Food Security and Carbon Footprint

Lessons from COVID-19 in the Indian Subcontinent

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Abstract

India is dealing with the most diverse, vast landholding where rural agriculture practice plays a key role to manage hunger, poverty, health, nutrition, and overall quality of life in a sustainable manner. Constraints, challenges, and regional inequality for food production, distribution, and nutrition program persist in different spatiotemporal frameworks here; their analyses under COVID-19 catastrophe may spot out the key determinants and linkages in solution finding, monitoring, and implementation for local conditions. Availability, access, and stability for complex food chains have been discussed where coexistences of economic breakdown, hidden hunger, inequality, and malnutrition are further threatening to aggravate rural distress, denials, and disease potential. This chapter intends to appraise multifaceted trends, consequences, and vulnerabilities in agri-food ecology, and requisite policy interventions and regional planning in pandemic response toward economic resilience and nationwide sustainable nutritional nourishment and food security have been suggested.

Keywords

Agriculture · COVID-19 · Food security · Pandemic · Climate change · Nutrition

1 Introduction

The United Nations Sustainable Development Goals (SDGs) launched in late 2015 are a compendium of 17 goals to upgrade the existence of human beings throughout the globe by 2030. The second goal, SDG 2, urges "to end hunger, achieve food security, improve nutrition and promote sustainable agriculture" (UN General Assembly, 2015). Current decades have experienced significant treads against hunger and malnutrition, although the challenges are stiffer ahead for 8.5 billion people estimated globally in 2030. India, the second-most populous country and fifth-largest economy by nominal GDP (2019) in the world, faced a remarkable incremental change in the last 50 years from 108.4 million tonnes of food-grain production in 1970–1971 to 284.8 million tonnes in 2017–2018 (GoI, 2018). Despite changing climate, finite natural resources, lack of farm mechanization and marketing infrastructure, etc., 44.2% workforce in the country depends on agriculture for their livelihood (National Statistical Office, 2019), and it still sustains almost 60% of the population.

India's achievement in self-sufficiency for staple grains often overlooks the sluggish growth rate and lower farm productivity leading to reduced farm profitability. It gradually shifts toward intensified, input-oriented extensive agricultural production, which negatively impacts soil fertility, lowers groundwater table, and accelerates agricultural pollution. Meanwhile, the complex, diverse socioeconomic issues, demographic, climatic, ecological, and landholding variations on a sub-national scale, are also the basis for widespread regional inequality from production

and distribution to the consumer's end. This substantial spatial and temporal variability and fluctuating trends of potential productivity are more relevant for determining direct physical and economic access to food. Also, it reveals other qualitative social indexes, e.g., rural poverty, employment, and undernutrition.

COVID-19, caused by a novel coronavirus (SARS-CoV-2), is a rapidly transmissible disease identified in December 2019 and declared a pandemic by WHO. Food and nutritional security have marked serious concerns worldwide due to threatening health crises from this pandemic and history's biggest post-lockdown phase. The pandemic may also seriously impact labor-intensive crop production and processing due to labor shortages (ILO Monitor, 2020). Farmers with perishable commodities have faced severe adversities due to disrupting the supply chain and cold storage facilities. The worker's migration from different states to their native homes has also triggered inconvenience in the processes of harvesting onward.

The agri-food sector is the most vulnerable part of society, usually affected by broad natural external factors, and this type of recent incidence exaggerates the situation. It is crucial to reassess the ongoing and possible impact of pandemonium with its consequences on food systems on a regional scale to implement suggestive mitigation measures.

Here we analyze availability, access, and stability, three backbones for food security in the spatiotemporal context under the COVID-19 pandemic situation, for regional planning and policy innovations in the postcrisis period.

2 Food Security Issues in COVID-19

Food security is the critical component of the United Nations 2030 Agenda to achieve Sustainable Development Goals (SDG) (UN, 2019). Food security links with a nation's socioeconomic and environmental dimension, which is often underestimated by biological context. Theoretically, Food and Agricultural Organization (FAO) defines this term as "exists when all people at all times have physical and economic access to sufficient, safe, and nutritious food that meets their dietary and food preferences for an active life" (FAO, 2018).

Ensuring a robust food security system is very challenging but imperative in times of pandemic crisis. The far-reaching ramifications of this pandemic will resonate with all the dimensions of food security – availability (whether or not the supply of food is adequate), access (acquiring food at need), utilization (intake of enough nutrients), and stability (accessing food at all times), but in the short term, its most intense effect will be on food availability and access (Adhikari et al., 2021). The number of people facing acute food insecurity skyrocketed in 2019–2021. Persons who already are or are at risk of becoming acutely food insecure are globally 272 million (WFP 2021). A study in an informal settlement in Kenya reported 88% of the households to be food insecure between December 2019 and April 2020 (Shupler et al., 2021). Food security remains highly demanding in developing countries like India, where three out of four poor people are from rural regions and predominantly rely on agri-livelihoods.

After the Green Revolution, there was rapid growth in production to be habitually self- sufficient despite India's steady population growth rate (Gadgil et al., 1999). By introducing a national agriculture development program (NADP) with high-yielding varieties (HYV), fertilizer technology, and modern irrigation infrastructure, accelerating supplies and access rates of staple grains have been marked gradually as major policy concerns. Thereof, intensive cereal production over the past 50 years has tripled, with rice and wheat contributing 44% and 30% of total cereal production in India, respectively (ICRISAT, 2015). In the last 20 years, the country's total food and grain production steadily proliferated from 198 to 284.8 million tonnes (MT) (GoI, 2018). Consequently, the country has topped to be the highest producer of jute, tea spices, milk, cashew, and pulses and has achieved the second highest position of global vegetables, oilseeds, and fruits production. Agricultural goods account for the country's 10% of exports, the fourth largest principal commodity (APEDA, 2016).

