockdown and quarantine measures. Consequently, many countries experienced a rise in domestic food prices, increased poverty, and weak currencies. The lockdown measures directly affected the population employed in the informal sectors. The pandemic adversely affected the purchasing power of consumers. COVID-19 also led to a surge in food fraud, such as food adulterations, misrepresentations, and food crimes [66]. This led to an increased risk of exposure to unsafe foods. Because local outlets or vendors closed due to lockdowns or curfews, consumers were forced to go to expensive outlets such as supermarkets, which reduced the purchasing power further. Overall, consumers' ability to access food was severely affected [67]. The COVID-19 pandemic affected multiple aspects of the macro-economy, too, including credit markets, exchange rates, and overall economic activities, all of which impacted agricultural and food demand [68]. The existing long-term effects on food security have resulted primarily due to both the direct and the indirect effects of the measures used to contain the virus, which slowed down economic activity, resulted in income loss, and reduced purchasing power.

Post-Pandemic Ripples of the COVID-19 Pandemic

The impact of the pandemic on food security lasted far beyond the pandemic period if low-income households were not supported with subsidized or free access to food, especially in developing countries, where the conditions affect food availability and food affordability even more sharply. Even if supply chain issues are eventually minimized and maneuvered towards post-pandemic situation, the influence of the pandemic on hunger could remain for a long period [69]. Losing jobs makes people vulnerable to poverty, hindering their ability to buy food. So, it is likely that poverty will increase in the post-pandemic period.

Nundy et al. (2021) [70] suggested that while recovering from the pandemic triggered a crisis, the progress towards sustainable development goals (SDGs) that had been hoped and worked for before the pandemic might even become worse after it. A meta-analysis conducted by Wang and Huang (2021) [71] found that the COVID-19 pandemic had a detrimental impact on 17 SDGs. Poverty is one of the most important SDGs that can directly influence global food security. Between 1990 and 2015, extreme poverty globally dropped by an average of 1% per year, with the rate of decline plateauing from 2013 to 2015 [72]. However, the pandemic-triggered job losses, and deprivation impacted more on those who were already poor and vulnerable, and it pushed millions of new people into poverty. The poor populations created by the pandemic also include those residing in urban areas, those with better education, and those less likely to work in agriculture. The pandemic has likely widened income inequality and threatened the inclusive recovery and future growth potentials. In the aftermath of the pandemic, the economic recovery likely depends on the extent to which it tackles this process toward the reduction of global hunger and food insecurity problems.

4.3. Conflicts among Nations Drive Scarcity and Impact Global Food Security

Conflict is one of the key elements that represent a threat to the global food system and food security. It can be classified depending on the actors and the area involved, as well as the number of people killed in battle. General categories of conflicts are low-intensity conflicts, which happen in local regions; interstate (country vs. country); intrastate (within the country, government vs. non-state group, etc.); internationalized intrastate conflict (intrastate conflict with significant foreign interference); and one-sided violence by the government or non-government group to civilians [73]. A country is at war if the annual direct conflict-related death exceeds 1000. According to Croicu and Sundberg in 2017 [74], interstate conflict has been the leading conflict for many years, while internationalized interstate conflicts have been increasing in recent years. However, conflict, regardless of the type, affects food security, although the extent could certainly differ. Furthermore, factors such as local food production, dependency on food import, and the economic status of the country could determine the extent of the effect of the violence on the food security of the country. Martin-Shields and Stojetz (2019) [73] report that the risk of food insecurity is greater in low-income countries than in high-income countries because the former have a greater prevalence of undernourishment, food deficit, percentage of cereals/roots/tubers consumption, food price volatility index, and cereal import dependency ratio. Short- and long-term threats to global food and nutritional security could stem from a variety of conflict-related factors and repercussions. All of these factors and consequences are interconnected and include lower crop production, a rise in food prices, a decline in biodiversity, the loss of infrastructure, and the possibility of a nuclear winter and climate change.

