CAUSES AND IMPACTS OF AGRICULTURAL FOOD SHORTAGES: HUMAN INTERVENTIONS AND CLIMATE CHANGE PLAY SIGNIFICANT ROLES

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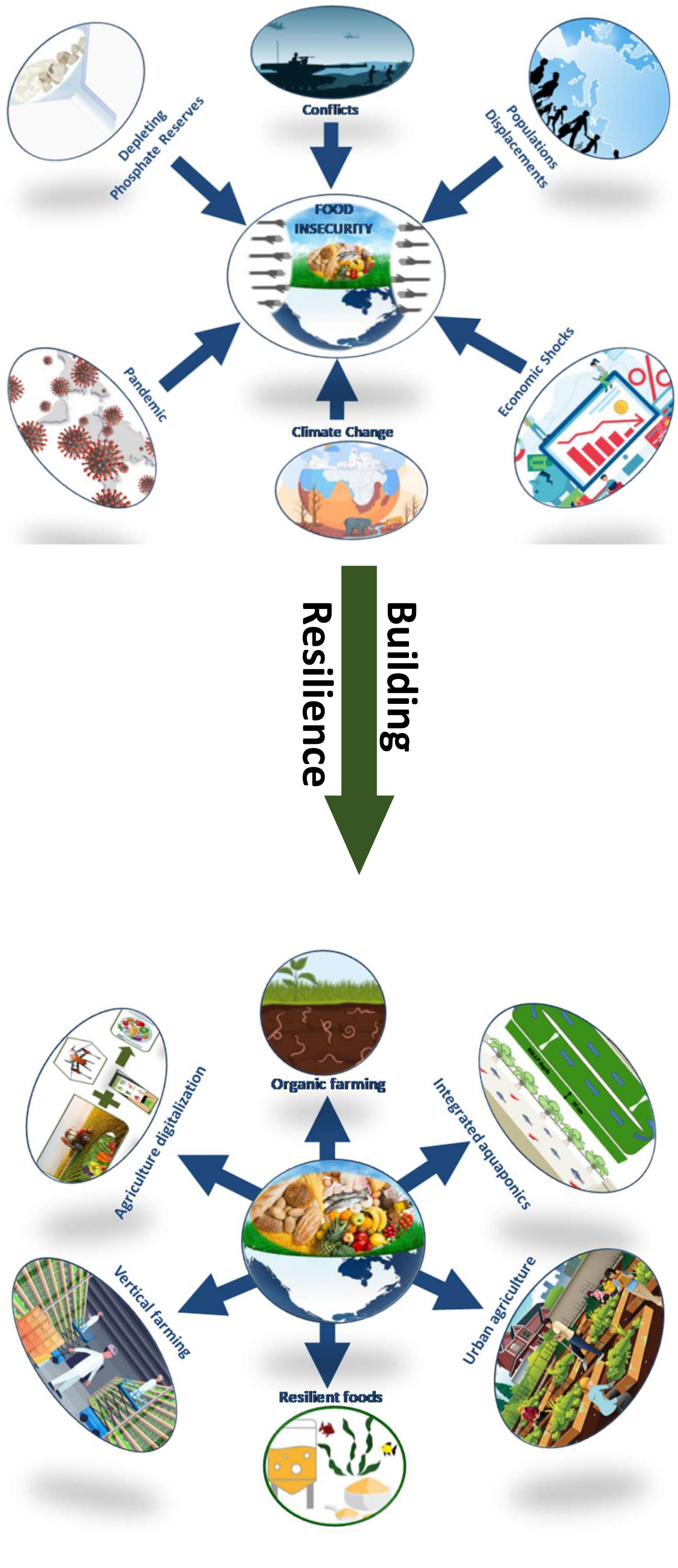
Agriculture Food Shortages: Human interventions and climate change

Abstract

Food security and nutrition are fundamental and principal human rights. However, these civil rights have been critically endangered by global drivers such as increasing war and political conflicts, climate change, natural calamities, destitutions, social inequalities, economic diminution, and pandemic diseases. The main factors to ensure global food security are definitive sources to obtain quality food and unperturbed access to the resources for food production and purchasing. Effective management of food systems, food supply chains and growth in the agriculture sector would enable the world populations to meet their dietary demands. As the world is facing scarcity and depletion of conventional natural resources, the developments in the agriculture sector would need further advancements to ensure both quantitative and qualitative requirements. The agriculture-led economic growth tackles both food security and poverty. However due to high demands for water and fertilizers, the steady and fast growth in agriculture and related sectors (livestock and fisheries) demand holistic and sustainable development model. The major challenges involved in meeting the demands for the resources in agriculture sectors are the abrupt supplies of fertilizers, water scarcity and climate change. Many regions of the world are facing unprecedented and persistent incidences of drought and flooding due to the underlying cause of global warming and climate change. The social, economic, and political disparities and conflicts between different regions of the world have been fueling the abrupt changes in the availabilities and costs of the fuel and fertilizers. The implausible political conflicts are imposing hindrances in attaining social equity and sustainable development goals for humanity. From the technological viewpoint one of the ways to tackle obstructions in agriculture growth includes transformative technologies which build up climate resilience in food production. In this paper, we focus on global causes and impacts of agriculture food shortages and consider mitigation strategies to overcome this global social-economic and political threat.

Keywords: Climate crisis, Conflicts, Food insecurity, Food shortage, Food system, Global hunger, Nuclear winter, Precision agriculture, Resilient foods, Smart agriculture, Sunlight reduction

Graphical Abstract



1 Introduction

According to the United Nations Food and Agriculture Organization (FAO), the food security stands on four pillars, namely availability, access, utilization, and stability (Brinkman, et al. 2020).

Of the 17 UN Sustainability Development Goals (SDG), the second goal would assure global food security by 2030 through concerted efforts by the governments, NGOs, and multilateral organizations. In the aftermath of the global food price crisis in 2007-2008, the FAO estimated that 1 million people across the globe were undernourished in 2009 (Botreau and Cohen 2020). Even though there is an accelerating momentum associated with the SDG; it is plausible if the system food approach is adopted worldwide. Food systems involve all the activities involved with the production, aggregation, processing, distribution, consumption and controlling wastage of the food derived from the multiple sectors namely agriculture, livestock, forestry, fisheries, and food industries (von Braun, et al. 2021).

The various components of agri-food system such as agriculture, livestock, forestry, aquaculture, and fisheries require physical inputs of energy, land, nutrients (Campanhola and Pandey 2019) and water. The human has traversed four important planetary boundaries namely climate change, rate of biodiversity loss, anthropogenic interference in the nitrogen and phosphorous cycles and the use of freshwater (Ceccarelli and Grando 2020). All these hugely impact agriculture food production and crop resilience. Food security is challenged by various factors such as climate change, structural shifts in food and agriculture systems, increased biofuels feedstock demands, land degradation, and emergent infectious diseases. The effective management of four different components namely the soil and land, the water resources, the supply chain and the emergent infectious diseases determine the food security (Figure 1).

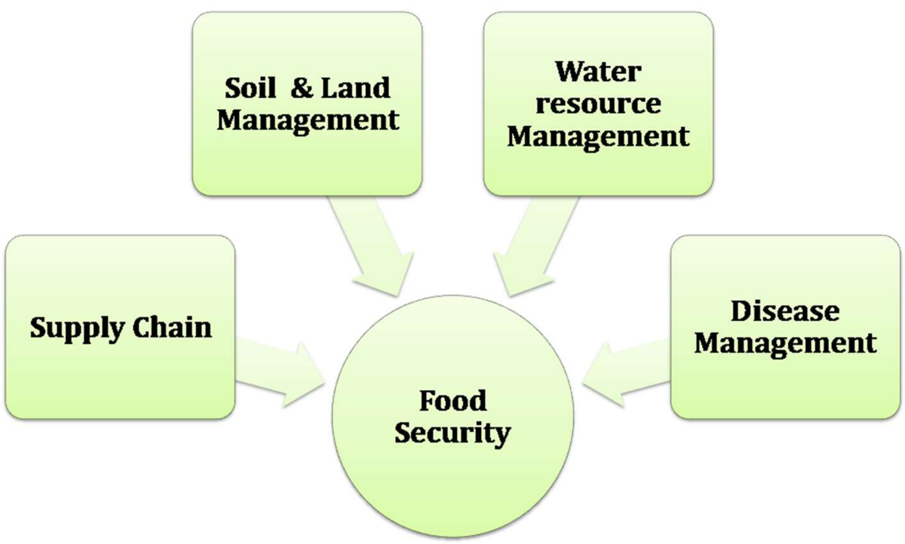


Figure 1. The proper and efficient management of four different sectors determines food security.

Agriculturally suitable soil is a limited resource with most land area already utilized for the cultivation yet it would not suffice the growing needs for food and fuel. The over exploitation of soils and conversion of forests into agriculture land leads to soil erosion and off-site soil sedimentation. Principally, soil has three components: physical, chemical, and biological. Soil erosion, compaction, desertification, and crusting are the phenomenon that cause physical land degradation. The nutrient imbalances, acidification, salinization, and leaching alter the chemical properties and degrade the soil quality. Under natural conditions, the nutrient balance of the soil is maintained through the flora and fauna. The chemical and physical changes impact the biological driven process in the soil such as carbon oxidation and loss (Havlin and Heiniger 2020). As fertilizer demands would be higher than the food; the effective soil and plant management practices must be adopted by the farmers to ensure enhanced crop productivity without losing soil fertility (Havlin and Heiniger 2020). Further to reduce the dependence on fossil fuel derived nitrogenous fertilizers and overexploitation of limited phosphate reserves; it would be inevitable to maximize the usage of biofertilizers.

The agriculture shortages menaced by the land degradation are further affected by salinity intrusion due to rising sea levels and global freshwater shortages. The unprecedented episodes of extreme climate that are manifested by the changing precipitation and temperature in its varying severity and duration negatively impact both rain fed and irrigated agriculture production. Climate change is also likely to alter cropping patterns and yields in the arid and semi-arid regions of the world (Kogo, Kuma and Koech 2021). The extreme and prevalent forms of droughts, flooding and frosts are associated with oceanic perturbations like El-Niño Southern Oscillations and La Niña caused due to climate changes. The occurrences of El-Niño and La Niña events have caused damage to the staple and cash crops and shortages of the subsistence food in the highlands of Papua New Guinea (Cobon, et al. 2016). The unprecedented seasonal heats around the globe dramatically and negatively impact the agriculture productivity, farm incomes and food security which will become norm by the end of 21st century (Battisti and Naylor 2009).

In arid and semiarid regions of the world, food scarcity would be greatly influenced by the water resource crisis which is in turn significantly impacted due to climate change. From reduction of precipitation in Sub-Saharan Africa to the accelerated retreat of Himalayan glaciers along with the rising sea levels, the increasing global mean temperature is threatening natural freshwater resources all over the world (Misra 2014). As the surface water resources get depleted, the over abstraction of groundwater further affects water scarcity. Therefore, the unconventional source of water obtained by recycling wastewater is expected to play an important role in water management.

The interconnection of soil and water management becomes crucial when low precipitations cause persistent droughts that eventually leads to the soil deterioration. The impacts of regional drought on agriculture are severe, not just locally but via ripple effects in other parts of the world.

For example, the flash drought of 2010 in Russia caused huge reductions in the wheat production which led to rapid increase of wheat prices that were associated with the cascading socioeconomic impacts on other parts of the globe, particularly in Egypt, Tunisia and Turkey (Hunt, et al. 2021).

The rapid expansion of agricultural expansion to meet the growing demands of human and feedstock populations have serious consequences for the environment in terms of depletion of resources, ecosystem degradation, and biodiversity losses. These impacts are multidirectional and widespread. The synthesis of nitrogenous fertilizers depend on fossil fuel resources and the conversion to phosphate-based fertilizers overexploit the mining reserves, both of which lead to depletion of resources and environmental degradation due to co-production of toxic wastes. Additionally, over usage of fertilizers in conventional agriculture causes eutrophication in water bodies and release of greenhouse gases which respectively cause water and air pollution. Apart from the fertilizers, the excessive uses of high-risk pesticides such as organophosphate and pyrethroid insecticides negatively affect both humans and other organisms.

One of the components of agri-food system namely the livestock farming have become intensively industrialized which has multiple negative consequences such as increase in pathogen pressure, contamination risks due to dissemination of diseases to the animals and humans living outside livestock industrial farms (Rivera-Ferre, et al. 2021). The risks associated with industrial livestock farming originated at regional level potentially migrate up to the global scale as evident from the COVID-19 pandemic where the infectious virus called to be erupted from the regional livestock market. The distribution or supply chain component of the food system has been greatly impacted due to the COVID-19 pandemic. The complex food supply chain system involves multiple drivers such as the producers, agriculture inputs, resource supplies, logistics, manufacturing, distribution, retailing and transportation; the latter involve export and imports. Both rational and irrational COVID-19 mitigation measures have caused disruptions in the global trade and food supply chain that unbalanced the demand and supply ratio

(Tasnim 2020). The food price fluctuations at global scale is multifactorial including global market value of crude oil and gas, political factors, insufficient food production due to unforeseen natural and manmade disasters.