Nutrition can be linked with agriculture with either generic or specific effects (Gillespie & Haddad, 2001). Generic effect emphasizes income, employment generation, and "women's role" by categorizing their social status and decision-making power in agri-sector and rural households (Bhavani & Rampal, 2018). Whereas specific effect relies on food access and availability, consumption, and allocation behavior (Gulati et al., 2012). Overall, comprehensive food policy should focus on diet diversity with minerals, micronutrients, and vitamin-rich diets, which ultimately positively impact national nutritional status (Bhavani & Rampal, 2018).

Although, with the squeezing of available resources and extreme weather event scenarios, a large section of agrarian communities across the country today is in a position of disaster, the rest of the population is still making a profit from it (Narayanan, 2015). In the face of increasingly scarce fertile land and water resources, India's cereal productivity is far below the national target of 5018 kg. ha^{-1} by 2030 with the current 2509 kg.ha^{-1} (GoI, 2019). Production of maize which dominates the Indian coarse cereal scenario has improved in the last decade. However, only 9% of it is used as food, leaving major parts as poultry feed and for the brewery industry. Estimated pulse demand accounts for 29–30 MT, where production attained 23 MT in 2016–2017, out of which only 8–10 MT of pulses are consumed directly as a food item (Dal) (GoI, 2017a). The remaining pulse food is imported due to lower productivity and cultivable area. Laterally, distribution and outreach are the ruling problem sustained in the nation's food system. With India's population continuing to expand, the persistent issue of food losses and wastage, coupled with substantial food exports, severely restricts the achievement of optimal per capita net food availability (GoI, 2019). These trends ultimately emulate pressure on the demand side for feeding overpopulating nations.

For the last few decades, per capita, food grains production has been impeded from 186.2 kg/year in 1991–1992 to 180.3 kg/year in 2018–2019. This declined cereal production in India has raised a fair chance of other options like dairy, eggs, pulses, edible oil, and sugar, which skewed scenarios toward high-value horticultural and animal products (Kumar et al., 2007). Now noncereal items share significant contributions for proteins and calories in rural and urban areas. The household expenditure on cereals was reduced from 18 and 10.1% in 2004–2005 to 10.7 and

6.6% in 2011–2012 for rural and urban India, respectively (NSSO, 2004–2005 and 2011–2012).

2.1 Hampered Food Production Systems

In developed countries, agricultural production systems of staple crops are being mechanized, and workers needed for operations are less, inherently following social distancing. These farms are somewhat resilient to disruptions emanating from strict COVID protocol. Complete farm mechanization is tougher in vegetable or fruit production systems wherein weeding and other intercultural operations, as well as manual harvesting, are heavily damaged even in developed countries. Travel bans and inter-country border closure have created an acute shortage of the labor force available for harvesting, which has heavily affected globalized food systems (Petetin, 2020). In countries like India (Rabi harvesting), where the lockdown has coincided with harvesting time staple crops, vegetables, and fruits, the non-availability of the migratory labor force has resulted in colossal food loss and economic loss of the farmers (FAO, 2020a, b, c; Ceballos et al., 2020). In India, vegetable harvesting is the hardest hit crop by COVID-19 and it is the most wasted crop due to a lack of harvest and marketing (Jaacks et al., 2021; Harris et al., 2020). Higher labor and machinery costs have made the labor and harvesting costs go higher in India (Jaacks et al., 2021; Ceballos et al., 2020). Lack of migratory labors, if it happens in the long run, in the twin Indian breadbasket states of Punjab and Haryana may delay rice transplanting, which will also defer subsequent wheat seeding (turnaround time between rice harvest and following wheat planting is typically only 2–3 weeks) exacerbating national food insecurity issues through attenuating yields of two major staple crops (Singh et al., 2020).

Seasonal labors in France, Germany, the United States, Canada, Australia, and Italy either faced a travel ban due to visa restrictions or border closure, creating labor shortages (ILO, 2020; Torero, 2020). In parts of Europe, restrictions imposed on the mobility of seasonal farmworkers have unfortunately left agricultural produce not harvested and rotting in the field (Torero, 2020; Laborde et al., 2020). These restrictions on farm labors can exacerbate food insecurity and may threaten their lives (IOM, 2020). Besides, the travel ban had heavy reverberations on procuring agricultural inputs like pesticides, fertilizers, and seeds for producers and increasing their costs (Rivera-Ferre et al., 2021). The massive lockdowns have exacerbated the peril of rural farmers even more. A survey conducted by Ceballos et al., 2020, reported that 74% of pulse farmers in the Indian state of Odisha, where subsistence farming is widespread and agricultural operations are poorly mechanized, suffered income loss due to delays in the purchase of products by the traders until travel restrictions were eased. Farmers could not place their produce in urban markets, schools, leisure establishments, sweet shops, hotels, and restaurant chains that are closed following safety protocol and the closure of public transport systems. The closure of mandis or licensed marketplaces (the bulk of the agricultural products are sold here) in India created a massive surplus of marketable commodities.