4.3.1. Decrease in Crop Production

A decrease in crop production is one of the major consequences of the conflict that poses a great threat to global food security. Different factors play a role in decreasing crop production, although the unavailability of resources like field labor, agricultural inputs, and their higher prices are the major reason behind it. During the war, farmers could not attend to their fields to plant and even harvest crops that were already planted. There is a higher risk of global food insecurity when war breaks out within or between countries with a higher share of food exports in the global food market. For example, the current conflict between Russia and Ukraine has presented a huge risk to global food security as some effects, such as an increase in the price of food, fuel, and fertilizer, are already seen worldwide. Russia and Ukraine are the leading producers and exporters of food and cash crops, such as wheat, maize, rapeseed, sunflower seeds, and sunflower oil, while Russia is one of the leading providers of nitrogen, potash, and phosphate fertilizer [75]. As reported in the executive summary by the FAO (2022), 20–30% of the area sown in winter remained unharvested in Ukraine, while farmers did not plant crops in spring at their full capacity. In addition, the decreasing income of a farmer in one season could impact the farming decision the next year. Furthermore, many trade sanctions against Russia could impact the agricultural inputs imported into Russia, such as seeds and pesticides affecting agricultural crop production and its export in the global food market, as they are highly dependent on seeds and pesticides in other countries. Because of the Russia–Ukraine war, international grain and vegetable oil price indices have already increased, while increased prices of fuel and fertilizer could affect crop production in the coming year, further exacerbating the already higher food prices in the global food market.

Localized civil war within countries also affects food security status within the region or in some cases globally but to less extent. The civil war in Syria reduced food production, for example, as cultivation shifted to safer zones, decreasing the total area of production [76]. A decrease in crop production within the country and a poor economy to import food resulted in a risk of food insecurity for the Syrian population. As discussed earlier, low-income countries are always at a higher risk of food and nutritional insecurities resulting from war.

4.3.2. Increased Food Prices

In the past few years, food costs have risen due to the pandemic (COVID-19) and the climate change effect, which is now being exacerbated by the Russia–Ukrainian conflict. A rise in food prices has had the greatest impact on the food and nutritional security of the poor, as impoverished households spend a bigger proportion of their budget on food [77]. During the war, there is likely a food shortage, and this fear drives the price of food even higher. When we consider the current scenario, different countries have restricted food exports for fear of food shortage and further inflation due to the Russia–Ukraine war. For example, Russia, Ukraine, Serbia, and India have imposed restrictions on wheat export from their countries, and Egypt, Algeria, and Argentina have all prohibited the export of vegetable oils [78]. Around 20 countries have now banned the export of around 33 food items, which is around 10.61% share of the global calorie market, excluding intra-EU trade. This export restriction of many food items could further increase food prices in food-importing countries due to food shortages. The high prices of agricultural inputs such as gas, fertilizers, and seeds, etc. also play a significant role in the war-induced increase in food prices, which eventually reduces food affordability as well as food and nutritional security.

4.3.3. Threat to Agro-Biodiversity

Higher agricultural biodiversity means the abundance of wild and domesticated animals and plant species in the environment are used as sources of energy and nutrition. Agriculture biodiversity is essential for the sustenance of agricultural crop production and the development of resistance to threats due to climate change and nuclear war [79]. Many wild species are not only sources of genetic variability but are also rich in micronutrients and safe to eat; the inclusion of such species in the diet further helps to enhance diet diversity and reduce nutritional insecurity [80].

Conflict among the countries, especially the ones with heavy machinery and nuclear heads, could threaten agro-biodiversity. This jeopardizes the agricultural production system, both terrestrial and aquatic, whether in regions or globally. In short, modern warfare has the potential to destroy many natural wild habitats and kill many species in a short period. Similarly, conflict could result in the exploitation of natural resources and higher deforestation. The case study of conflicted regions like Ethiopia and Mozambique has also proved the point discussed above [81]. The use of biological weapons (such as plant and animal diseases) in the war could further affect biodiversity with their fast spread and could even make some species extinct if biological weapons were used on a large scale [82]. Therefore, a decline in agrobiodiversity due to interstate or intrastate conflict could reduce food diversity and affect food and nutritional security.

4.3.4. Infrastructure Damage

Conflicts could also compromise the population's food and nutritional security by causing infrastructural damage. Those infrastructures could be ports, food processing facilities, industries, or energy grids, as well as water supply channels. Damage to the abovementioned infrastructures could result in a humanitarian crisis. Furthermore, billions of dollars need to be spent to build damaged civilian infrastructure, which is a huge economic burden for the countries in the war, which often leads to economic crises. For example, as of May 2022, it was projected that the ongoing Russia–Ukraine conflict has cost Ukraine approximately 97.4 billion USD in damage to its civilian infrastructure [83]. On the other hand, damage to the ports and the port-related infrastructure directly affects the import and export of goods, including agricultural inputs such as seeds. Even if crops are produced, damage to the energy grid and processing facility or industry could hamper the food processing capacity, affecting the prices and ultimately increasing the chance of food and nutritional insecurities.