The past two years of COVID-19 pandemic have shown us how the two major sectors of the economy namely food and health are intertwined and interdependent. We must take the opportunity to assess how the unsustainable industrial food production systems, land use and loss of habitat loss of animals have inescapable potential to cause emerging infectious diseases which in turn disrupt the food production and supply chain. There is a direct relationship between the emerging infectious diseases and global industrial-scale agricultural processes or agri-food systems which are complex socio-ecological systems prevailing at the human-nature interface (Rivera-Ferre, et al. 2021). The importance of nutrient rich food that has globally been recognized lately during the COVID times had been a fundamental human right. In this respect, the dietary colonialism has resulted in increased dependence on imports of energy-dense processed foods which not only has marginalized the traditional local food system but has also reduced the diet quality and enhanced the risks of nutritional disorders. The local or traditional food production practices involve terracing, multicropping, agroforestry which protects the environmental biodiversity, minimized soil erosion and preserved soil nutrient status. The destabilization and drifting away of local food systems from the traditional, small scale production towards intensive plantation of cash crops, sugarcane and coconut created nutrition deficits, environmental pollution, overexploitation of water resources and inequitable land management (Marrero BSPH and Mattei 2022).

Strategically, the world is living in the era of socio-political conflicts which further is an important threat to global food security particularly in the poor and developing nations where hunger and malnutrition is an existing issue. The social and political conflicts put constraints on the flow of fundamental natural resources including fossil fuels. As fossil fuel is one of the natural resources on which conventional agriculture production depends, the surge in fuel prices further destabilize the agricultural economy of developing nations due to poverty. The global political conflicts impact availability and prices of fossil fuels due to which there is worldwide surge in biofuels that put constraint on food prices. This is particularly evident in developed nations such as United States where over a third of corn is used to produce ethanol and European Union where half of vegetable oils are consumed for biodiesel (Ilaboya, et al. 2012). The rapid development of biofuels industry across the globe aggravates food security in developing countries (Subramaniam, Masron and Azman 2019).

Among the global catastrophic risks, the use of nuclear weapons in wars comes with the expected environmental blowbacks that would become the tipping point for global devastation. In the environmental blowback, there will be abrupt reduction in the sunlight resulting in nuclear winter and cooling climate which could disrupt agriculture for around 6 years with famine death toll in the billions (Throup, et al. 2022). The other global catastrophic events which can potentially cause the abrupt sunlight reduction include super volcanic eruptions and asteroid or comet impact (Throup, et al. 2022). Such global catastrophic risks pose serious threats to the outdoor farming and crops that are cold intolerant and growing such crops on energy or electricity inputs would be unsustainable for meeting the demands of billions of starving people (Martínez, Alvarado and Denkenberger 2022). Under these scenarios, the repurposing of the biomass based raw materials towards the production of resilient foods such as edible sugars provide possible solution (Throup, et al. 2022). Some of other categories of the resilient foods proposed in the literature, for instance the non-biological synthesis of fats from the fossil fuels (Martínez, Alvarado and Denkenberger 2022) does not seem to be a sustainable option.

The food system must be embedded in a sustainable circular economy such that the resources required for food production and distribution are transformed and can be made inexhaustible. The development of sustainable food systems ensures food security and nutrition and safeguards the natural resources for future generations. Achieving food security must also ensure climate neutrality, reduction in the emissions coupled with carbon sequestration, protection of ecosystems and tackling and minimizing food loss holistically by integrating science, technology, policy making and equitable governance. The emerging and cutting-edge technologies involving the Internet of Things (IoT), digitalization, artificial intelligence and advanced biotechnological tools can potentially advance both food and health systems.

2 Food insecurity and world hunger

The world is a much different place compared to what it needs to be in 2030, to support the target the UN set for committing to end global hunger, food insecurity, and malnutrition by that date. The world has not been progressing at an expected pace either towards ensuring access to safe, nutritious, and sufficient food for the entire population all year round (SDG Target 2.1) or towards eradicating all forms of malnutrition (SDG Target 2.2) (FAO, IFAD, et al. 2021). Conflicts, displacements, economic shocks, climate crises have been the major contributors to slowing down the progress to curb global hunger. Likewise, the COVID-19 pandemic has made the way towards SDG2 further difficult.

In 2020, an estimated720 to 811 million people suffered from hunger (FAO, IFAD, et al. 2021). High cost and low affordability imply that billions fail to obtain healthy and nutritious food, causing undernourishment. The prevalence of undernourishment (PoU) increased to 9.9 % between 2019 and 2020, as compared to 8.4% in the previous year. In 2020, the number of undernourished people globally accounted for 768 million, out of which, i.e. more than half accounting for 418 million belongs to Asia, and more than one-third, accounting for 282 million belong to Africa. The world faced varying degrees of food insecurity in the year 2020 (Figure 2).

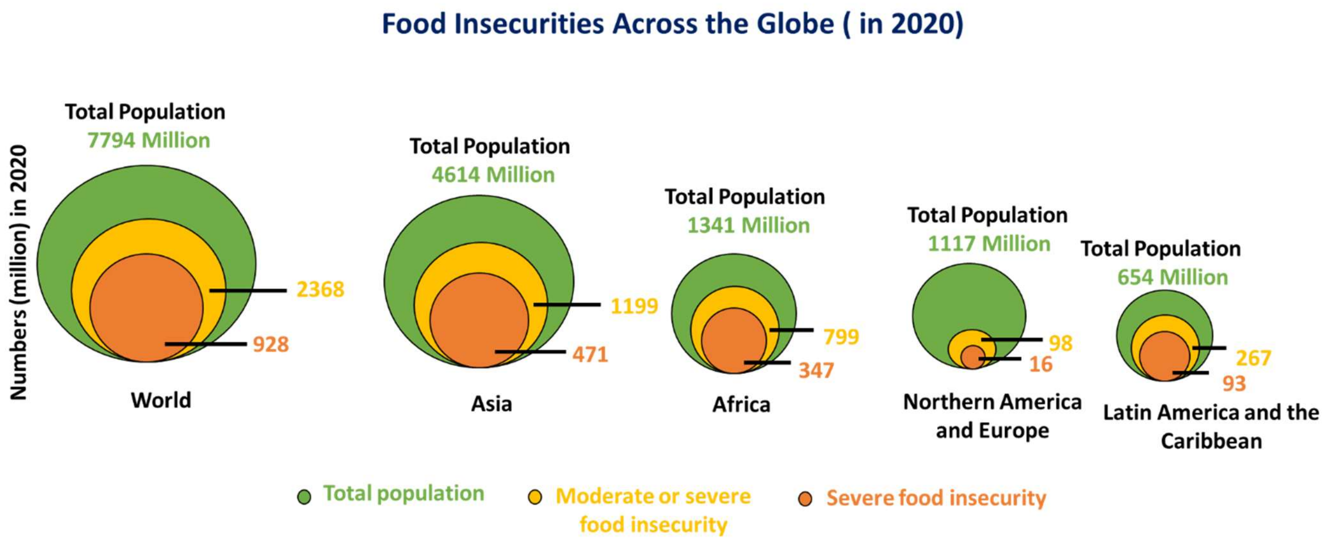


Figure 2. The food insecurities across the different regions of the world in 2020 (FAO, IFAD, et al. 2021).

An estimated 660 million people would suffer from hunger in 2030 as a long–term impact of the COVID-19 pandemic on global food security which would be around 30 million more people if the pandemic had not occurred. Approximately one in three people in the world (approximately 2.37 billion) failed to obtain enough food in 2020. This accounted for an increase of around 320 million people in just one year. of 2020

Rampant childhood malnutrition was also present in 2020. It manifested in different ways, depending on the location and situation. An estimated 5.7% or 38.9 million children under five years old were found overweight, 22% or 149.2 million children showed stunted growth, and 6.7 % or 45.4 million children were "wasting" (WHO, UNICEF and WB 2021).(Stunting refers to the child, too short of his/her age; overweight refers to the child being too heavy for his/her height, and wasting refers to the child too thin for his/her height.)

Quantity and food quality plays a vital role in determining the health of the population and eliminating the different cases of malnutrition. The exact formulation of a healthy diet varies greatly depending upon the individual characteristics, cultural background, local availability of the foods, and dietary practices; however, the fundamentals of the healthy diet remain the same. There occur large differences in the per capita availability of the foods across different income countries. Low-income countries majorly depend on staple foods and minimally on fruits, vegetables, and animal sources of foods as compared to the high-income countries. Grievously, the fruits and the vegetables that provide various types of essential micronutrients and minerals are consumed by the people (complying with the FAO/WHO recommendation of consumption of 400g/person/day or five portions per day) in Asia and the upper-middle-income countries only. Globally, 1 in 3 children of the age group 6 – 23 months can achieve the recommended minimum dietary diversity which varies greatly among the different regions of the world (FAO, IFAD, et al. 2020).Food insecurity in terms of diet quality is impacted even at moderate levels of severity. The populations facing moderate to severe food insecurity have lower consumption of meat, dairy products, fruits, and vegetables in comparison to the populations facing moderate food insecurity.

The global food market also plays a critical role in determining food insecurity. The world food markets have swiftly changed in the mid- 2000s. Globally, there has been a constant increase in food due to the growing population, record harvests, new technologies, increased incomesmins and changes in dietary preferences. The food prices declined steadily in the last two decades while the grain prices were high during the year 2004. Despite the peak production, the growing demands for the food surpassed the supply which created food stock depletion. The other factor responsible for the declined food supply was poor harvests in the year 2005 in major food-producing countries. The world cereal production fell by 2.1% in 2006, followed by a rapid increment in oil, fertilizers, and other food production costs in 2007 (UN 2020). The instability in the global food market accelerated the food prices to unprecedented levels pushing several countries of the world to seek ways of safeguarding themselves from increasing food shortages and prices rise. To deal with the fragile food market, several food-exporting countries set up export restrictions. That compelled major food importer countries to purchase the food at any price to maintain their domestic supplies. However, it became quite evident that the global economic crisis in 2008 and 2009 resulted in food insecurities in many countries across the globe. (UN 2020) The need of the hour is to accelerate the progress in food production that can eliminate major causes of food insecurities, malnutrition, and inequalities which ensures food access for millions of people. These actions act as potential drivers for eradicating hunger by 2030.

3 Global Food Shortages: causes and concerns

The intensity and scale of food crises deteriorated in 2020 mainly due to prolonged global conflicts, economic instability due to COVID-19, and climate crisis, which aggravated the existing insubstantialities. The same followed in the year 2021, with more severe famines in several regions of the world. The global goal of achieving 'zero hunger' by 2030 seems almost a far-fetched dream. The major drivers of global food insecurities are discussed in the following sections.

3.1 Socio-political conflicts and population displacements

Population displacement due to political and social conflicts disrupts the livelihood and agricultural activities of the region as observed in the Democratic Republic of the Congo during the growing season in late 2020. Some of the major forced displacements witnessed in the last decade are listed below.

- The eruption of the Syrian conflict
- South Sudan's displacement crisis
- The conflict in Ukraine
- A heavy influx of refugees and migrants in Europe by sea
- A large migration of stateless refugees from Myanmar to Bangladesh
- The massive flow of Venezuelans across Latin America and the Caribbean.
- Aggravated conflicts and security fears in Afghanistan, Iraq, Libya, and Somalia.
- The distressing conflict in the Central African Republic.
- Large internal displacement in Ethiopia
- Many episodes of outbreaks of fighting and violence in the Democratic Republic of the Congo
- Large humanitarian displacement in Yemen

Around 82.4 million people were the victims of forced displacement at the end of 2020 due to ill treatment, conflicts, violence, and human rights violation and due to other issues related to the law and order of the state altering the public order (UNHCR 2020).

Displacement and insecurity restrict the household's ability to access agricultural lands, the ability to produce crops, and labour challenges, resulting in a decrease in food and income and accelerating the need to procure food in many markets.

For example, in the Central African Republic, decade-long conflicts and insecurities resulted in a negative impact on agriculture and livestock activities, trade, livelihoods, and humanitarian access. Despite the peace agreement in 2019 (UNSC 2019), violence continued triggering the displacement of more populations. Likewise, the conflicts resulting in internal and cross-border displacement rob the population of their opportunity to earn a livelihood, disrupt the market, trade, and crop production thereby, restricting the pastoral worker from accessing their pasturelands and ultimately increasing the food prices (FSIN 2021).Amidst conflicts and wars, the farmers are compelled to stay at home for safety purposes, which impact their sowing/growing/harvesting practices, ultimately resulting in the loss of productivity. The availability of seeds, fodder fertilizers, and other resources dwindles due to various intra and inter boundaries restrictions.

The conflicts result in the forced migration of large populations into the neighbouring countries. These refugees in the need of food and fuel largely destroy the livestock, trees, and other natural resources accessed on their way. Upon forcible settlement to the new premises, they compete for land and other essential commodities, which adversely impact the local market, raising the prices of basic commodities. However, in need of cash to buy food, the migrants tend to sell their livestock and other possessions into the new market-leading to drop-in livestock and prices of other assets. This results in disruption of the economy in the migrants' recipient countries, interfering with the responding power of locale against droughts and food shortage as observed in the case of Western Darfur Sudan receiving migrants from the Chadian fighting (de Waal 1989).The displaced populations suffer from a lack of sanitation, water, and health services and are specifically vulnerable to the respiratory and gastrointestinal disorders that risk their lives. Additionally, children are more susceptible to micronutrient deficiencies, which exemplify the need for emergency food rations that fundamentally comprises only cereals, legumes, and edible oils. Furthermore, women in the displaced population witness both violence and hunger in their refugee camps, where the male muggers often control the supply of emergency ration. It has been often observed the loss of human lives during the wars due to indirect parameters such as hunger far ahead of the direct killings.