There are also reports of the culling of animals due to a fall in demand in hotels and restaurants (Barling, 2020). Fishery production systems are also hit at large due to reduced demands (Rivera-Ferre et al., 2021). Farmers' dependence on other players in food production and delivery systems has made them vulnerable to damage. A study in 200 Indian districts by Jaacks et al., 2021, reported that landless farmers are ten times and small or marginal farmers three times more likely to miss out on meals or starve the entire day – the nadir of food insecurity. Many rural farmers in India fed strawberries to cows because they could not mobilize the produce to urban marketplaces (Torero, 2020). In Peru, the United States, and Canada, farmers had to throw away their cocoa to landfills and milk inroads either due to a lack of transport or the closure of business operators who would buy the produce regularly (Torero, 2020). East African high-value flower export systems were suspended due to the closure of international passenger aviation systems compelling farmers from Ethiopia and Kenya to dump tonnes of high-quality flowers (Bhalla & Wuilbercq, 2020).

2.2 Consequences for Food Supply Chain

Guaranteed supply of raw materials from suppliers and smooth flow of food products from manufacturers to consumers are two critical components of the food supply chain (Alonso et al., 2007) which is mainly offtrack during the pandemic. Most farm production activities and food supply are intricately connected; even a small delay can significantly create a butterfly effect, ultimately declining yield (FAO, 2020b) and affecting food availability. Food delivery chains in high-income countries are more resilient because they are knowledge and capital-dependent. In contrast, small and informal food sector operations in poor and developing countries are highly manual labor oriented and severely wrecked due to social distancing guidelines (Swinnen & Vos, 2021). In parts or whole of Australia, Madagascar, Colombia, India, Kenya, and Ethiopia, high-value perishables, like milk, fruit, egg, tea, vegetable, and fish production, and the supply chain were hampered due to the unavailability of agricultural inputs like seeds and fertilizers, shoddy transport system, night curfew, or restricted market trade (ILO, 2020; FAO, 2020a). Compared to high-value produces, staple food items require less labor but are more capital and knowledge-intensive. In the staple food product supply chains, travel restrictions and social distancing guidelines also created a negative impact (FAO, 2020c). Almost every stage of the food supply chain of China was either dismantled or severely affected (Kim et al., 2020). An estimate by Laborde and coworkers, 2020, estimated as high as 5% postharvest produce loss in agricultural production.

The bounty of COVID-19 is heavy on the Indian food supply chain putting food security in danger. Colossal production of export-quality Darjeeling tea in India had gone wasted in the first lockdown, and there are fears for the second (BBC, 2020). Total 92% of food consumption in India is purchased, a majority from by private sector (Reardon et al., 2020). Indian farmers faced the most difficulty in procuring seeds, fertilizers, and labor, as reported by Jaacks et al., 2021. These problems have

created a significant impasse in supplying food to markets. Logistic hindrance has reduced the supply of high-value goods for their shorter shelf life (FAO, 2020b). Grape and onion in Maharashtra (the largest onion trade market in Asia) and biscuits, noodles, and other snack production in India were wrecked (Kim et al., 2020). The impasse in logistics has forced the farmers to sell their produce at a much lower price.

Not only poor or developing countries, but the food supply of the rich ones, who have highly developed and modern systems, are also hit. More than 30,000 workers in meat processing plants in the entire USA and Europe have been affected by the disease, resulting in closure or reduced production (Laborde et al., 2020). In the USA, there are reports of nearly 75,000 unhatched eggs per week and onions rotting due to disruptions in the supply chain (BBC, 2020). Nearly 5 million liters of milk per week are threatened by wastage in England (Aday & Aday, 2020). These accounts suggest the importance of smooth logistic systems to cope with global pandemic events.

Public food distribution is also affected, which further adds to the number of food- insecure people. More than 160 countries have enacted school shutdowns covering 87% of the world's student mass, which have often dented the only source of food and nutrition in many families (FAO, 2020c). The nationwide shutdown of schools in India had impacted millions of children due to the suspension of the midday meal program, which caters to nearly 110 million children nationally at school, and about 100 million pregnant and lactating mothers, as well as children below the age of 6 depending on Anganwadi centers (village child care centers) under the aegis of Integrated Child Development Services Scheme, are affected (Alvi & Gupta, 2020). School closure has also affected poor children in the USA who rely on meals provided thereat (Laborde et al., 2020). The suspension of school feeding programs has cut the jobs of meal suppliers and caterers (FAO, 2020c). Restrictions in movement and quarantine protocols cause vessels to remain on shores for an extended period causing owners and workers to incur substantial losses and delays in the supply of raw materials (Havice et al., 2020).

2.3 Fallouts in Food Access

COVID-19 has hampered access to food and increased food insecurity through reduced household income and assets and the imposition of physical constraints like reduction or closure in mass transportation facilities. Lack of income for covering fuel charges of personal vehicles culminated in a significant barrier to food access.

Many poor households had to travel long distances or to several food stores to find affordable food items in the USA (Kinsey et al., 2020). Households already suffering from food insecurity are more vulnerable to limited food access (Niles et al., 2020). Access to food is also hampered due to food market closure. In some areas of Nepal, people could not procure food because shops were closed (Shahi & Gautam, 2020). Shop closure also affected people who solely rely on supermarkets

for food. Food prices in New Zealand skyrocketed due to their only being available in supermarkets in crisis times (New Zealand Herald, 2020). In many cases, food retailers where they are the only food source during the pandemic looted customers or suppliers by increasing prices or reducing the cost of raw materials.