4.3.5. Nuclear Winter and Climate Change

In the context of increasing regional conflict and dispute among countries powered with nuclear weapons, the chance of using nuclear warheads against each other increases. Nuclear weapons not only directly kill thousands of people but have long-standing consequences, including structural damage, resource depletion, and, more importantly, the potential change in climate that causes a nuclear winter. A nuclear winter is the condition of a global cooling effect that can potentially result after a heavy-scale nuclear war [84]. Thus, nuclear winter conditions would alter the scenario of global food production and consumption, posing a threat to the global food system and food security. In addition, the environmental effects of a nuclear war could travel without boundaries (such as smoke, pollution, and chemical toxicity in the air) and cover a huge portion of the stratosphere, reducing the amount of energy—in adverse extremes, this could produce a decade-long reduction in the temperature of the earth, affecting solar radiation and the pattern of the rainfall, which, in turn, would affect agricultural production. Jägermeyr et al. (2020) [85] have investigated the potential impact of nuclear war on world agricultural production using a simulation model that considers the possibility of a nuclear fight between Pakistan and India. They reported that the global mean temperature could decline by 1.8 °C and precipitation by 8% for at least 5 years due to the emission of more than 5 Tg soot from the nuclear fire. They predicted a decrease in maize, wheat, rice, and soybean production by 13%, 11%, 3%, and 17%, respectively, for more than 5 years, with a scenario of using only <1% of the nuclear arsenal currently present in the world [85]. This study only included climate change's effect on food production. We should note that there could be other major effects on food production resulting from a nuclear war, such as infrastructure damage, resource unavailability, human disease problem, labor shortage, and disruption in the global food chains. The condition and threat to global food security would further escalate if multiple countries with high nuclear power were involved in the war at their full capacity.

5. Resolutions to Address a Triad of Modern Challenges to Agriculture and Global Food Security

Agriculture in the twenty-first century has several challenges. It needs to meet increased food demands for the increasing human population as well as satisfy sustainability goals and adapt to climate change. Food production and supply are significantly complicated by climate change scenarios, unexpected events such as pandemics, and conflicts across nations. By the end of the twenty-first century, the temperature is projected to rise by 3.4 °C while CO_2 concentration will be almost four times higher [26]. Such forecasts raise serious questions about the sustainability of current farming systems as they are subjected to these substantial threats. Moreover, epidemics and pandemics are uncertain with unprecedented challenges. Similarly, international conflicts slow down human activities while increasing resource depletion and structural damage. Hence, all these challenges faced by the modern world and their interconnections necessitate policy integration strategies with urgent implementation for long-term sustainability. Because of the interlinkage between climate change, pandemics, and conflicts, it has become evident that these issues cannot be addressed unless these factors are approached in an integrated way. Figure 4 shows the summary of our discussion regarding the resolution, and in the following sections, we present the key area that can be focused on when tackling these challenges.