Conflicts accounted for the main driver of food shortage at the global level, with almost 100 million people in crisis or worse phase (IPC/CH Phase 3 or above) or equivalent in 23 countries and territories globally in 2020 (GRFC 2021).

Note: Integrated Food Security Phase Classification (IPC) and the Cadre Harmonisé (CH) are the main sources for acute food insecurity data.

IPC Acute Food Insecurity classification determines the different levels of food insecurity into five distinct phases from less to more severe food insecurities. These phases are 1) Minimal/None, (2) Stressed, (3) Crisis, (4) Emergency, (5) Catastrophe/Famine.

The two-way links between hunger and conflicts are well established. Violent conflict tends to destroy many aspects of the food system such as production, harvesting, processing, financing, marketing, and consumption (Grebmer, et al. 2021).Similarly accelerated food insecurity contributes to more violent conflicts. Without solving the food insecurity, it is hard to create sustainable peace and vice versa; thereby reducing the probability of ending global hunger. The armed conflicts make deliberate use of food as a weapon to weaken the opponents either by seizing or destroying their opponents' food stocks, livestock, and other resources, particularly in the rural areas. Additionally, the opponents cease the sources of food or livelihood, involving destruction of food markets in urban and rural settlements.

The use of hunger as a war weapon is quite evident in many conflicts, but several instances account for the combatants seizing and diverting the relief food from the planned recipients, while efficiently keeping away the emergency ration from the impacted civilians and displaced populations. Military seizes the food provisions for their strategic plans and benefits. The government in Sudan in 1990 sold grain reserves to fuel to the military but declined to declare a food emergency. The government and the opponents created famine as an instrument to control territories and populations, prohibited any food aid by attacking the relief convoys, and caused ethnic and religious oppression (Keen 1994).

Land and water resources are subjected to the contamination that forces the unidirectional migrations of the people from their permanent habitats. (Messer 1998)The prolonged food shortages compel the farmers and herders to face a drastic reduction in their abilities to produce food, mainly due to forced labour recruitment and war-related exhaustion of the resources. On the other hand, outbreaks of diseases are also linked to the destruction of health facilities, hardship, and hunger hat further decrease the human capacity to produce food. Several NGOs, bilateral and multilateral relief agencies are called upon to increase food production and livelihood in the war-struck zones.

The recent Russia-Ukraine war (2022) is projected to increase the food crises globally by several folds. The war will not only impact the socio-economic framework of both participating nations but will have rippling effects on the entire globe. The rest of the world heavily relies on Ukraine and Russia specifically for wheat and several other essentials Russia and Ukraine together account for 30% and 19% of global wheat and corn exports respectively (Figure 3). Ukraine is the major contributor of sunflower seed oil supply 50% to the global market. The war will essentially cut off the supply chain which subsequently drives the prices of already high food commodities to shoot up during times when several nations are facing economic instability due to the COVID-19 pandemic. The war at large is predicted to severely impact the Middle East and North Africa (MENA) region as the top destinations for Russian food exports, especially grains. Turkey, Egypt, Iran, and Saudi Arabia have strong food-trade ties with Russia (Heigermoser, Jaghdani and Götz 2022).Other heavily reliant countries that are most likely to face the food crisis include Cameroon, the Democratic Republic of Congo, Libya, Nigeria, South Sudan, Sudan, and Yemen. According to the data extracted from FAO 2020 balance sheet, Lebanon imports 81% of its national wheat consumption from Ukraine and 15% from Russia. Similarly, Egypt imports 60% of the total wheat it consumes from Russia and 25% from Ukraine, while Turkey imports 66% of the wheat from Russia and 10% from Ukraine.

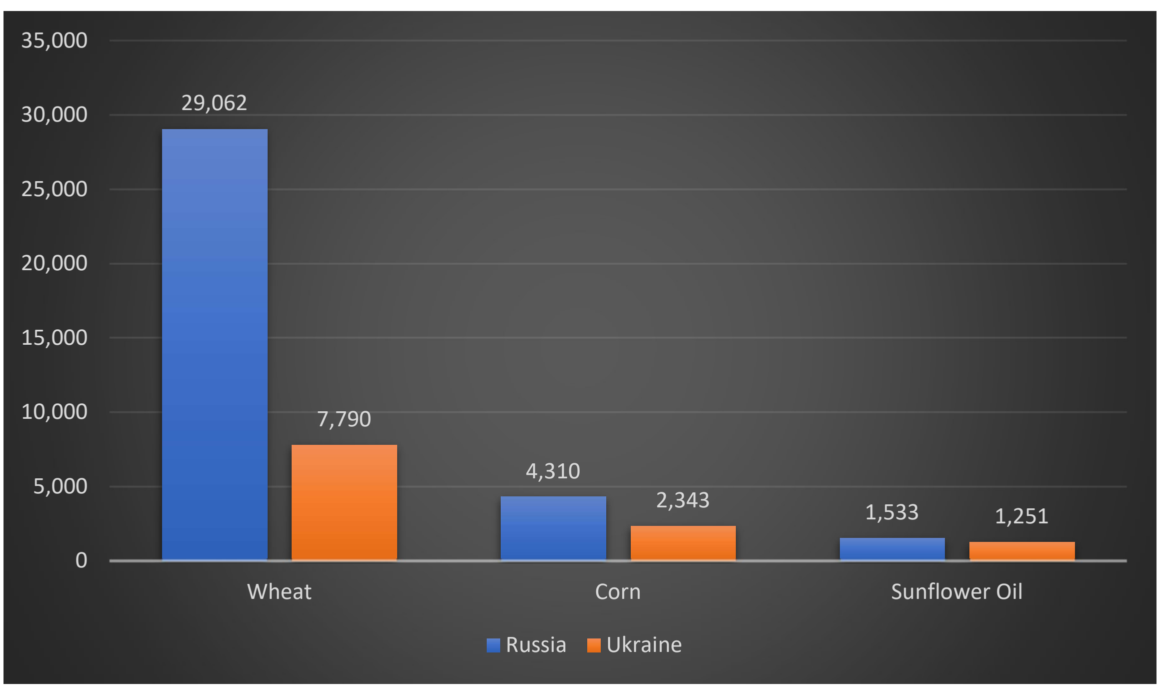


Figure 3. Export volume of priority commodities from Russia and Ukraine in 2018 (Melkadze 2022)

Similarly, Russia along with Belarus contributes up to 15% of the total global needs of fertilizers. Countries such as Mongolia, Kazakhstan, and Azerbaijan largely depend on the fertilizers imported from Russia. The sudden decrease in the supply of fertilizers will have immediate impacts on agriculture globally, which will further aggravate food insecurities and shortages. Russia heavily exports natural gas to the European Countries (Figure 4) and therefore, the supply cut of the gas from Russia will likely increase the prices of each commodity in the dependent nations.

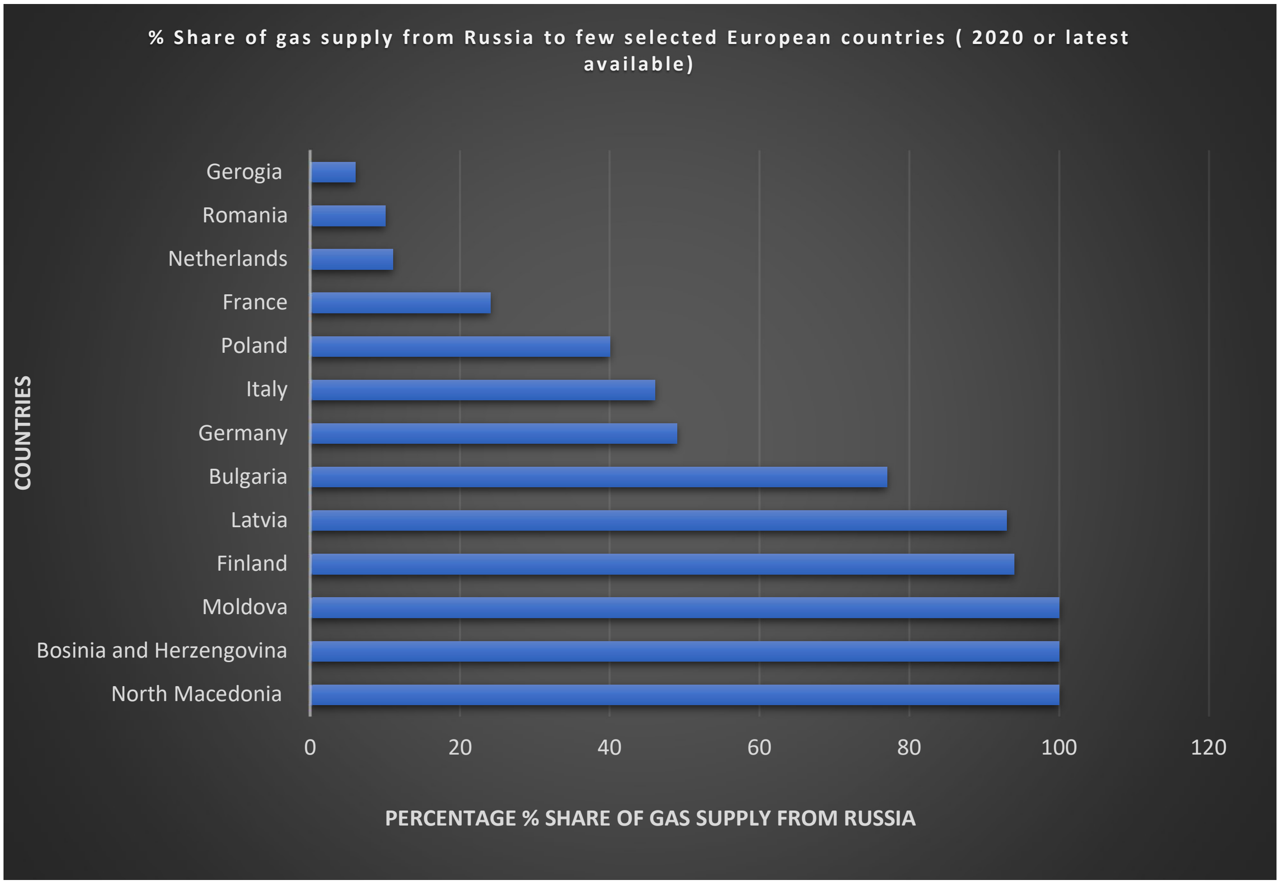


Figure 4. Percentage share of gas of supply from Russia to European Countries 2020. (Buchholz 2022)

Higher energy-related costs would result in lower agricultural outputs, an increase in the prices of agricultural products, drastic reduction in farm income and farm productivity that leads to food shortages (Sands and Wescott August 2011).

3.2 Economic Shocks

Economic shocks can be addressed as random, unpredictable events rendering adverse impacts on the economy, while their causes are outside the scope of economic models. Economic shocks can be classified as fundamentally impacting the economy from either supply or demand side. These shocks also are one of the substantial drivers of food crises in 2020 as an indirect impact of the COVID-19 pandemic. The socioeconomic influence of the COVID-19 pandemic exacerbated the worst food crises in Haiti, Sudan, and Zimbabwe (FSIN 2021), where the economic shocks had been already intensified in 2019. Several measures to curb the pandemic resulted in significant income and employment losses, leading to a sharp reduction in household purchasing capacity, further pushing the population towards hunger.

Additionally, a disruptive supply chain resulted in sudden spikes in food prices, specifically during the initial lockdown period, and remained high priced thereafter. Increasing inflation rates, particularly in import-dependent countries, further resulted in poor food accessibility to the population. Declining economic growth and reductions in government financial reserves render these countries incapable of supporting the food needs of a vulnerable population. A massive decrease in export and domestic revenues and increased costs to support healthcare resulted in unsustainable levels of public debts in various countries.

Economic decline in several countries such as Yemen along with persistent inflation with the local currency in free fall and depletion of foreign exchange reserves have contributed to rising food prices and food crisis. The Yemeni riyal, from mid-December 2019 to mid-June 2020, lost an average of 19 percent of its value against the US dollar, significantly greater than the 2018 crisis level (UNICEF 2020).

Short-term economic shocks resulting from abrupt natural calamities also generally decrease food availability in the affected areas, forcing those countries involved to depend entirely upon aid to obtain enough food for the affected population. However, unsuitable world response, such as unnecessary food aid by the U.S. to Guatemala's following the 1976 earthquake, often results in disruption of markets and loss of local farmers' income, who faces dipping food prices and agricultural income even when they have fresh crops (Messer and DeRose 1998).

Communal or government intervention is required to ensure the sustainability of food production, price stabilization, crop insurance, contingency plans for famine relief, unbiased, and ensure competitive market situations (Upton 1993). Likewise, public funding in the agriculture sector is obligatory to encourage growth in food provisions.

3.3 Climate crisis

Global warming and climate change also directly affect freshwater resources worldwide, leading to persistent mega droughts in some regions and in contrast excessive flooding in other parts of the world. In addition, rising sea levels and salinity intrusions obstruct crop farming and aquaculture production in the coastal zones.

The increasing temperatures in water resources also cause shift in the habitats of many fish and shellfish species which impact the functioning of the ecosystems. The increasing temperature and the CO_2 concentrations cause misbalance of the nutrients in the soil, impact soil moisture, water availability and other parameters related to the crop performance. The changing precipitation patterns leading to the droughts and floods severely challenge the farmers to maintain crop productivity on their farms. Potentially, there are many adverse impacts on agriculture and related sectors namely livestock and fisheries due to global warming and the climate change (Gomez-Zavaglia, Mejuto and Simal-Gandara 2020).