Worldwide, 1.5 billion people already cannot access healthy diets based on diverse plant- based foods (Hirvonen et al., 2020). At the time of writing this report, there are mounting apprehensions of a third wave (could be several waiting!) to hit India and other countries; It is foreseeable that the magnitude of the impact will remain substantial even after this crisis subsides. The downscaling of income arose due to a reduction in agriculture and nonagriculture income. As high as 70% of the income in poor households is spent on buying food compared to 15% in affluent families (Laborde et al., 2020). It is not wondrous that the poor and downtrodden people will be badly hit by the price rise of foods as they do not have savings or food reserves. A very recent forecast for average household income decline predicts a 9.3% fall in European Union countries due to the crisis (Almeida et al., 2021). India suffered a significant per capita income drop (Deaton, 2021). There are forecasts that the number of poor people in South Asia will increase by 15% or 42 million people (Laborde et al., 2020). Although governments in almost every country substantially provided relief measures, there are concerns about food access arising from those. Lack of communication with many vulnerable populations has deprived them of free-of-cost food (Adhikari et al., 2021). In developing countries like India, Indonesia, Ethiopia, Kenya, Mozambique, Rwanda, and Tanzania, food price increments were 3.8, 2.5, 3.4, 4.2, 10.5, 19.5, and 12.3%, respectively (Global Alliance for Improved Nutrition, 2020). Prices of meats, fruits, and vegetables in Algeria, fruits and vegetables in Tunisia, rice and pasta in Egypt, and milk in Albania increased, as reported by CIHEAM (2020), rendering those unaffordable for the weaker sections of the society.

Food prices in Southeast Asia spiked during the pandemic (Kim et al., 2020). Apart from food scarcity at the national level, food access issues are at the household level. Nearly 380 million Indians are employed in informal sectors, unprotected by labor laws, and lack secure job contracts (Summerton, 2020). The prolonged lockdown measures have downscaled casual labor employment due to the halt of business and farm activities. For many labors, lockdown is “an order to starve” (Abi-Habib & Yasir, 2020). Lack of savings and a poor social security net of the labor depended on households taking fewer, lesser, and cheaper meals. Even in the prosperous economies, people’s dependence on food relief spiraled, which is evident from budget allocations of the countries like the USA ($25 billion in food assistance), Catalan countries (4 million € to buy fresh food from marginal farmers), and UK (Rivera-Ferre et al., 2021).

There will be far-reaching reverberations, especially for young children, due to malnutrition arising out of the inaccessibility of food for their cognitive development, and delayed educational attainment might be hampered, notwithstanding the recession is short- lived.

3 Spatial and Temporal Food Security: Explaining Scale-Dependent Diversity

Regional divergence and inequality are two inherent parallel stories of Indian food policy. So far, food security is highly concerned with the synergism of policies on various scales that may be temporal and spatial for the underprivileged, which is an utmost need for adequate consideration and planning. The normative concerns include agricultural sustainability's economic, social, and environmental impacts. Historical growth series indicate that superior technology and institutional reforms moved a step forward, with the growth rates ranging from 2.2 to 2.7%, higher during 1988–1996 and highest during 2004–2014, 3.72%. This may be due to more public and private investment and a trade boost which declined to 2.55% during 2014–2017. The area dedicated to fruits and vegetables has witnessed a significant twofold increase, expanding from 3.0% during 1975–1989 to 6.5%. Meanwhile, the allocation for pulses and cereal crops such as rice and wheat has experienced a relatively stable distribution, with pulses accounting for 13.3% to 12.2%, while cereals' share has remained largely unchanged, comprising 36.0% initially to 37.3%.

It occurred due to much acceleration in yield compared to the growth area. In parallel, prices determine the prime role in raising farmers' incomes. Shares of all cereals and pulses declined while fruits and vegetables, condiments and spices, livestock, and fisheries increased in total price over periods (GoI, 2017b). Surprisingly, the surging of consumer food prices did not correlate strongly with the rising agricultural growth (Mahendra Dev, 2018). The reason may be that price control plays a significant role in rising output growth with a strong association wherever output growth fails to control the price, which is the primary cause of agrarian misery. India has various seasons throughout the year, influencing the agriculture output; therefore, it is necessary to analyze data on various timescales.

India's total or agricultural growth rate becomes futile except due to consideration of inter-state variance and their spatial scale assessment. The country has 20 agro-ecological zones, with 46 out of 60 soil types in the world. Different states' primary investments in food production and parallel goal toward nonagricultural sectors, along with resource availability, influence production growth rate. Few states experience less economic growth due to low crop yield or cereal-focused strategy compared to others where higher productivity benefits from technology or infrastructure buildup (Pingali et al., 2019).

The impact of regional diversity is accelerated due to extreme weather events frequently. Northwest states like Punjab and Uttar Pradesh lead in wheat, whereas West Bengal is the "rice bowl" of the country. Pulse has markedly switched into central and southern from the north, which accounts for >90% of total production (GoI, 2017a).

Production environment and food choice play a pivotal role in determining demand and price extensively with regions, household patterns, and income levels. Inequalities of reasonable prices of produce are very often spatial, increasing class conflicts. Lower access to institutional credit, investments, insurance, and poor technology dissemination in many states are the ground reality for regional growth differences and may be measured by other indicators such as poverty and

malnutrition. Agricultural foods are primarily perishable, and the situation has become more threatening during the crisis of COVID-19. Huge income loss among the working poor adversely strikes food demand-price-supply channels. The situation will be more complex if the pandemic sustains.