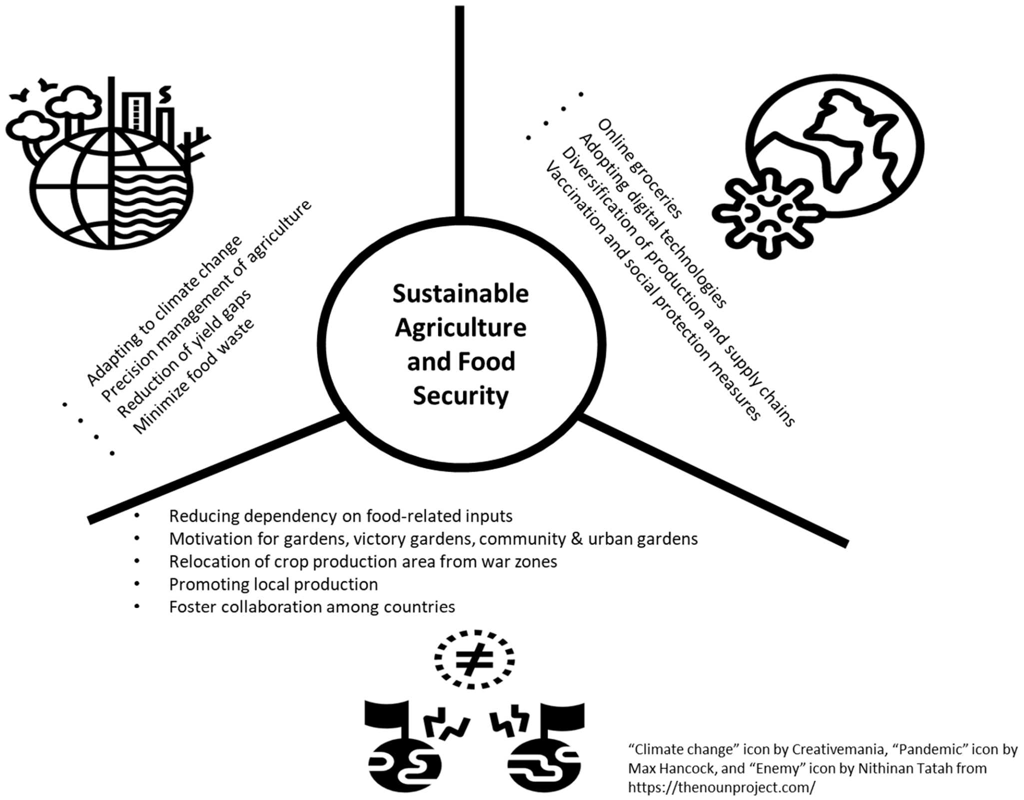

Figure 4. Summary of possible key points of resolution to address the trio of challenges to global food security.

5.1. Adapting to Changing Climate

Although adaptation strategies to the changing climate need to differ according to the various world regions and to be site and climate specific, there are some promising basic principles that one can stick to. For example, an increased level of component integration and diversification in cropping systems can reduce the vulnerability posed by extreme climatic conditions, thereby increasing resilience. Monoculture practices are vulnerable to pest outbreaks, soil degradation, nutrient depletion, and other challenges compared to diversified agroecosystems with multiple crops and vegetation. Diversified systems enhance soil health, conserve water, and promote natural pest management, making them more resilient to climate change impacts. Diversification also provides options to generate revenue from the crop portfolio even if the yield in one crop fails. Integrated cropping systems, such as having a continuous plant cover with winter annuals, summer annuals, and perennials, and integration of livestock with crops, can also provide adaptation benefits. Integrated cropping systems, such as integrated agroforestry (agriculture and silviculture) and specifically planting trees in the landscape, can make farms more resilient in many ways by improving the local micro-climate, increasing water availability, mitigating soil erosion, and balancing the effects of harsh weather [86]. Shifting production from one crop variety to another or locally adapted annual or perennial species may be another option for adaptation. A recent evaluation also emphasized using practices based on agroecological principles such as crop diversification, agroforestry, and mixed cropping and livestock systems for improving food security and environmental sustainability [29]. These agroecological practices replicate the local environment, are affordable, ecologically friendly, and culturally aligned, making them particularly beneficial for smallholder farmers in poor and middle-income countries facing the climate crisis, helping them to build climate-resilient communities that address the interrelated issues of climate change, food security, and human health. While these adaptation strategies can reduce the impact of climate change on agricultural productivity, at the same time, other studies, such as [87], suggest that concrete irrigation water supply, extension, transfer of knowledge, technologies, and credit facilities must also be used for better yields and positive impacts. Strategic planning, implementation, and monitoring of cropping systems according to the changing climate plays a pivotal role in sustainable food production. The European Green Deal of 2019 and Farm to Fork are the most recent efforts that recognize the role of integrated cropping systems on production while dealing with the changing climate [88].

5.2. Precision Management of Agriculture

In addition to adapting to the changing climate, precision management of agriculture can play a major role in making farming informed and more sustainable, without compromising crop productivity. This can become a larger part of the solution for reducing different forms of nitrogen losses from agricultural cropland. Precision agriculture can allow a grower to use fertilizers and other inputs more wisely and efficiently [89]. Modern precision management technologies such as site-specific field management or variable-rate application technologies allow for different rates and amounts of fertilizer to get applied in different sections of the field, as soil fertility and yields differ even across a single field and need different amounts of fertilizer. This technology helps to identify which areas are fertilizer deficient and which have enough to supply throughout the growing season. This, in turn, can decrease the emissions of N_2O, which is a potent greenhouse gas. This also minimizes fertilizer runoff, preventing pollution in water bodies nearby. Such actions taken to enhance agricultural efficiency while reducing environmental pollution will have a positive impact on both food security and the reduction of greenhouse gas emissions [90]. As a result, site-specific management practices can also play a crucial role in mitigating agriculture's adverse effects on the environment. In addition, precision agriculture can also integrate site-specific data with decision support systems (including crop and soil models that can simulate climate change projections). The adoption and implementation of advanced internet technology, improved cropping and management techniques, enhanced agricultural services, and precision-based informed decisions can greatly contribute to the promotion and success of climate-smart agriculture [91]. These tools can also help to evaluate potential climate change scenarios, such as changes in crop species selection, crop rotations, and other cropping systems and management practices, thereby maximizing revenue.