Currently, climate change is impacting the vulnerable populations of the developing countries and unless prompt actions are taken, the effects will be expanding to other parts of the world. The temperate regions such as United Kingdom (UK) where moderate changes in the climate will be experienced need longer term planning and operational changes in the agriculture and livestock system (Wreford and Topp 2020). The country such as Bhutan which is considered as carbon negative is prone to the weather disturbances due to climate change such as untimely rains, drought, soil erosion and drying irrigation sources (Chhogyel, Kumar and Bajgai 2020).

One fifth of the world's population lives in the South Asia and it is the most disaster-prone region on the planet; additionally, the rapidly growing population, degrading natural resources, high poverty and inadequate food security further make it the most vulnerable to the impacts of climate change (Sivakumar and Stefanski 2010). The co-existence of natural (hot and humid climate) and manmade stressors (high population density, poverty-driven low adaptive capacity) increases the vulnerability of South Asia towards the global warming. South Asia where the agriculture sector is the pillar of their economies and so 60% of the working population which works in the open fields is at severe risk due to the heat stress. The major impacts of climate change are seen through global increases in environmental temperatures, melting of the glaciers and ice and the rising of the sea levels. These are some of the consequences of climate change which have cascading effects on the global weather conditions, which leads to forest fires, floods, droughts, catastrophic storms, cyclones and declining freshwaters resources. The holistic analysis of current and historical climate variability in terms of extreme meteorological events such as tropical, winter and hail storms, tornados; hydrological events namely floods, flash floods, landslides, storm surges; and climatological events like freezing, wildfires and droughts is carried out to develop the Global Climate Risk Index (CRI) (Eckstein, et al. 2020). One country namely Bangladesh where socio-economic crisis are prevalent is worst hit due to climate change and sea level rise. The prevailing conditions in countries like India, Bangladesh and Sri Lanka are inhospitable for millions of people including the farmers which can negatively affect the human and consequently food productivities in these agriculture dominant economies. These three countries are among the top 10 countries in the world that are most affected due to climate change. The simulation studies based on climate models like Massachusetts Institute of Technology Regional Climate Model (MRCM), the TW_{max} has been projected to increase the survivability threshold at various locations in India namely Chota Nagpur Plateau, northeastern India, and Bangladesh (Im, Pal and Eltahir 2017). The rising temperatures will negatively impact the crop yields of the tropical zones where they are already being cultivated near to their temperature threshold values. The crops also suffer from the indirect impacts due to the water shortages, droughts, loss of soil quality and diseases and pests (Sivakumar and Stefanski 2010).The fluctuation in the mean annual temperature adversely impacts the growth of crops and accelerates the rate of deterioration of the harvested crops if stored inappropriately. The changes in the climate, weather, precipitation, and CO_2 concentration directly impact the growth of the crops. Agriculture is adversely affected by the impacts of changing climate on freshwater resources which are steadily declining worldwide.

The weather extremes due to climate change were the primary driver of acute food insecurity in 15 countries with around 16 million people in the crisis or worse (IPC/CH Phase 3 or above) or equivalent in the year 2020 (GRFC 2021). Adequate rains in some regions improved the crop yields, while heavy rains lead to floods, death displacement, and loss of properties, crops, livestock, and critical infrastructure in the most food-insecure countries such as South Asia, the Middle East, and Africa. Likewise, Central America and Haiti faced tropical storms, hurricanes, flooding, and drought which caused acute food insecurity in the regions. Weather extremes were likewise, the major drivers resulting in extreme food insecurity in Madagascar, the United Republic of Tanzania, Angola, and Burundi, because of prolonged droughts and flooding.

Besides the abiotic consequences, the biotic components of our ecosystem are also affected due to climate change; The spread of pests and diseases under the impact of climate change has increased drastically. Climate change has adversely impacted the pastoral and agro-ecosystems. As climate is the driving factor for pathogen infections and toxin production, the unprecedented changes in the temperatures, precipitation and increasing CO_2 concentrations hugely impact the host-pathogen interactions and the geographical distributions of the pests (Perrone, et al. 2020). The potential threats of food-borne diseases and invasive alien species that are harmful for plant and animal health due to climate change affect agriculture and livestock productivities. The abiotic components of climate change namely increasing temperature and increased incidences of flooding can potentially increase the pathogen load, alter weed, fungal and insect populations resulting into the enhanced use of harmful pesticides (Maggiore, et al. 2020). The food security and the food safety are intertwined; and climate change impacts the food safety and nutrition at each stage of supply chain from farm-to-fork. The food and nutrition safety also include livestock production where the enhanced productivities are attained by the overuse of antibiotics which is leading to antibiotic resistance in human populations which further challenge their ability to fight evolving bacterial infections (Aiyar and Pingali 2020).

The increasing concentrations of CO_2cause increased susceptibility of soybean to invasive insects. Similarly, the varying growth of insects due to the global warming has caused 10-25% reduction in the global yields of three staple grains namely rice, wheat, and maize (Ceccarelli and Grando 2020). The physical phenomena related to climate change such as increasing temperatures, torrential rains, drought, and tropical storms not only affect the crop yields directly but also contribute to the spread and transmission of the insect pests and plant diseases (Ceccarelli and Grando 2020).

Climate change negatively impacts the yields of some crops (for example maize and wheat), generally in lower-latitude regions, while positive impacts are observed in the yields of some crops (such as maize, wheat, and sugar beets) in several higher-latitude regions during the recent time.

Warming along with drying has negatively impacted the crops yields in several parts of the Mediterranean. Likewise, climate change is considered as the major cause of food insecurity in drylands, specifically in Africa and the high mountainous region of Asia and South America (Mbow, et al. 2019).Due to the interconnectedness of extreme events and food systems, the risk of food systems increases many folds with the onset of extreme weather events.

Several economic models project the increase of 1-29% of cereal prices in 2050 due to climate change, impacting the purchasing ability of consumers globally, however, the regional effects may vary. Though higher levels of carbon dioxide at elevated temperatures have proven beneficial for crop productivity, the nutritional quality of the crops will dwindle. Climate change between 1981 and 2010 is estimated to reduce the global mean yields of maize, wheat, and soybeans by 4.1, 1.8, and 4.5%, respectively (Mbow, et al. 2019).

Climate change adversely impacts fruit and vegetable yields, which form the major component of healthy diets. The production of fruits and vegetables tends to decline under elevated temperatures, especially in tropical and semi-tropical regions. Heat stresses induce a reduction in fruit set and accelerated development of annual vegetables, accounting for the loss of yield, lowering quality, food loss, and waste. Warmer winters pose risk to the fruits and vegetables which necessitate a period of cold accumulation to produce a useful harvest.

A few of the major impacts of climate change on crop production in different continents are as listed:

Australia:

- The decline in rainfall and rise in daily maximum temperatures resulted in a drop of water-limited yield potential by 27% from 1990 to 2015, countering the positive impact of elevated atmospheric CO_2. (Zvi, Gobbett and Horan 2017).
- High temperature and low rainfall during the reproduction stage of crop growth caused negative impacts on wheat yields in New South Wales. (Innes, et al. 2015).
- Projected reduction of Australian wheat, beef, dairy, and sugar production by around 9-10 percent by 2030 and 13-19 percent by 2050, relative to the reference case (Gunasekera, et al. 2007).
- Elevated levels of heat stress lead to water stress (drought or waterlogging) and alteration in distribution & abundance of insects, pests, pathogens, and weeds on crops and pastures (Glover, et al. 2008).

Asia:

- Drastically affected agriculture and food security.
- Delayed dates of sowing and emergence of spring and winter wheat, with a prolonged period of flowering, maturity, and reproductive growth period from 1981-2011 in China (Liu, et al. 2018).
- Alteration in phenology and productivity of spring cotton in Northwest China. (Huang and Ji 2015).
- Reduction in wheat yields by 5.2% from 1981 to 2009, even with adaptations that may have occurred at that time. (Gupta, Somanathan and Dey 2017).
- A shift in spring maize growing period from 1980 to 2014, by an average of 4.6 days per decade earlier, while delayed sowing of autumn maize by 3.0 days per decade in Pakistan (Abbas, et al. 2017).
- Shifts in sowing, emergence, flowering periods, and maturity of fall and spring crops due to an increase in mean temperatures from 1980 to 2016 in Pakistan.
- Increased climate change made the people of the Hindu-Kush Himalayan region (comprising parts of Pakistan, India, Nepal, and China) more vulnerable and lead to food insecurity due to poor infrastructure, restricted access to global markets, geographical isolation, low productivity, higher cost of transportation and higher exposure to Glacial Lake Outburst Floods (Hussain, et al. 2016). The region faced weather

extremes, frequent floods, and drought, negatively impacting the agricultural yields and increasing food insecurity.

- Uneven warming across the continent leads to severe crop yield losses, impacting the prices, trade, and food security excessively largely impacting the poor people. Majorly hit regions will be South, Central, and West Asia, according to several predictions (Rosegrant, et al. 2010).
- Spoilage of rice production in the Southeast Asian deltas by flooding and storm surges, resulting due to rising sea levels and higher precipitation. Reduction in rice production in North-eastern Thailand by up to 17.8% from the current baseline, without any adaptation by 2030. (Teng, et al. 2015).
- Higher food insecurity was observed in several Southeast Asian states, such as the Philippines, Laos, Cambodia, Burma, and Indonesia. Severely impacted 'rice basket' regions which form the major rice source of several regions, for example, Vietnam's Mekong Delta, which feeds as much as half the country's population, is considered a high-risk region (NIC 2010).
- Higher temperatures decline the rice production by 3.8% by 2100 in Thailand, Bangladesh, southern China, and western India, while increases are predicted for Indonesia, Malaysia, and Taiwan Province of China and parts of India and China due to CO_2 fertilization (Shekar 2018).

South America:

- Alteration in the timing, severity, and pattern of the yearly weather cycle, adversely impacts the crop yield, in the mountainous region of the Andes.
- Climate change affected the crop yields and compelled farmers to alter the timing of planting, their soil management techniques, and spatial distribution of crops in Coloma and Bolivia as per the study in 2012 and 2014 (Saxena, et al. 2016).
- An increased yield unpredictability of maize and soybean was observed in Argentina (Iizumi, and Ramankutty 2016).These changes adversely impacted human health, agriculture, and regional biodiversity.
- Elevated levels of atmospheric and soil temperature result in loss of agricultural yields. For example, a significant drop in yields of corn and soybeans by 18% and 10% respectively was observed in the U.S. during the summer of 2012 (Wescott and Jewison 2013).
- Significant reduction in agricultural yields, livestock, fisheries across South America, however, an improved opportunity of increase in rice yield in LAC countries or improved fish catch potential in the southernmost South American waters was observed (Reyer, et al. 2015).

Africa:

- Reduction in yields of staple crops such as maize, wheat, sorghum, and fruit crops such as mangoes across Africa.
- Severe impacts of climate change on the livelihood of the arable crop farmers.
- High levels of malnutrition experienced in Sahel region of Cameroon, due to the negative impact of the climate crisis on agriculture (Chabejong 2016).
- Severe high temperature, stress, fluctuation in relative humidity, and flood frequency – major divers of loss of crop in Ebonyi state and Nigeria 2017.
- Elevated temperature by 4.5°C by 2030 is predicted to severely impact the agricultural systems in Africa with a significantly high level of food insecurity (Ngaira 2007).
- Reduction in land for agriculture due to the conversion of the high agricultural potential area into arid regions, submergence of coastal areas impacting the fishing activities and human settlements, increased desertification, and disappearance of ice and snow on mountains.
- Higher incidence of farm pests and diseases, food insecurity, and poverty especially in Tropical regions of Africa. (Ngaira 2007).

Europe:

- Adverse impact on European crop yields, due to long-term temperature and precipitation patterns since 1989, largely reducing the yield of wheat and barley by 2.5% and 3.8% respectively, with a minor increase in maize and sugar beet yields, across the continent (Moore and Lobell 2015).
- Increased warming in the cooler regions such as UK and Ireland with increment in rainfall.
- Increased temperatures in warmer regions such as Southern Europe, and accelerated drying scenario in Italy, accounted for the loss of yield by 5% or more.
- Significant impact on wheat and barley production in Greece.
- The onset of certain positive long-term impacts of the recent warming on the production of cucumbers and tomatoes 4.9% to 12% with an increase in 1% of regional temperature, however, a significant decrease in the production of root vegetation in the warmest region of Czech Republic (Potopová, et al. 2016).
- Negative impact on temperature crops in Hungary.
- Negative impact of increased temperature in northern Europe during winter and southern Europe during summer.
- Increased water shortages along the Mediterranean and in the southwest Balkans and south of European Russia.
- Significant decrease in the agricultural yield due to water shortage and extreme weather events such as heat, drought, and storms, dominating southern Europe. Intensification of agriculture in northern and western Europe, while intensification and abandonment in the Mediterranean and south-eastern parts of Europe (Bhindi and Olesen 2010).

3.3.1 Impacts of climate 'mal-adaptations' on fertilizer depletion- case study on first generation biofuels

The misguided efforts to reduce the fossil fuel dependency gave momentum to convert the grains and staple food items into the feedstock to produce biofuels. The impetus gained due to the global over consumption and threats of fossil fuel depletion led to the developments of various generations of biofuels. The first generations of biofuels, which are totally based on agricultural crops, compete with food crops for resources such as fertilizers, crop land and water.