4 Climate Change and Population Pressure on Nutrition: Agricultural Impacts and Adaptation

One of the largest concerns facing the globe today is climate change, which is defined as significant changes in the average values of meteorological components, such as precipitation and temperature, for which means have been estimated over a long period of time. The progress accomplished in the fight against hunger and malnutrition so far is in danger of being undone by climate change. Additionally, it could present health risks for people and have a considerable impact on price stability, food markets, and exchange flow. According to a recent assessment report from the Intergovernmental Panel on Climate Change (IPCC), food security concerns are growing and becoming more severe for the most vulnerable populations and countries. Out of the eight important risks brought on by climate change, the IPCC AR5 highlighted four that have immediate implications for food security:

- Rural livelihoods and income loss
- Marine, coastal ecosystems, and livelihoods loss
- Terrestrial, inland water ecosystems, and livelihoods loss
- Food systems breakdown and food insecurity

The effects of climate change on precipitation, runoff, snowmelt, hydrological systems, water quality, water temperature, and groundwater recharge will be felt. Increased water scarcity brought on by climate change will be a substantial obstacle for climatic adaptation in many parts of the world. Surface salinity and groundwater conditions in coastal locations will change as a result of rising sea levels. The frequency and severity of outrageous incidents will change as a result. According to a recent FAO analysis of 78 postdisaster needs assessments conducted in 48 developing countries between 2003 and 2013, the agriculture sectors in developing countries are responsible for 25% of all economic losses and damages brought on by medium- and large-scale climatic hazards like droughts, floods, and storms.

It indirectly has an impact on agricultural production systems. A change in physical characteristics, such as temperature and precipitation distribution, can have direct implications on certain agricultural production systems. Through changes in other species like pollinators, pests, disease vectors, and invasive species, indirect effects have an impact on productivity. Given the numerous interacting elements and relationships that need to be defined, these indirect effects can be quite important even though they are much harder to analyze and estimate.

Results from significant agrarian model inter-comparison projects show that, despite ongoing weaknesses in how models depict the portrayal of combined carbon

dioxide fertilization, ozone stress, and high-temperature effects, there is agreement on the direction of yield changes in many major agricultural regions at both low and high latitudes, with clear adverse effects occurring most often at lower latitudes and higher levels of warming. The IPCC has expressed high confidence that crop output in low-latitude nations will be regularly and negatively impacted by climate change in the future. In northern latitudes, however, it can have either favorable or unfavorable effects.

In a recent multimodel study, the most extreme warming scenario used by the IPCC was found to have a mean global effect of minus 17% by 2050 on the yields of four crop categories (coarse grains, oil seeds, wheat, and rice, which account for around 70% of the world's harvested crop land). The most extreme radiative forcing scenario and the assumption of limited CO_2 fertilization impacts in 2050 were combined in the hypothesis for this multimodel evaluation, but the harmful effects of elevated ozone concentrations, biotic stresses from a variety of pests and diseases, and the likelihood of an increase in the frequency of outlandish events were excluded.

Climate change effects on farms and households could decrease income and stability by influencing production costs and productivity. Such changes may result in the sale of productive capital, such as cattle, which lowers the long-term potential for household productivity. Threat exposure reduces the incentives to invest in production systems, which frequently has negative effects on sustainability, returns, and long-term productivity. It has also been demonstrated that household ability and desire to spend on health and education are impacted by reductions and risks to agricultural revenue. The accessibility and stability of food supplies for the entire population can be affected by shocks to crop production and food availability, with risks of market disruptions, effects on supply and storage systems, and spikes in agricultural commodity prices. By deterring investments, climatic concerns might also impede agricultural development.

People whose livelihoods depend heavily on agriculture and natural resources are those most at risk from the effects of climate change. Droughts will notably affect poorer households and may affect women disproportionately due to their vulnerability and limited access to resources, according to recent trends in food insecurity and inequality. Indigenous peoples are particularly at risk in places like the Arctic, mountainous regions, Pacific islands, coastal areas, and other low-lying locations because they depend on the ecosystem and its biodiversity for food security and nourishment (FAO, 2015b).

5 Malnutrition Paradox: Reality Check Under Pandemonium

"Let food be thy medicine and medicine be thy food," a famous quote by Hippocrates, and what to eat and what not to is relevant during the recent COVID-19 scenario. COVID-19 is affecting the poor and the vulnerable heavily, which is a significant concern (Mardones et al., 2020). Headey and Ruel (2020) argued that the COVID-19 pandemic has all the makings of a perfect storm for global malnutrition.