5.3. Enhancing Food Production by Reducing Yield Gaps while Maintaining Sustainability

With a large increase in the urge for energy, grain, and livestock products for the increasing human population, [92] projected that every unit of existing agricultural cropland will need to produce substantially greater crop yields than current yield levels. However, agriculture intended solely for high production would come along with different detrimental effects on the ecosystem. To ensure global food security with a minimal effect on the environment, the existing agricultural land must be used more productively but wisely. Focusing on the region where yields are currently limited by different resource constraint factors can improve crop yields. Global spatial analysis by [93] observed large variations across the different regions of the world, even within the regions where growing conditions are the same, indicating the existence of huge yield gaps. Productivity can be improved just by incorporating better management practices and supplying enough resources in most of the regions of the world. For example, better nutrient management and water availability can significantly increase yields across many crop-growing regions of Africa, Asia, Latin America, and Eastern Europe, where yield gaps seem to be greater. For example, [94] identified that enabling farmers in such regions with enough resources to narrow these yield gaps and sustainably stabilize them is imperative to achieving long-term global food security. Several studies across the world have supported the fact that such existing gaps in production potential are exploitable and can be achieved under ideal management [92,95,96]. Thus, reducing yield gaps can increase global food production and contribute to global food security.

Progress has been made in developing the best management practices (BMPs) and strategies for reducing yield gaps for major crops, yet there are several challenges to this. It is important to address differences within a cropping system, niche, region, and the gross productivity of the number of crops produced per year. Researchers [94,97] have found that strategies such as limiting agricultural expansion, investigating the reasons behind yield gaps on underperforming lands, better utilization of existing lands, increasing cropping efficiency, shifting dietary patterns among people, and reducing waste could increase food production from given resources or land without compromising the environment. Production can also be maintained by reducing unnecessary uses of water resources, nutrients, and agricultural chemicals [98]. So, the idea of increasing resource use efficiency can maintain and probably also increase the sustainable food delivery system. The current agricultural practice has disproportionately used resource inputs. Identifying low-efficient areas and focusing on better management can allow more production. For example, in places with water as a limiting factor, better land management practices and systems should be built for better irrigation efficiency without compromising food production. In addition, improved crop varieties that are resistant and adapted to climatic change can be another opportunity for improvement. The beginning of any strategies for reducing crop yield gaps must begin through a precise understanding of not only knowing their size and geographical distribution but also the biophysical and socio-economic causes behind these yield gaps at local, regional, and global levels. To summarize, the adoption of resource-conserving practices, technologies, and services that increase crop yields with lower water, labor, and input costs should be promoted.

5.4. Reducing Food Wastage

Another important strategy would be the better utilization of foods and reducing food waste at different production and processing levels. There is a strong discrepancy across the globe between crops are grown for direct human consumption and those used for animal feed. [94] observed that only 62% of crops produced globally are allocated to human food. Food that is already in production or being produced can be better utilized by properly allocating or channeling it to populations with a severe food insufficiency. For food that is already in circulation, more can be done by reducing food waste. In addition, [94] mentioned that a large amount of food is wasted along the supply chain and only a small portion reaches ports of consumption. The FAO claims that about one-third of food produced goes to waste; this percentage is even higher for developed countries. To achieve global goals for food security and sustainability, it is necessary to effectively manage and reduce the amount of food that is lost or wasted throughout the global food supply chain. To accomplish this, three main steps are necessary: assessing the causes and extent of food waste, educating the food supply chain on waste reduction, and creating strategies to maximize efficiency for better utilization of foods and minimize waste. For example, better processing, storage, transport, and allocation can simply improve food availability by reducing food waste. On top of that, addressing this holistic issue also requires a comprehensive approach that involves economic, environmental, and social aspects of sustainability, as well as the active participation of all actors involved in the food supply chain, including farmers, processors, distributors, sellers, and consumers, from the production to the consumption stages [99].