Due to lack of pro-poor and pro-environment policies, the advantages of biofuels in tackling climate change, greenhouse gases emissions, deforestation seems dubious. Among its many impacts, the first-generation biofuels have negative impacts on the global biodiversity (Bindraban, Bulte and Conijn 2009) and food security. The world has seen a steady rise food prices since 2000 and one of the contributing factor is the first-generation biofuels production in global economies namely the United States Japan, Brazil, and the European Union (Renzaho, Kamara and Toole 2017). The overwhelming demands on the food supply system prior to biofuels bloom that caused world hunger and malnutrition further aggravated the food insecurity, particularly in poor countries where soaring food prices and shortages caused social unrest (Tenenbaum 2008). The tradeoff between agriculture food and biofuels production compromises the future food security (Hein and Leemans 2012).

3.3.2 Impacts of elevated levels of temperatures on soil microbial communities

Climatic changes have altered the composition and distribution of the soil microbiome. Several studies illustrate a significant shift in species distribution and interaction in response to climate change which activates the cascade of changes resulting in the alteration of biodiversity and the function of terrestrial ecosystems. The soil organisms interact with each other as well as plants in a way that formulates and maintains the ecosystem's properties. The elevated temperatures alter the relative abundance and function of soil communities as soil microbial communities differ in their physiology, temperature sensitivity, and growth rates. Studies reveal that warming by 5˚C in a temperate forest, may alter the relative abundances of soil bacteria and increase the bacterial to the fungal ratio of the community (Classen, et al. 2015).

The changes in the abundance of the microbial community adversely impact the different soil processes. For example, changes in the relative abundance of the microorganisms regulating the processes such as nitrogen fixation, nitrification, denitrification, and methanogenesis, have a direct impact on the plants' growth. The microbial responses such as decomposition of soil organic matter, microbial respiration, and microbial growth are short-lived under elevated temperature by several experimental field studies.

Experimental warming was observed to alter the composition of microbial communities causing the abundance shift of gram-positive and gram-negative bacteria (Zogg, et al. 1997). Shifts in microbial activity lead to alteration in decomposition, nitrogen mineralization, and organic carbon storage. However, it's been evident from several studies that the warming effect may similarlry take several years before an evident change is observed.

The alterations in the temperatures are generally clubbed with the changes in the soil moisture, which highly influences the soil microbial community. The rates of microbial activity are restricted by diffusion and the microbial contact of the substrate is also confined. (Zak, et al. 1999). A small change in the soil moisture content (30% reduction in the water holding capacity) causes the shift of soil fungal communities from one dominant species to another; however, the bacterial communities remain constant. (Classen, et al. 2015).A significant shift in bulk soil microbial community induced due to climate change may result in long-lasting effects on the plant growth, performance, and establishment of soil carbon balance. Therefore, climate change alters the soil microbial communities and determines the plant species' establishment and growth. Several studies likewise prove that alteration in microbial communities alters the plants' functional traits (Lau and Lennon 2012).

The warming causes significant leafing out in plant species as well as early flowering in the growing season. Climate change similarly adversely impacts root phenology and consequently the plant-rhizosphere interaction; however, these processes are less researched in phenological studies. Additionally, root symbionts such as *Rhizobium* and mycorrhizal fungi which influence plant productivity by altering the plant nutrient status also are adversely impacted by the climate alteration. The impact of specific strains of *Rhizobium* on other plants' characteristics may be similarly important under the global climatic change. The additional importance of *Rhizobium* strain fixing nitrogen in soil includes the increase in plant-specific leaf area and carbon assimilation rate. Likewise, mycorrhizal fungi are associated with carbon and nutrient-cycling processes, influencing plant carbon to nutrient ratios and subsequently the plants' productivity. Additionally, mycorrhizal fungi also affect the decomposition activity of the soil microbial community by modifying the plant litter quality as well as carbon inputs. Few mycorrhizal strains also alter plant reproduction, tiller production, root biomass production, and rooting depth (Ellis, Larsen and Boosalis 1985). These mycorrhizal community compositions can alter with the changing climatic factors such as temperature (Deslippe and Simard 2011).

The elevated levels of carbon dioxide can lead to the increased C allocation at the root zone and significantly change the root exudation composition (Mekala and Polepongu 2019). These alterations may lead to decreases in the availability of chemo-attractants, the signal compounds and the C/N ratio or nutrient availability. The low molecular weight carbon compounds present in the root exudates appear to play a vital role in increasing the microbial abundance, their activity in the rhizosphere, their structure, and their function. Therefore, the impact of climate change on root exudates adversely affects plant growth. Consequently, microorganisms with beneficial effects on plants' growth and health might also be malfunctioned, in terms of exhibiting their useful properties and their colonization capabilities.

Several studies link the increase in the CO_2 to increase colonization of plant-growth-promoting fungi, however, increase CO_2 levels may stimulate changes in the community composition of arbuscular mycorrhizal fungi (AMF) (klironomos, et al. 2005).AMF is responsible to improve plant nutrient uptake and provide other benefits. However, the changes in the microbial composition due to climatic stress may lead to competition with different microbial communities changing the colonization behaviour. Additionally, several studies suggest that the elevated CO_2 may interact with the plant-fungal symbiosis leading to increased endophyte infection frequency, though with lowered toxin production. (Nelson, et al. 2009).The impact of CO2 on the host plant and its endosymbionts may also change the plant carbohydrate content. Likewise, alteration in the plant beneficial soil microbiota (such as mycorrhizal and nitrogen-fixing bacteria which provides up to 80% N and up to 75% P respectively), ultimately influences plant diversity and functioning of soil microbiota. The elevated levels of CO2 combined with soil moisture, drastically reduce the abundance of ammonium oxidizing bacteria, actively involved in altering the nitrogen cycle in the soil.

Drought is one more undesirable event of climate change. Drought elevates the differential temperature sensitivity of fungal and bacterial groups (Briones, et al. 2014). Drought often is responsible for the reduction in the growth of roots and aerial plant parts, making the plant susceptible to other pathogenic attacks. The combination of elevated temperature and moisture may lead to the shift in the methane-oxidizing bacterial community, which otherwise plays a vital role in mitigating the flux of atmospheric methane (Mancinelli 1995). However, the exact mechanism of impact of climate change on the soil microbiota is yet unclear and other factors which display the impact on soil microbial communities and models are required to be studied.

4 Food production and depleting phosphate reserves

The use of conventional synthetic fertilizers in extensive agriculture all over the world will become a major limiting factor in achieving sustainability in food, oil, and fodder crops. Besides fertilizers, water scarcity, pollution and climate change also limit agriculture productivity and consequently food security. As the conventional animal and aquaculture feed is also dependent on agriculture, the livestock and fisheries sector are going to equally impacted by the climate change related unavailability of the resources. Due to high costs and inefficient management, countries of the African, South American and Eastern Europe continents are suffering from high phosphorous depletion rates and so the agriculture soils worldwide would be in future (Alewell, et al. 2020). The slow geophysical phenomenon of rock weathering and the anthropogenic inputs of inorganic fertilizers are the main contributors towards the replenishment of phosphorous depletion in the agriculture soils. Phosphate fertilizers are obtained from the phosphate rocks (PR) reserves and approximately 70% of the PR reserves are found in Morocco and Western Sahara followed by US and China (Nedelciu, et al. 2020).The importance of these two regions would be remarkable after 2030 to meet the global requirement (Mohr and Evans 2013). The mineral P deriving from the non-renewable geologic reserves get wasted during agriculture run-off discharges and untreated wastewaters into the inland and coastal water bodies causing eutrophication. In addition, the mining and processing of PR release by-products such as phosphorgypsum and heavy metals toxic waste containing cadmium and uranium causing air and water pollution (Nedelciu, et al. 2020). The regions of the world such as the US-mid west, Western Europe, the Ganges Valley and East Asia have high P application rates in their agricultural fields and thus will transgress into the biogeochemical Planetary Boundary for P in a zone of high risk (Stefen, et al. 2015) (Nedelciu, et al. 2020). Tackling the P losses associated with the cradle-to-grave supply chains could best be achieved by improving the efficiency of fertilization and recovery of P from the wastewaters that also subsequently ensure food security, sustainability, and establishment of circular economy.

The genetic materials of all organisms contain P, thus an essential nutrient necessary for the survival of species. The phosphorous supply chain is an important component of the right and access to food which must match the extent of growing populations in a region. Therefore, food security is related to the regional phosphate balance. In accordance to the population dynamics, the world regions namely South Asia, Latin America and the Caribbean will have an increase demand for P followed by North Africa and Sub Saharan Africa and West Asia (Nedelciu, et al. 2020). A higher than supply requirement in 2040 calculated using System Dynamics modeling indicates inadequacy of the current P production to meet needs for growing world populations (Nedelciu, et al. 2020).

5 Impact of COVID-19 on Global food storage

The rapidly spreading of different variants of SARS-CoV-2 has tremendously impacted the global agriculture and food markets. International Monetary Funds (IMF) has significantly downgraded the GDP growth in a few months due to the COVID-19 pandemic. The newly projected economic environment is most likely to cause deep impacts on the food demand, access to food a nutritional need in the coming years. The global food (cereal) stock held globally at the beginning of COVID-19 2020 was multi-year high accounting for 850 million tons (Schmidhuber 2020). This high stock should provide a buffer against any crisis such as bad weather events observed in the 2020/21 season. However, the high stocks held globally may not provide the buffer capacity due to the disruption in the global supply chains, for example, a breakdown in bulk shipment facilities.

5.1 Disruption of supply chains and agricultural systems

The Food supply chain can be aptly divided into several stages involving agricultural production, post-harvest, handling, processing, distribution, and consumption. Due to the COVID-19 pandemic, there have been significant restrictions in the transportation (land, water, and air transport) of goods, as well as migration of labour, globally. Several reports indicate that the utilization of trucks for food distribution declined by 60% since the restrictions in France, which otherwise formed 30% of the traffic (Bakalis, et al. 2020).

Temporary or seasonal employment is quite common in several countries, especially in developing and underdeveloped countries, for planting, sorting harvesting, processing, and transporting of goods. Therefore, the supply chain becomes highly susceptible to the absence of local or migrant workers owing to sickness or lockdowns. Similarly, the SARS-CoV-2 infections restrict the movement of the labours, which caused severe disruptions in several labour-intensive sectors such as livestock production, horticulture, planting, harvesting, and crop processing (Stephens, et al. 2020).The severe shortage of labour force retarded the delivery of food and agricultural inputs creating issues in providing food supply to markets. Likewise, logistic barriers disrupting the food supply chain, further deteriorated high-value goods owing to their short shelf life.

Production of agricultural produce and its distribution is finely tuned and highly inter-connected. A little disturbance/delay in any of the stages causes a big loss in the agricultural yield and outputs. Many reports state the destruction of the farm products by burning or leaving them to deteriorate due to the perishable nature of the agriculture produced, by farmers globally. For example, dairy farmers in America Co-operative dumped 14 million litres of milk every day due to the disrupted supply chain (Aday and Aday 2020). Similarly in England, the union of dairy farmers reported the risk of approximately 5 million litres of milk in one week. In Nepal, the dairy product of around NPR 2 billion was damaged and dairy stock approximately of NPR 5 billion have been on the verge of damage (Poudel, et al. 2020). Even in India, logistics challenges have reported the loss of tea plants. In China, the pandemic has caused a higher impact on livestock farming due to limited access to animal feed and labour.The fishing activities dwindled majorly in Africa, Europe, and Asia due to physical distancing, restricted input supply, and labour shortages. (F. FAO 2020). The inability of the fish farmers to sell their harvest and obtain seed and feed for aquacultures adds up to the fish food crisis.

World Merchandise trade faced a decline of 13% to 22% due to the pandemic. The disruption in the supply chain causes discontinuity of agricultural businesses, resulting in a negative effect on the food quality, safety, freshens, affordability, and hinders access to the market. The movement restriction also impacted the demands of consumers. Owing to restrictions, the consumers failed to go to the restaurants and avoided the visit the markets and supermarkets due to fear of catching the disease. This led to the disruption of food markets and spoilage of stored food and economic losses related to food.

The supply chain not only affects the producers, distributors, and consumers, but also the labour-intensive food-processing facilities. Several productions plants were shut down due to a lack of workers due to the fear of contracting the disease, especially in meat-processing food companies. Due to these reasons, there was a significant reduction of 25% in the production capacity of pork industries in April 2020 (Aday and Aday 2020).Around 462 meat packaging, 257 food-processing plants, and 93 farm and production facilities were adversely impacted by the pandemic only in the USA. Similar reports were also obtained from England, Wales, and Gana. These close downs had a significant impact on the food supply chain. The producers were compelled to cut down on their farm animals, due to the shutdown of most of the food plants. The entire scenario shot the prices of the meat products, evenly impacting the food services, where the restaurants stopped the serving of beef and pork items. Along with meat products, other agricultural goods, seafood, dairy products were similarly affected. The export of the food was also impacted, not only due to the movement restriction but also due to the stringent requirements implemented for food export in a few countries. For example, food exporters to China were demanded to produce an officially signed declaration that guaranteed the food to be free from coronavirus contamination. The COVID-19 pandemic not only disrupted the supply chain leading to severe global food shortage but also caused alteration in the supply-demand balance, leaving the small producers and labourers in a dire situation.