Unhealthy diets and nutritional immunity are the main preconditions for a viral disease, e.g., COVID-19. Therefore, dietary assessment and nutritional strategies are the best way for precautions or treatments when any pharmaceutical approach is still unknown. The result from a review of previous clinical trials with nutrition- based interventions for viral diseases has positively correlated with vitamin-A, C, and D along with zinc, and selenium, which favors modulatory effects (Jayawardene et al., 2020), which is critical for India, where one in five persons suffers from non-communicable diseases (Hindu Business Line, 2018). Micronutrients, tea bioactive, garlic, fruits, vegetables, and various probiotics can also shield the elderly and new age population against any viral infection like COVID-19 (Rodriguez-Leyva & Pierce, 2021). Persons with obesity, malnutrition, high use of saturated fat in the diet, etc., are vulnerable to this pandemic (Rodriguez-Leyva & Pierce, 2021). Vitamin D deficiency and malnutrition are widespread in COVID-19-infected patients admitted to an intensive care unit (ICU) (Goncalves et al., 2020). Analysis of COVID-19 deaths among African Americans revealed that vitamin D deficiency adds to greater morbidity risk (Kohlmeier, 2020). A study by Allard and coworkers (2020) reported that 39% of COVID-19-infected patients had a malnutrition prevalence. A very close result found by another study was that 42% of infected patients and 67% of ICU patients of COVID-19 were suffering from malnutrition. As reported by Rodriguez-Leyva and coworkers in 2021, 24% and 18% of COVID-19-infected patients exhibited moderate and extreme malnutrition, respectively. The world is lagging in achieving its 2030 SDG targets of hunger and malnutrition, further exacerbated by the pandemic (FAO et al., 2020).

Disruptions in the rice-wheat production systems may trigger significant ramifications in Indian food and nutritional security because these two crops provide 60–70% calories and 50–55% protein intake in India (Singh et al., 2020). Perishable farm produces like vegetables and fruits are often the most nutritious (Beal et al., 2017). Therefore, a deadlock in transport facilities has hindered these crops' harvest and marketing, negatively hampering diet quality. A survey done by Harris et al. in 2020 in India reported pulse, dairy, and vegetable consumption sank in 20–30% of surveyed households, which may magnify malnutrition.

The healthy dietary concept is still a way for India, where the principal portion of the population struggles against poverty and hunger. In contrast with remarkable economic growth in recent years, India is encountering the so-called "triple burden of malnutrition" – the widespread coexistence of inadequate calorie intake, undernutrition, and excess dietary energy intake among most of the population (Narayanan, 2015). India ranked 102 out of 119 countries as per Global Hunger Index in 2019, mainly due to "hidden hunger." Nearly 50% of Indian children are malnourished, anemic, or starved, and roughly 10 lakh newborn die before 1 month of age (IFPRI 2016).

At the onset of the corona pandemic, followed by a massive lockdown, an additional 130 million people (with the previous 135 million) are estimated to be forced to the verge of starvation of which the majority is from India. The economic impact could potentially devastate even more than the virus itself (WFP 2020).

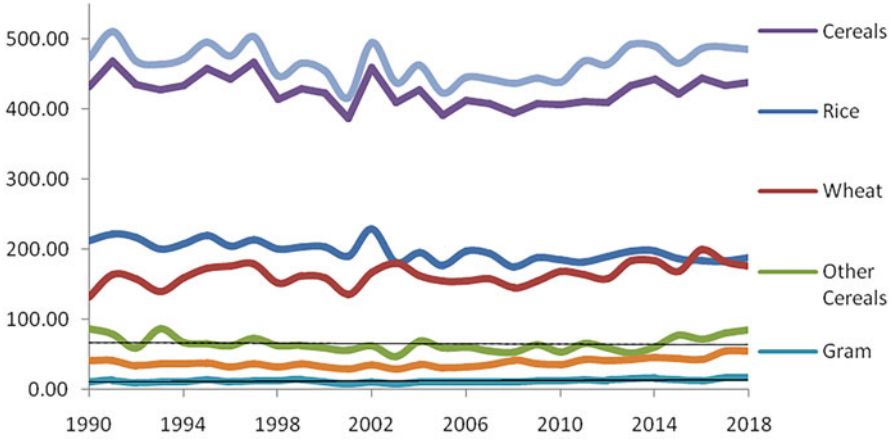

Fig. 1 Per capita net availability of food grains (g/day), India, 1996–2018

Current agricultural food production has prevented famine and starvation by supplying carbohydrates. Over the last 20 years, total per capita food-grain availability increased only from 475 to 484 g day^{-1} where pulse production is improved (by 66%) to 55 g/capita/day (GoI, 2019) (Fig. 1). Now is it adequate to tackle undernutrition and the rising incidence of community diseases like corona?

Staple-grain-focused policies restricted farmers from expanding their production toward high market-demanding nonstaple food, e.g., fruits, livestock, and vegetables. However, there is utmost demand for promotion from calorie sufficiency to diversified food system approaches. The current dietary average intake pattern is far below sufficiency. It is mainly for declining rice and wheat intake over a period, i.e., 204–186 and 176–174 g day^{-1}, respectively (GoI, 2019) (Fig. 1), and exiguous livestock and vegetable consumption which fail to fill the gap. Till now, about one-fifth population could not get dietary fruits or milk, while more than half of urban and rural people are devoid of animal proteins. Only a small section has access to balanced diets, leaving many Indian households only cereal dependent. Irrespective of poverty, the nation faces hidden hunger, poor immune function against any infection like COVID-19, and increased mortality risk. Different nutrients have been found deficient in both groups of people in separate patterns or intensities (Fig. 2) (Kumar et al., 2016).