5.5. COVID-19: A Wake-Up Call to Reconfigure Existing Food System

COVID-19 is undoubtedly a global problem, but, to some extent, it has also opened opportunities for many stakeholders associated with food-supply chains. The pandemic altered the way of buying and selling agricultural produce. More specifically, it accelerated the transition from offline grocery stores to online. This is proved by the fact that online stores experienced historically higher sales during the pandemic in 2020 and 2022 [100].

The current food system is best described by industrial production, processing, specialization, and trade of commodities via complex global supply chains extensively controlled and managed by regional and international corporations. The COVID-19 pandemic imperiled the livelihoods of growers who specialize in crops as the demand for those fell during the early phase of the pandemic. Similarly, the illness of workers associated with the food system adversely affected the global supply chains. Additionally, export restrictions imposed by governments worsened food security in developing countries relying on imports. These are indications that the current food system is incredibly vulnerable. As a result, analysts are currently advocating transformative change in the current food system. The COVID-19 pandemic marks an inflection point and warrants a fundamental shift in the food system.

Given the fragile nature of the global food supply chain laid bare by COVID-19, there is renewed interest in the local food system. The impacts of the pandemic might likely catalyze the transition of agricultural production and business toward sustainability and resiliency. For a long time, smallholders were not at the center of policy forums; however, the COVID-19 food crisis proved that smallholder growers are the key stakeholders in keeping the global food system functioning and resilient.

The adoptions of digital technologies such as robots, drones, toll-free numbers, and autonomous machines will aid in countering the pandemic's aftereffects and combating potential food crises in the future [101]. Greater emphasis should be given to increasing technological adoptions to enhance productivity, improve growers' access to finance, and manage the environment and resources. The sustainable, resilient, and secure food supply, rational decision making, and income expenditure balance for both food producers and consumers should be at the heart of the post-pandemic food systems [102]. Governments and policymakers should emphasize the diversification of production as well as supply chains, and they should implement social protection measures to build a resilient food system in the face of the challenges posed by the COVID-19 pandemic, climate change, and wars.

5.6. Mitigate the Conflict Effect on the Food System and Nutritional Security

Conflicts increase the likelihood of food and nutritional insecurity in populations that are already vulnerable due to climate change and pandemics such as COVID-19. Nonetheless, some measures or activities might be initiated to minimize the food and nutritional insecurities that could be caused by different types of conflicts. As previously discussed, countries with a significant reliance on food and agricultural imports are more susceptible to food price inflation and food and nutritional insecurity. So, reducing the dependency on food and agriculture-related inputs from other countries can make an individual country's food system more resistant, especially during pandemics and wartime. One approach to increasing local food production could be the revitalization of the concept of the "victory garden." During World Wars I and II, the United States successfully implemented the concept of victory gardens by encouraging families to plant vegetables on unused land around them and encouraging them as a sign of patriotism. The main aim of the victory garden was to reduce commercial food demand and reduce packaging and transportation needs by producing their food locally and supplying the remaining ones, as the war had caused a significant reduction in food production [103]. Around 18–20 million American families had victory gardens in 1944 during World War II, and these gardens supplied around 40% of the total domestic demand for vegetables [104]. However, most people gave up their victory gardens when life returned to normal after the war. The concept of a victory garden is not only suitable during wartime but also to combat modern-day issues such as climate change and food insecurities, and also for agricultural sustainability by providing fresh and nutritious food to the local population. The idea of the victory garden was also emphasized during the COVID-19 pandemic as a feasible solution to ameliorate food and nutritional security challenges imposed by the pandemic [105].

During intrastate (intra-country) conflicts, especially, relocation of the crop production area along with the agricultural input such as labor to war-unaffected areas could help to maintain the total agricultural production within countries. This approach could be more useful in the country with an even distribution of arable land throughout the country. Intrastate (intra-country) conflicts happening in different countries have shown a significant reduction in crop production in war-affected regions and increased production in safer areas. For example, crop production in the northwest and southeast regions (a safer zone) increased in Syria after the insurgence of the Syrian civil war [76]. Therefore, relocating agricultural resources contributes to an increase in crop production and reduces food insecurity among war-affected populations.