5.2 Food insecurity

The pandemic has caused intensive food insecurity throughout the globe and is considered as the immediate and direct impact of the pandemic. Some of the main drivers of food insecurity tied to this are listed below:

1. Reduction in the purchasing ability of the workers due to loss of income, permanent or temporary.
2. Extended lockdown resulting in reduced access to food markets and local food gathering events.
3. Prolonged shut down of institutions supporting the social safety network, such as food banks and school feeding agendas (Stephens, et al. 2020).
4. The inability of the supermarkets to restock the inventories from the centralized distribution system to support the unprecedented demands.
5. Disruption of transportation network leading to wastage of fresh farm produce, fruits, vegetables, and milk.

These are all the ripple impacts of the disrupted food supply chain and the loss of agricultural products due to restricted movements and fear of contracting the disease. The inability of governments and several others authorized organizations to take quick action against food insecurity led to the food crisis severely affecting the most vulnerable group of the population. Different measures must focus on keeping the global food supply chain lively and mitigating the impact of the pandemic entirely across the food systems. Likewise, various social programs/plans/ agendas serve as a mediator to minimize the effect of short-term food crises. Governments/NGOs must protect the most vulnerable group of population involving the population suffering from chronic hunger, small farmers, and children from low-income families. Thus, it is a moral obligation of each country to guide their programs towards maintaining the social food programs and taking necessary precautions to confine the transmission of the coronavirus (Siche 2020).

6 Low cost practical solutions for mitigating global food crisis

The global food crisis due to all the above-mentioned causes has deeply penetrated the global society. Millions of people across the globe are struggling to meet their daily food needs. Global hunger is increasing exponentially, especially due to the COVID-19 pandemic and the Russia-Ukraine war in present times. It is quite essential to formulate and implement several mitigations plans or solutions to curb the global food shortage to save millions of lives on the planet. Few of the generalized mitigation plans need to be adopted by the different countries of the world.

- Minimizing the shocks to the agricultural field by allowing the farmers to work, plant, and market their crops, despite COVID-19 restrictions.
- Involvement of the government for aiding the farmers to plant and purchase their produces and issuing of crop insurances.
- Utilization of previously fallow land into agricultural use, for raising easily-grown plants such as cassava shoots.
- Reduction in tariff on food imports. Several African countries such as Burundi, Rwanda, Kenya, Tanzania, and Uganda, impose high tariffs on food imports. These tariffs are usually imposed to protect the regional farmers and generate revenue under normal market conditions. However, waiving off the tariff can aid the mitigation of food shortages, along with the implementation of a flexible trade policy (Terp, Shah and Jahn 2020).

- Provision of food rations and coupons by the government to provide its own stock or purchased from the private traders. The composition and distribution of the rations must be regulated by the governmental aegis. Such practice is already followed in several countries worldwide, for example in Egypt. However, the rationing of the stocks must be protected from being expensive and abusive over time. Rationing of the food stocks and issuing of the coupons may likely hold a good place for short-term mitigation of food shortages, during pandemics and extreme weather events.
- Scaling up microalgal production in the coastal areas may provide a decent alternative to animal feed and could be utilized as a highly nutritional food additive. Production of microalgae holds a noteworthy position in curbing the food crisis, as the labour-intensive production of fruits and vegetables is affected by the pandemic. Likewise, they are prone to spoilage during inappropriate storage and transport. The microalgae can be grown easily by vegetative propagation, involving a rapid growth cycle, and requires no land, freshwater, or fertilizers for their growth.

6.1 Urban agriculture and home gardens

The COVID-19 pandemic has entirely disrupted the food supply chain. Therefore, it becomes quite crucial to tighten up the local food production at the household and community levels. Home gardening involves the farming system which combines the several different physical, social and economic functions of the land surrounding the family home to enhance the supply of fresh food at the household level. Globally, home gardens hold an important position in supplementing sources of food, nutritional security, and livelihoods. Food production on small plots beside human residence isn't a new form of farming but practiced for many years. The home garden provides easy daily access to fresh vegetables and fruits, allowing the consumers to relish the balance diets providing an additional source of proteins, vitamins, and minerals (Galhena, Freed and Maredia 2013). Likewise, plating of the medicinal herbs enhances human health and wellbeing. Therefore, home gardens provide the means of improving food security, diversity, nutritious value, and greenery around the houses.

The characteristics of the home garden are a) located near the family homes; b) comprises a high diversity of plants c) the food produce is supplemental and not the main source of family consumption and income; d) necessitates smaller plots and e) largely beneficial to the poorer section of the society. (Mitchell and Hanstad 2004). Home gardens are generally developed on lands that are not suited for field crops or fodder cultivation due to their size, topography, or location. The size of the home gardens varies from household to household, normally being smaller than the arable land owned by the household. Innovations and techniques have also allowed families with very little or no land to involve themselves in home gardening. The home gardens can be efficiently supplemented with kitchen waste, animal manure, and other organic residues thereby, serving the dual benefits of fertilizing the garden and reducing the waste.

The structure and composition of the home garden largely depend upon the socio-economic status of the family. For example, in Indonesia, it was observed that the families practicing home gardening became more economically stable, shifted from the production of staple foods to horticultural foods, and raised livestock. The home garden generally uses family labour such as women, children, and elders. Though home gardening activities require a lesser amount of farming and agronomic knowledge, crop losses can be greatly reduced, if the house members are better skilled and thoughtful.

The key benefits of home gardening are as listed:

- Enhanced food security.
- Availability of better nutritional food.
- Availability of diverse food.
- Improvement in the source of income.
- Providing aesthetic beauty in the neighbourhood.
- Improving the environment by increasing the recycling of water, waste nutrients, preventing soil erosion, and maintaining and enhancing local biodiversity (Landon-Lane 2004).

Urban agriculture (UA) comprises all forms of agricultural production (food and non-food) occurring within or around the cities (Wagstaff and Worthman 2013). Apart from the benefits listed in Table 1, UA efficiently improves several ecosystem services such as improving human health, improving accessibility of food to local communities, improving the economic prospects, enhancing aesthetic beauty, and strengthening community resilience. Likewise, UA may comprise land-based outdoor urban gardens and farms and indoor production systems such as hydroponics or aquaponics.

The conventional systems of bringing food from farms into large cities involve the transportation of several kilometres which have become vulnerable due to disruption of the food supply chain largely due to the pandemic. Therefore, there's an urgent need for shifting towards a more resilient food system to meet the food demands and alleviate the food crisis. Small scale UA has the potentiality of producing high crop yields through sensible management inputs required for achieving high sustainability of the system.

UA is practiced with varying intensities in different parts of the globe. For example, the percentage of families practicing UA varies from 10% in some large cities in North America o 80% in some smaller Siberian and Asian cities (Thomas 2014). In 2013, 42 million American households were practicing HGUA (home gardens and urban agriculture) by growing their own food either at home or in community gardens (Algert, et al. 2016). HGUA is equally practiced in New York, Moscow, Los Angeles, Paris, London, Sydney, etc.

During the COVID-19 pandemic innovations in HGUA systems aided in curbing the food crisis among a large population residing in mega and giga cities, supported in cutting down the food wastage and food mileage, provided nutritive food to eliminate hunger, and offered a stable source of income during lockdowns. HGUA can efficiently produce food within urban centres, including urban buildings.

Sr. No.	Societal Benefits	Economic Benefits	Environmental Benefits
1.	Increase in the food supply.	Providing employment opportunities.	Conservation of land and water resources.
2.	Enhancing the poor nutritional levels in urban settlements.	Reducing poverty.	Recycling of urban wastes
3.	Improving public health.	Increasing productivity of the urban environment.	Reduction in GHGs.
4.	Decreasing the unemployment rate.	Providing employment opportunities.	
5.	Reducing the probability of social conflicts.		

Table 1 Benefits of Urban Agriculture (Galuh Syahbana and Agustina 2012)

6.2 Indoor Farming/ Vertical farming

Indoor farming is a procedure of cultivating crops or plants, either on a small or large scale, entirely indoors. The pre-requisite of these procedures are well-regulated and maintained environmental parameters for the growth of the plants. The amount of light, nutritive needs of plants, moisture levels must be monitored and controlled by the farmers when they are growing crops entirely indoors. Though growing plants indoors may limit the options of produce obtained, lettuce, tomatoes, peppers, and herbs are widely cultivated through indoor farming.

A wide variety of plants can be grown by indoor farming, but generally, vegetables and herbs adapt well to this cultivation method. Large-scale indoor farming enhances the food supply and provides fresh produce to the population in large cities. Many of these farms are vertical farms and can produce much more crops in a small area as compared to outdoor, soil-based cultivation. One of the types of vertical farming systems – Aquaponics is discussed under.

Aquaponics implies a symbiotic combination of two systems: (a) Hydroponics which grow plants (without soil) in water and (b) Aquaculture for rearing fish (Figure 5). The water essentially re-cycles within these two systems. The plants consume the waste released by the fish resulting in the purification and oxygenation of water by plants for supporting the growth of fish in the system. The naturally occurring bacteria/bacteria present on the plant's root convert the fish waste (ammonia) present in water to nitrate (plant's nutrient) by the process of nitrification. The subsequent absorption of nitrates by the plants enhances their growth.

The three essential components of the system, i.e., fish, plants, and bacteria live side-by-side and function together for the creation of a mutually advantageous environment. Therefore, a successful, healthy, and functional system necessitates the correct balance between the three components. Achieving this balance requires optimization and thorough knowledge of each component of the system. It involves several trials and errors as well as technical know-how to develop a successful aquaponics system.

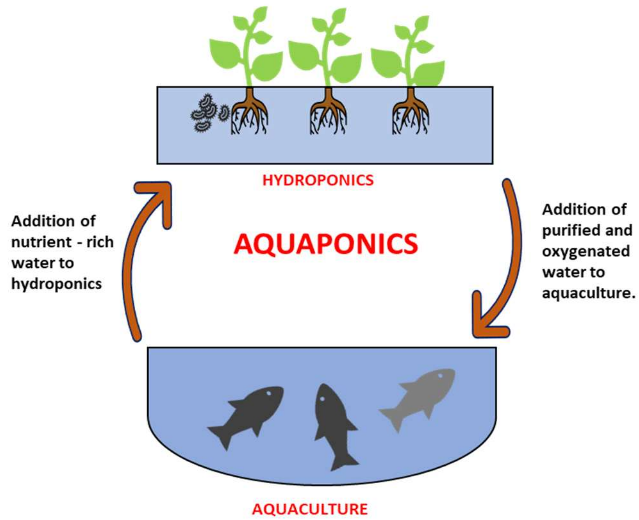


Figure 5. Aquaponics - System Overview

The plants have a few fundamental needs for growing successfully, which include air, water, sunlight, and nutrients. These essentials along with the process of photosynthesis enable the plants to form their food in form of glucose, which constitutes the building block of all the vegetative matter. In the aquaponics system, the fish serves as the provider of nutrients to the plants in contrast to the manures used in conventional farming techniques. The bacteria present in the system process the fish waste because the accumulation of fish waste at high levels proves to be toxic to the fish, converting into a highly accessible form by the plants. The aquaponics cycle begins with the feeding of fish. The waste matter generated by the fish gets converted into nitrates by the nitrifying bacteria, which in turn is utilized by plants for their growth. The plant filters the water and returns the water to the fish tank. Aquaponics is a promising solution to mitigate the food crisis and possessing to alleviate global food shortages. Aquaponics supports the growth of leafy lettuce, basil, kale, spinach, chives, radish sprout, swiss chard, arugula, pak choi, wheatgrass, etc., in a smaller-scale system, while, cabbage, cucumber, tomatoes, squash, beans, cabbage, etc. are adequately grown in larger systems. Aquaponics offer a sustainable, low maintenance and environmentally friendly option for simultaneous production of crop plants and fisheries (Figure 6).

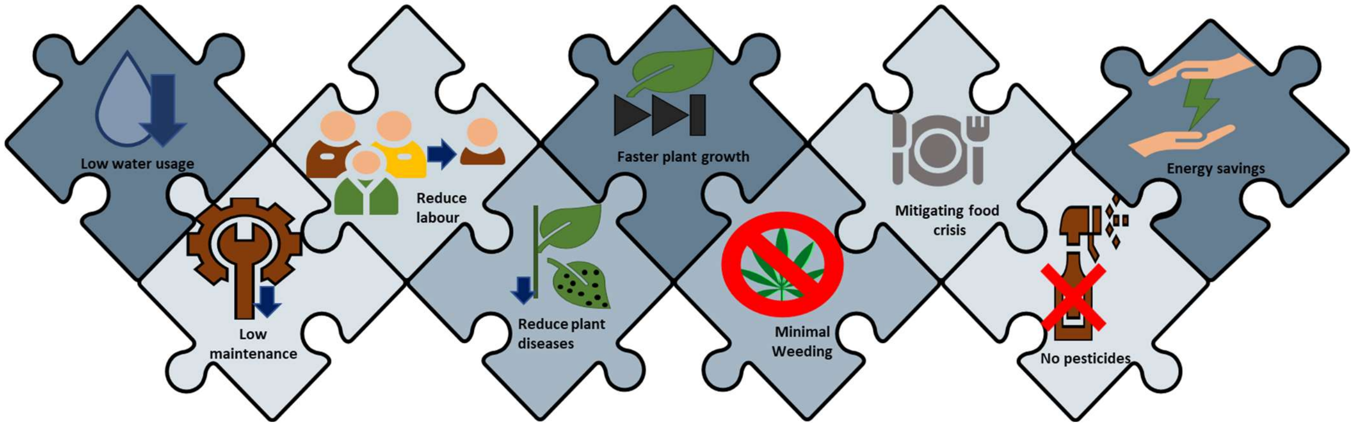


Figure 6. Advantages of Aquaponics Systems

6.3 Climate Smart Agricultural Solutions

The crops such as grains are not only crucial for food security but are both culprits and sufferers of climate change. One of the consequences of climate change is water scarcity which hugely impacts agriculture production as this sector is the major consumer of freshwater resources. Water management and implementation of effective adaptation measures ensures distribution of water for food production and consumption. Water conservation in the irrigation sector can be achieved by adopting smart and IoT-based precision agriculture sensor systems that monitor various parameters of soil quality and water quantity in the field along with weather conditions. The IoT solutions for automated irrigation further ensure better use of water resources at affordable cost without compromising on the farm yields. Precision agriculture systems monitor various parameters of the field including water and nutrient statuses to generate the data which is integrated into algorithms that determines irrigation requirement by creating fuzzy alerts. The IoT based machine learning systems support sustainable farming by creating fuzzy irrigation alerts such as low, high, and maintained water levels, low pressure and cyclonic storm (Veerachamy and Ramar 2022).