6 Spatial Food Security and Sufficiency: Need of the Hour

The ongoing global health disaster from COVID-19 is impacting every societal aspect. It is a situation like "The most severe crisis since the Second World War." With severe public health hardship, employment losses are a global concern for approximately 2.7 billion workers, and food systems are under enormous distress

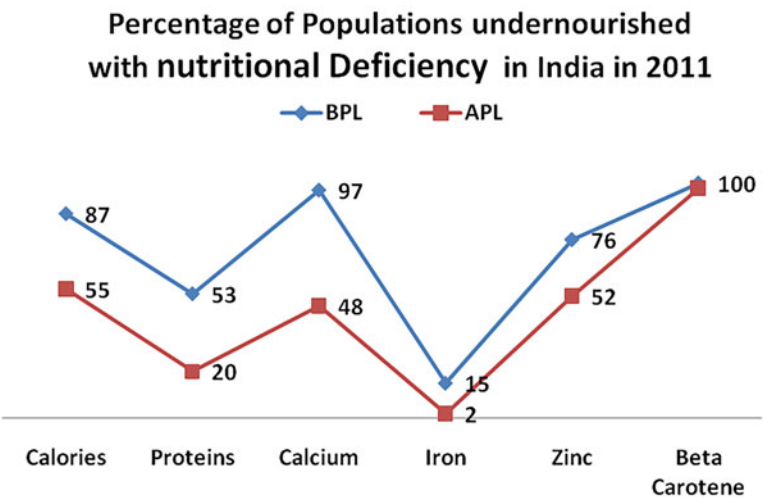

Fig. 2 Percentage of the population undernourished in India in 2011. (Note: *BPL* population below the poverty line, *APL* population above the poverty line. Source: Computed from NSS consumer expenditure data (NSSO, 2012))

(ILO Monitor, 2020). The world is moving toward a massive recession, whereas in India, a sharp downturn already began last year and now forces toward more shock.

Food prices (WPI) for most items, particularly vegetables, namely, onion, potato, and tomato, jumped up and continued to the top in 2020. The lockdown, followed by supply bottlenecks nationwide, impels much higher prices for consumers for a range of perishable foods. India's food-grain output projection is higher, but spatial food security and access are at threat due to more transportation costs and associated uncertainty from farm gate to market. At the same time, farmers risk losing their market precisely in the trades of horticultural, fishery, and animal husbandry, resulting in sharp falls in their farm-gate prices.

Poor storage and marketing channel, inadequate postharvest processing, and inadequate infrastructure are escalating the difficulties of harvesting current crops and planning for the next session. Migrant workers are forced to return to their homes, leaving agricultural operations with associated high costs. FAO estimated that nearly one-third of the world's food is lost or wasted (FAO, 2015b), the value of which may be Rs. 92,651 crores or more in India (PIB, 2016). Feed shortage is also a crisis forcing low-cost livestock products to distress selling. The situation is triggered by higher consumer costs, limiting farmers' income.

Of late, 70% of Indians are residents of rural regions, of which 40% occupancy is still devoid of transport facilities. Total 82% of farmers are under the small and marginal category (FAO, 2019) and facing all sorts of troubles. The country has witnessed acute supply and demand imbalances sporadically due to intensified single crop policy, which is wreaking havoc under this COVID outbreak. Unemployment,

income loss, deprivation, and rural distress are the associated outcome of this prolonged lockdown.

Therefore, particular short-term actions, maintaining supply chains mechanism, planned procurement, and allocating adequate credit and agricultural inputs with government interventions, are urgent during this challenging time for regional upscaling of food security and farmers' income. Highly perishable seasonal agricultural commodities are crucial now for household nutrition. Assuring diversified locally available food produce per local demand through smoothened prices under agri-allied sectors is needed.

In this panic moment, the poorest and the weakest part of society, including jobless migrant workers, laborers who depend upon public food assistance programs, and school children who rely on school meals to meet their nutritional necessities, are facing a "crisis within a crisis" situation. These larger sections are weak and vulnerable to disease attacks. With their independent regional resources, they need scaling-up assistance of free food and agricultural stability, the temporal dimension of food and nutrition security. Serious multifaceted challenges and a variety of shortcomings are undergoing millions of struggling lives. Stability minimizes external risks such as the COVID-19 pandemic. Some fundamental changes and appropriate government policies to build resilience at the state or district level may help society beat the situation.

7 Food Safety and Traceability

Food safety is a serious global issue, and unsafe food markets like Wuhan, China, can have a far-reaching worldwide resonance (Galimberti et al., 2020). Foodborne illness, which is attributed to significant societal costs, emphasizes the need for holistic food safety measures (probability of food to deter consumer health risks) (Souza-Monteiro & Hooker, 2013) and their traceability (ability to detect the origin and spread of the hindrance to safe food consumption from farm gate to the consumer's plate) (Golan et al., 2004). However, the inability to link food chain records, and inaccuracy and errors and delays in obtaining essential data serve as major setbacks to authentic food safety and traceability (Badia-Melis et al., 2015). To ensure food safety, a traceability system must encompass breadth (quantity of information), depth (tracking of information in both forward and backward directions), and precision (accuracy and assurance of food transshipment).

The traceability systems accrue three significant benefits for the producing firms: improve management of supplies, trace back food safety and quality, and attribute marketable differentiation for quality food promotion. It helps build trust, confidence, and peace of mind as a consumer. This approach further ensures end-to-end supply chain management (Aung & Chang, 2014). Seventy-six million cases of foodborne diseases are reported annually in the USA alone. Whereas in India, the food market is governed by small and medium enterprises with poor agricultural practices: Inadequate postharvest storage and management infrastructures, knowledge, and technology and awareness gap create more difficulties in maintaining

safety and traceability standard. Several agencies have cropped up, including FSSAI, APEDA, GS1 India, NABARD, FPO, ITC's eChaupal, Reliance industry, etc.