Another strategy for developing a resilient food system during times of war is to focus on heirloom local varieties and promote the production and consumption of locally available crop species. By doing so, dependence on the foreign seed supply chain and fertilizer and pesticides is reduced, as local heirloom and wild varieties are typically resistant to disease and drought and require less fertilizer than commercial hybrid cultivars [106]. The cultivation of local varieties with low fertilizer requirements reduces the cost of production for farmers, thereby helping to keep food prices affordable. Similarly, the inclusion of local and wild edible species and their diversity in the diet could help to meet the body's nutritional needs [107]. Wild and locally available edible species are generally rich in different bioactive compounds such as total phenols, vitamin C, flavonoids, anthocyanins, and antioxidant compounds [108,109]. With these efforts, there could be potential to exploit underutilized wild crop species as a possible food source for the future. Scholars [110] have also discussed the potential use of underutilized wild crop spices to mitigate the burgeoning issue of malnutrition and food insecurity.

Importantly, collaboration among countries on natural resource utilization such as oil, minerals, and medicinal plants could help to reduce the risk imposed by the pandemic and conflicts. For example, many countries have stopped the export of foods such as wheat, vegetable oil, etc. to avoid future shortages of such goods in their countries [78], which is driving food prices even higher, making certain goods unaffordable for many people. In such circumstances, international dialogue and cooperation could be the key to reducing the global risk of food insecurity. By implementing a holistic approach, such as relocation and better use of available resources, increasing local food production, incorporating underutilized wild and diverse crop species into the diet, and fostering collaboration between countries and people, the risk of food insecurity caused by conflicts could be mitigated to some extent.

6. Conclusions

In this review article, we have assessed food and agricultural systems in the context of three critical threats: pandemics like COVID-19, climate change, and conflicts among countries. Presenting the review findings and discussing the inter-relation of pandemics, climate change, and conflicts in food and agriculture, we posit that the trio of challenges and their interfaces are remarkable in that they threaten anticipated goals on sustainability, hunger reduction, and food security. Both short-term and possible long-term impacts are apparent to the production and distribution systems and supply chains of food and agriculture. Documentations and estimations on the individual effects of climate change, COVID-19 situations, and conflicts not only show the direct effects through the distorted food supply, food prices, and hampered consumption, but also indicate the further progression toward the long-lasting cause of critically alarming issues in agriculture, food, and humankind. These include, for example, increasing incidences of extreme weather and natural disasters of high impacts, invasion of more aggressive pests and diseases, the decrease in crop production, distorted supply chains, increased public health issues and illness, food scarcity, increased food prices, reduced agro-biodiversity, infrastructure damage, and even the extreme of a decade-long nuclear winter. The interactive effects of the factors in this trio could further escalate all of these issues to an even greater magnitude.

These issues and interactions have complex effects on food and agriculture. However, to prevent or overcome the adverse effects, we should use some mitigation strategies as possible resolutions. Climate change actions and adaptation efforts are increasingly necessary to adopt and embrace along with strong global commitment. In production agriculture, precision management and emphasized examination of specific managerial and yield gaps could support the increase of food production. In distribution and food supply chains, we should put strong efforts into the reduction of food waste and the reconfiguration of food systems during COVID-19, climate change, and conflict-created situations. Finally, we should use some strategies to make our food systems less vulnerable to conflicts. We have presented a discussion of each of these prospects in the paper.

Environmental and climatic factors are integral parts, and, therefore, the changes in these should be dynamically adopted in food and agricultural systems. COVID-19, its uncertainty, and its effects have shown that adverse economic impacts of these issues are not static but are sequential, dynamic, and long-term. This has helped to identify vulnerable systems and to be prepared by building resilient food systems, and it has further highlighted the roles of some specific factors that were not critically examined before. For example, it has increased the realization of the roles of strong short supply chains, smallholder growers and farmers, local supplies, innovations in food distribution systems, urban and community gardening, and identifying yield and managerial gaps for focused targets in enhancing production. Conflict situations have further suggested that we delve into the food self-sufficiency prioritization of a nation. Even relatively less dependency of a nation from others on critical aspects, such as food, helps to prevent extreme adversities of famine and hunger during conflicts. With the possibility of global economic effects that are hard to mitigate in the short term, our comprehensive findings have also suggested that the food and agricultural systems should prioritize emphasizing enhancing resource use efficiencies and allocative efficiencies in addition to production and technical efficiencies.

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