6.4 Agriculture digitalization- precision agriculture technologies opportunities

The COVID-19 pandemic has globally affected the food supply chain as import of many commodities including raw materials were severely impacted due to the lack of cross border transportations and logistics. The countries which were successful in controlling the spread of Covid-19 namely Vietnam were unable to import the raw materials from other neighboring Asian countries due to import restrictions and thus its supply chain was hit hard (Tasnim, Disruption in Global Food Supply Chain (FSCs) Due to Covid-19 Pandemic and Impact of Digitalization Through Block Chain Technology in FSCs Management. 2020).

The world's population is set to grow to around 10 billion in the next 30 years and therefore the agriculture supply must increase to meet the global food demands. The extremes and irregularities in temperature and weather phenomenon causing drought, flooding and the water shortages are some of the challenges related with climate change. The site-specific management practices can be automated using computer-based data driven monitoring systems. Paying attention to crop physiological traits, abiotic and biotic stresses, nutrient status, soil quality including moisture levels are the most important considerations for farm management practices. Land degradation and soil erosion due to unsustainable agriculture and land practices such as proliferation of cash crops, herbicide usage, intense tillage and use of heavy machinery subsequently impacts the hydrological response of the soil (Igor, Josip and Paulo 2020). Soil degradation due to unsustainable agriculture practices becomes unproductive for crop production. The farm production is laid on the strong foundation of good quality soil that play vital role in food security. In addition, the soil also acts as a potential carbon sink and thus has a role to play in sequestration of CO_2 emissions. Along with other nutrients the soil organic carbon plays essential roles in improving soil quality and agriculture productivity. The effective soil and resource management depend on assessments, effective monitoring, and automation of technologies of the precision agriculture which allows implementation of remedial measures such as optimized nutrient applications and controlled spatial and temporal irrigation and pesticide administration in the fields (Sarkar and Jha 2020). There are different components of soil management practices such as shown in Figure 7.

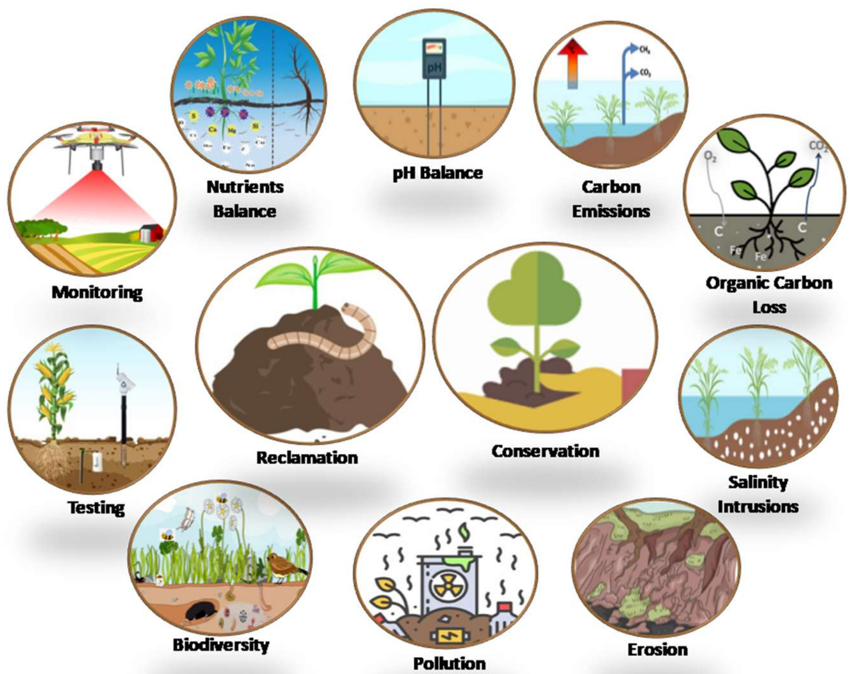


Figure 7. Various components of soil management.

Access to the on-farm advanced data driven tools and technologies would allow the farmers to take informed decisions and implement appropriate soil management strategies including soil fertilization. The overuse of nitrogenous fertilizers by the farmers is often in-efficiently absorbed by the crops which accounts for the nitrous oxide air pollution and nutrient overloaded agriculture discharges. The conventional soil testing methods are cumbersome, time consuming and expensive and require well equipped laboratories. In contrast, the digital and smartphones-based monitoring systems are inexpensive and easily accessible options. These digital platforms are based on different soil parameters and qualities such as texture and soil color; later is an important classifier for various soil constituents namely soil organic carbon, iron and silica compounds and carbonate minerals (Heil, Jörges and Stumpe 2022). The soil color can also be influenced by the interactions of various constituents and other soil properties such as soil water content, salinity, surface roughness and redoximorphic features (Heil, Jörges and Stumpe 2022). The spectral monitoring of soil organic carbon can be done using low cost, potable digital cameras and smartphones that can potentially be used as proximal soil sensors (Heil, Jörges and Stumpe 2022).

The site-specific recommendations regarding soil fertilization is crucial for both enhanced agriculture production and environment protection. The precision agriculture based on various hyper- and multi-spectral sensors that are either mounted on space, air or ground borne vehicles (Sarkar and Jha 2020) can assist growers in making timely decision with predictable outcomes that promote agri-food sustainability (Ingram and Maye 2020). In the 'farm-to-fork' concept, the digitalization of agriculture has potential to promote sustainable crop production at the farm level, and across the value chain till the food reaches consumers plates (Figure 8).

Figure 8. The 'farm-to-fork' concept of agriculture digitalization that promotes sustainable agri-production and supply value chain.

Farmers trained in soil testing can administer optimum fertilizer application in their fields which could further improved through the use of digital technology. Improved decision making regarding soil fertilization can aid farmers to enhance in-farm crop productivities without an overuse of fertilizers. The nutrient application in soil is not linearly correlated to the crop yield due to spatial and temporal variability which affect fertilizer use efficiency (Rurinda, et al. 2020). The Internet-of-Things (IoT) based system comprising of the Nitrogen-Phosphorous-Potassium sensor that calorimetrically monitor and analyze these nutrients in soil can alert the farmers about any soil deficiency (Lavanya, Rani and Ganeshkumar 2020). The smallholder farmers in different agroecological zones of Nigeria, Tanzania and Ethiopia have been benefitted by a simple and cost-effective computer-based decision support tool called the Nutrient Expert that allowed them to maintain high maize yields at lower fertilizer input cost than the conventional methods (Rurinda, et al. 2020).

6.5 Organic farming

Organic farming was developed to mitigate environmental damages caused due to the excessive utilization of pesticides and synthetic fertilizers in traditional agriculture that simultaneously offer numerous economic and environmental benefits. Organic farming refers to the crop production method where plants are never exposed to any form of synthetic chemicals at any stage from seed treatment to the final post-harvesting, handling, and processing.

Organic farming plays a vital role in sustaining the health of the soil, plants, and humans. It integrates conventional agricultural practices with innovation and science to offer substantial pros to the environments and the associated biotic components. It largely depends on four principles, health, ecology, fairness, and care. (Behera, et al. 2011). From a border perspective, it includes the use of biotechnology, biofertilizers, and biodiversity. All the countries have developed specific logos to indicate the organic produce and their compliance to stringent international guidelines and inspection schemes.

6.6 Characteristics of organic farming

Organic farming efficiently solves the major issue of environmental protection and sustainability by aiding soil conservation. The farmers practicing organic farming most certainly practice crop rotation to improve and enhance the soil fertility with natural resources. Organic farmers must follow the guidelines set by the local organic farming association. The crop nutrients are provided by the utilization of insoluble nutrient sources through soil microbes that efficiently elevate the nitrogen levels of the soil. Planting legumes alternating with the main crop plant substantially increases the nitrogen levels of the soil.

Organic farming strictly evades the utilization of chemical products to be administered on the farm animals, to control fleas or parasite issues, rather these problems are tackled by shifting the animals to new pastures and by utilization of home remedies to control the plant and animal pests.

Organic farming includes the farming of flowers and vegetables using composite manure.Some fundamental principles of organic farming are detailed as following:

1. Building of the biological fertility of the soil, supporting the plants to absorb the required nutrients from the steady turnover within the soil nutrients and their release without harming the soil/crops (Behera, et al. 2011).
2. Controlling the pests, diseases, and weeds by developing an ecological balance within the system and by utilizing the bio-pesticides and several cropping patterns such as crop rotation, mixed cropping, etc. to enhance the crop yield.
3. Recycling of all the farm wastes as manure and composts for improving the soil fertility and crop yield.
4. Enhancement of the environment in a way that conserves and supports wildlife.
5. Enhancement of soil fertility to support the higher floral and faunal diversity.

The various advantages of organic farming are listed below

- Reduction in the cost of production by almost 25%, due to eliminating the use of expensive synthetic fertilizers.
- Reduction in soil erosion almost up to 50% and increasing the crop yield to around five-folds.
- Easy transition from conventional to organic farming with a well-planned strategy and knowledge of effective organic farming practices.
- Highly beneficial in maintaining the ecological balance and biodiversity.
- Provision of nutritive, tasty, and healthy food with several health benefits.
- Improving the health of the cattle involved in the dairy industries.
- Efficiently cuts down the soil population and its degradation.
- Improves the soil fertility by supporting the microbial flora of the soil which improves the yield of the crops for several years without getting exhausted.

Owing to these advantages and in the interest of public health and to alleviate the food crisis, organic farming is practiced throughout the globe with varying degrees (Figure 9).

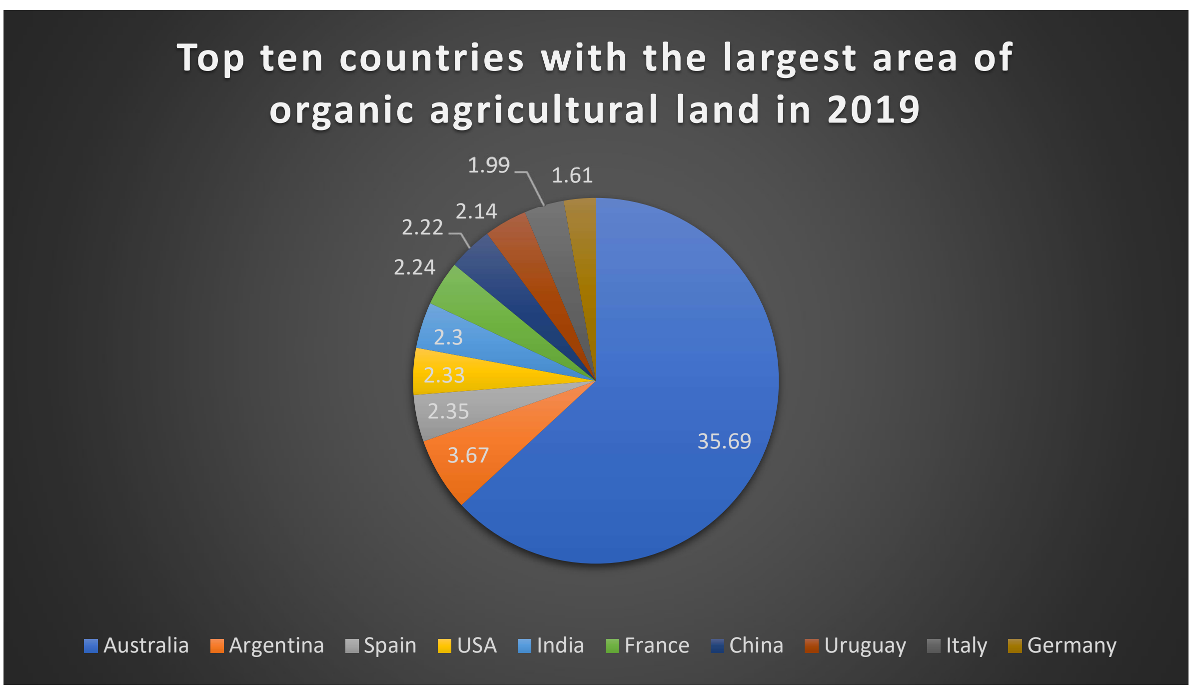


Figure 9. The graph below illustrates the top ten countries with the largest area of organic agricultural land in 2019. (Willer, et al. 2021)

6.7 *Techniques of organic farming*

The success of organic farming depends upon the success of each technique listed under:

6.7.1 *Improving soil fertility*

A fertile soil forms the basis of organic farming. The soil microorganisms play a vital role in enhancing soil fertility by several processes such as biological decomposition, aggregate formation, mineralization, humification, and nitrification/denitrification (FiBL 2021). The diversity of the soil population can be effectively improved by the supply of suitable food from crop residues, perennial clover grass meadows, green manures, and catch crops. The population of the soil microbes can also be improved by the utilization of manure or compost. Likewise, shallow cultivation of the soil without turning, rotating, or compacting, improves the soil structure and is quite beneficial for the growth of earthworms in the soil.

Organic farming necessitates gentle and effective tillage to avoid any extensive fractures of the soil, disruption of the soil structure, and soil erosion. Organic farming tries to maintain the natural structure of the soil and turns only the topsoil to promote fertility.

The building of humus in the soil is essential for maintaining soil fertility. The soil lacking enough humus could lead to soil compaction, lower water absorption capacity, and nitrogen supply potential. Contrary, an increase in the humus content results in more biologically active soil with neutral pH, better nutrient availability, and high nitrogen supply. The most rapid way of increasing the humus comprises the use of green manure or manure compost (FiBL 2021).

6.7.2 *Crop rotation*

Crop rotation is the practice of planting different crops sequentially on the same land to improve soil health, optimize the nutrient content of the soil, combat pests and weeds. Generally, legumes are grown alternatively with the crop plant to reintroduce the lost nitrogen from the soil. For example, clover – grasses are essential in organic crop rotation to maintain high yield levels. The crop rotation provides the following advantages.

- Improves soil fertility.
- Provides nutrients to subsequent crops.
- Destroys the weeds.
- Controls diseases and pests.
- Prevents soil erosion.
- Generates long-term profits.
- Provides onsite fodder production.

6.7.3 *Nutrient supply from organic sources*

Good nutrient inputs are even essential in organic farming, like conventional farming. However, the means of providing the nutrients in organic farming and conventional farming differs. In conventional farming, the nutrients are mainly supplied in mineral forms, while in organic farming, the nutrients are supplied in natural, organically bound forms, found in crop residues, farmyard manure, compost, and green compost (FiBL 2021). These organically bound nutrients must be mineralized for their active absorption by plants. The soil microbes are chiefly responsible for the mineralization process. The plants release energy-rich substances to promote microbiological activity in the root sphere. This process is hampered by using added mineral nutrients as in conventional farming.

The important nitrogen sources utilized in organic farming include manure from the farm, on-farm compost, commercial organic fertilizers, permanent meadows, leys, green manures, and grain legumes. Similarly, the most important organic fertilizers include manure (Balanced – cattle; P-rich – poultry), slurry (K-rich – cattle; P-rich – pig), compost (P-rich), and digestate (liquid – N-rich, Solid N-rich). Several commercially available biofertilizers are likewise utilized, especially for the cultivation of organic vegetables.

6.7.4 Control of weeds

Weed infestation greatly reduces the crop yield and substantially reduces the harvest. In organic farming, herbicides are not utilized for controlling the weeds, rather organic farming relies on several preventive measures and the use of some modern mechanical equipment such as harrows, hoes, and brushes to prevent/eliminate weeding. Some of the preventive measures to control weeds include (but are not limited to the following).

- Use of weed-free, certified seeds
- Avoiding the propagation of root weeds by fragmentation of rhizomes.
- Practicing crop rotation, involving the use of clover-grass, alternation of winter and summer crops, catch crops, and green manures.
- Appropriate ground cover involving close row spacing, under-sowing, and mixed cropping.
- Suitable seedbed preparation, by periodic use of plough and shelling during stubble cultivation.
- Use of well-rotted (manure) compost as fertilizers and adequate nitrogen application.

6.7.5 Measures to control diseases and pests

The use of synthetic chemicals and pesticides is prohibited in organic farming. Therefore, to prevent the spread of diseases and pests, several optimum preventive measures should be practiced. The

The preventive measures to avoid diseases begin by keeping the soil fertile by sustainable humus management, tillage, preventing compaction, and improving soil cover. The plants must be provided with balanced nutrition by utilizing organic fertilizers. Likewise, resistant plants and crops suited for the location (soil, climate, and farm) must be cultivated. Several suitable methods of cultivation such as practicing diverse crop rotation, mixed cropping, under-sowing, strategizing the sowing and planting time, and managing planting distances must be adopted to prevent the crops from pests and diseases.

Several biological plant protections are effectively used to alleviate the risk of plant pests and diseases. Biological plant protection involves the use of living beneficial organisms and biotechnical interventions to prevent and control pests. The commonly used biological protection includes the application of bacterial preparation such as *Bacillus thuringienesis* against pest caterpillars.

Biotechnical crop protection measures involve the use of a fine-mesh net against insects and glue rings on fruit trunks to trap the pests. Insect traps with several attractants such as juices, vinegar, and different colours to attract the pest, are chiefly utilized to monitor the infestations. These monitoring methods allow the formulation of suitable protection measures and treatment times to prevent insect infestations.

Examples of some of the biopesticides widely used in organic farming include Examples of some of the biopesticides widely used in the organic farming includes *Bacillus thuringiensis var. israelensis, Bacillus thuringiensis var. kurstaki, Bacillus thuringiensis var. galleriae, Bacillus sphaericus, Trichoderma viride, Pseudomonasfluoresens , Beauveria bassiana* (Tulipa and L.C 2019).

Some of the benefits of the biopesticides are listed under:

- Targets only the specific harmful species of insects and are non-toxic to beneficial insects.
- Eco-friendly and biodegradable.
- Minimums side effects with high performance.
- Less toxic as equated to chemical pesticides.

7 Resilient food systems

The current food systems involving intensive agriculture, food processing and globalisation of diets have significant negative impacts on the natural resource systems which are already pressed due to climate change. The massive environmental degradation and rapid depletion of natural resources would foremost and strongly affect the marginalised populations across the globe. Consumers play a crucial role in bringing the changes to the food systems. The rapid urbanization and worldwide increase in the middle-income group demand more processed foods which are produced through unsustainable cultivation systems.

To ensure continuous supply of food under the crisis situation is the fundamental principal of the food resilience. The communities must adapt and bounce back to the global shocks that endanger the food systems such as in the case of the recent COVID-19 pandemic. One of the ways to confer resilience to food system is by reducing the excess reliance on the imported food and developing policies that promote local food production practices (Ferguson, et al. 2022). The reliance on imported food becomes critical in the event of natural disasters such as cyclones that directly affect local food production (Ferguson, et al. 2022).

The three different notions of food resilience are i) robustness to resist the disruptions, ii) recovery and iii) re-organisation. The food system can be adapted or re-organised either by changing farming systems and/or by diversifying the sources of primary nutrients (Ingram 2019). Due to the changing dietary patterns and consumption demands of the overgrowing urban populations in the developing countries, the heavy reliance on the imported food commodities which resulted in the displacement of traditional foods. For example, the sub-Saharan African countries namely Kenya and Uganda imports up to 68% and 95% of wheat to meet their high urban demands for refined wheat breads (Noort, et al. 2022). Traditionally, rural African communities prepare a variety of nutritional meals such as dry grain snacks, porridges, gruels, fermented and unleavened flatbreads, fried and steamed dough from their diverse range of traditional crops such as cereals, psuedocereals, pulses, roots and tubers, oil seed legumes grown under local environmental conditions. Thus, the socioeconomic and environmental are important drivers that influence food supply chain. Apart from the shift in consumer's choices, another important parameter that displaced production of traditional food crops is that the major staple crops such as wheat, maize, rice and soybean has been the focus for the science and technology-based improvements of the agriculture productivities (Noort, et al. 2022).

The impacts of drought and high temperatures associated with climate change on productivity of traditional crops such as sorghum (most drought and high temperature resistant cereal) would be significantly lower than the wheat. On the contrary, there would be positive impacts on climate resilient crops namely sorghum, pearl millet and amaranth due to the expected high temperatures and precipitation in West Africa (Noort, et al. 2022). As the harsh climates would negatively impact the productivities of staple food crops such as wheat and maize; the shift towards the holistic development of climate resilient crops which are better adapted to abiotic stresses would ensure that agri-productivity keep pace with the growing demands (Noort, et al. 2022).

The communities that have incorporated the climate resilient crops in their diets are better adapted to the global shocks including the pandemic which has the worst attack on the food supply chain. The diets containing local produce of fresh vegetable, fruits, lean meat and seafood along with seeds and nuts provide nutritional diversity as compared to the processed and imported food items that lack adequate fibers and micronutrients. The inadequacy of nutrients in the modern diets makes communities prone to chronic metabolic disorders, obesity, all of which are relates to the severity of COVID-19 illness and morbidities. During the first shock wave of the COVID pandemic in year 2020, the rural food systems in the Pacific countries that are moderately relying on the global food supplies are found more resilient to the food insecurities; vice-versa, the over dependent communities on imported food supplies more likely reported food insecurity during pandemic crisis (Ferguson, et al. 2022).

For the development of the more productive food systems, there is an inevitable need to re-orient the consumption of physiologically unnecessary and unhealthy energy rich processed food that overburdens the existing food system and the environment (Ingram, Food system resilience 2019). The resilient food systems are interconnected with the ecosystem services and the food security for small holder farmers including fisheries. The contribution of ecosystem services is immense to nullify the effects of natural hazards triggered by the climate change at the small holder food system level (Varyvoda and Taren 2022).

7.1 Advanced technological interventions to develop resilience against abrupt global catastrophic risks

The abrupt sunlight reduction scenarios (ASRS) linked to nuclear winter, super volcanic eruption and attack by the space objects would massively reduce the agriculture productivity. The nuclear winter would alone have the potential to cause 75% global fatality owing to the famines and food starvation. The deployment of a suite of resilient food solutions such as cellulosic sugars, single cell proteins, and seaweeds would be conducive for warding off the ill effects of ASRS and other food system risks (Rivers, et al. 2022). The marine macroalgae such as seaweeds which have high tolerance to low sunlight and cold temperatures could rapidly scale to high productivity to meet the global demand for proteins under the ASRS (Rivers, et al. 2022). The low cost, rapidly scalable seaweed farming produces ample biomass rich in proteins, macro, micro-nutrient and bio active compounds without need of arable land and freshwater resources. Thus seaweeds offer sustainable climate resilient food solution to ensure global food security. In addition, the seaweed farming complies with the UN SDGs to ensure nutritious food to everyone without greatly impacting the environment (Bizzaro, Vatland and Pampanin 2022). The various options for the resilient food are seaweeds, single cell proteins, leaf protein concentrate, sardines, mushroom, bacteria growing on biomass, ruminants, lignocellulosic sugar production and industrial or synthetic fat (Martínez, Alvarado and Denkenberger 2022) (Throup, et al. 2022).

8 Conclusions

It is a quite evident and known fact that the world is facing an acute food shortage. The conventional form of food production is expensive, resource intensive, with a high degree of environmental impacts. In addition, the present forms of food system are vulnerable to the impacts of climate change. Furthermore, global food insecurities also arise from socio-political global conflicts, wars and emerging infectious diseases such as the COVID-19 pandemic. The COVID-19 pandemic has elevated hunger throughout the globe due to the unpreparedness of the global community for this abrupt crisis. Unprecedented disruption to the food supply chain, especially in underdeveloped and developing countries has pushed millions towards hunger and malnutrition. All these factors underscore the immediate need to enhance the resilience in the food systems.

The inefficient management of food systems and inappropriate consumer practices also leads to significant wastage of food. Circular economy strategies provide sustainable solutions that ensure food security, reduction in food system resources, wastewater reuse, recovery, and generation of renewable energy from waste food and water. An effective management of the various components of the food production system and supply chain namely soil and land, water, climate, and diseases is prerequisite for ensuring global food security. The increasing global temperatures and changing precipitation pattern is reducing both the surface and the ground water recharge capacities. Consequently, it leads to persistent droughts followed by soil and land degradation. In contrast, the excessive rainfall in other regions of the world is causing unprecedented flooding which directly destroy the standing crops.

The falling agriculture productivities due to various abiotic factors related to soil and weather conditions are beginning to be addressed using digital tools and Internet of Things. The use of smart phones for advanced monitoring sensors makes them affordable to small and marginalized farmers. Precision agriculture made possible with the use of advanced soil sensors helps farmers to attain higher productivity with minimum use of fertilizers. This would be economical and environmentally sustainable. Development and implementation of several innovations in farming techniques, such as urban farming, house gardens, and organic farming prove to be promising techniques in mitigating the ever-increasing food crisis globally.

Besides improving the agricultural and food production systems, the global catastrophic risks due to political conflicts resulting in the nuclear war and other natural calamities such as volcanic eruptions and comet impact put additional pressures on food system. The existing food production system would not suffice the needs during the abrupt sunlight reduction scenarios due to the global catastrophic risks. Therefore, complementing the existing food system with climate resilient crops and food sources is the need of the hour. Climate resilient food solutions encompass socio-economic changes, shift in dietary patterns of consumers, adoption of nature based agro-ecosystems, reverting to traditional climate resistant crops, seaweeds, repurposing of the lignocellulosic biomass, biorefineries and industrial foods including single cell proteins and synthetic fats.

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