The current COVID-19 pandemic has put forward the necessity of ensuring food safety and security. A wide range of social, economic, and in many cases environmental consequences are attributed to foodborne anomalies. The pandemic has quite aptly emphasized that food quality should not be synonymously coined with food safety. A product that may appear high quality (i.e., well-colored, appetizing, flavorful, etc.) may be unsafe because it might be contaminated with undetected pathogenic organisms, toxic chemicals, or physical hazards. COVID-19 is not foodborne. The disease is reported to be transmitted by respiratory droplets from person to person. There is report of the virus neither causing COVID-19 (SARS-CoV-2) to be transmitted through food packaging, nor can it multiply in food (Mardones et al., 2020). However, there are some reports of infected cases by imported food (Marti et al., 2021). However, most food business operators globally have taken sufficient safety protocols to curb the spread of the disease by food workers in food items or food packaging.

Thus, thorough evaluation approaches by hologram, genomic analyses for foodborne pathogen identification and traceability, barcode, radio frequency tags, geographical identification tags, biotracing, tools adapted from landscape ecology (species distribution and niche modeling), Social Network Analysis for predicting patterns of disease outbreaks, nano-sensor for precise GPS identification, and information and communication technology must be ensured with specific governmental policies and standard marketing channels for safer food to the consumers along with better price for the producers (Dandage et al., 2017). Furthermore, proper demand-driven marketing hubs, effective supply chain management, strict food safety laws and regulations, and hygiene practices in food and livestock marketing processes must ensure better human health protection for future pandemonium.

8 Soil and Carbon Footprint Impact Under the Pandemic Situation

Soils are fundamental to our lives and must be recognized and valued for their importance in global climate change feedback, particularly their enormous potential to mitigate climate change. However, the role of soil organic carbon (SOC) or soil organic matter (SOM) in ensuring food security is often forgotten, which is achieved by enhancing soil productivity and maintaining consistently high yields, particularly by increasing water and nutrient holding capacity and improving soil structure, thus improving plant growth conditions (Zdruli et al., 2017). Many studies have precisely quantified the contributions of SOC in food production that a 1-tonne increase in the SOC pool of degraded cropland can increase wheat yields by 20–40 kg ha^{-1}, maize by 10–20 kg ha^{-1}, and cowpeas by 0.5–1 kg ha^{-1}. Therefore, the sustainable use of soils is a critical issue in the climate change context. Maintaining or improving soil fertility is a prerequisite for many essential ecosystem services, including sustainable food and fibers. The most immediate impacts of the COVID-19 pandemic on soil and vice versa are human activities resulting from a decline in human consumption,

giving rise to surplus food being disposed of and added to the soil. Reduced consumption of meat led to food waste. This has long-term consequences for land use, groundwater quality, biodiversity, human health, and land value. A potato glut has occurred due to a decline in the consumption of French fries, resulting from the cancellation of sporting and cultural events and the closure of restaurants. This huge potato surplus impacts soil when farmers plow under crops and plan to discard surplus potatoes currently in storage by working them into the soil on a scale never seen before (Bernton, 2020). A similar supply-chain-soil situation is faced by dairy farmers (discarding millions of gallons of milk per day) and also impacting beef producers. A reduction is following this in acreage being planted to adjust to decreased demand. Sustainable management of soil toward nutrition-enhanced food production through the restoration of soil health is critical to reducing the risks of food and nutritional insecurity. The nutritional quality of organically grown food may be better than fertilizer- based management (Murphy et al., 2008). The functions and services enable soils to support the primary supply of food and natural products required by the human population, even under high external pressure. They have moved the importance of soil functions higher on the agenda in soil science research (Vogel et al., 2019) and in a policy setting.

In addition to the primacy of human health care, the maintenance of all critical infrastructures and, in particular, the supply of the population with food and natural products from agriculture, forestry, and fisheries have the highest priority, and this has increasingly been challenged under the COVID-19 pandemic (Moran et al., 2020). Besides nutrition, the social dimension, such as disruptions in food prices, is also important (Barrett, 2020). A decline in soil health and resiliencies is also a constraint to advancing the Sustainable Development Goals of the UN which have been aggravated due to COVID-19. The effects of countermeasures happened to have been tested out by the COVID-19 pandemic event, during which an abrupt drop in CO_2 emissions equivalent to 17% of the total for 2019 was recorded in the first 4 months of 2020. Jeff Tollefson (Data Story, Nature) reported that global carbon dioxide emissions, after rising steadily for decades, reduced by 6.4% (equivalent to 2.3 billion tonnes) in 2020, because of the squelched economic and social activities in the worldwide COVID-19 pandemic situation. However, Zhu Liu, an Earth-system scientist at Tsinghua University in Beijing who coleads the International Carbon Monitor Program, expressed his concern: "The emissions decline is already less than what we expected. I imagine that when the pandemic ends, we probably will see a solid rebound." Notably, the aviation sector, being the most affected energy sector due to the pandemic, experienced a significant 48% reduction in emissions during 2020-2021 compared to 2019, primarily attributable to the constraints imposed by pandemic restriction. The United Nations Environment Programme estimates that the world needs to cut carbon emissions by 7.6% per year for the next decade to prevent the globe from warming by more than 1.5 °C above preindustrial levels – a goal set in the 2015 Paris climate agreement. However, the pandemic has changed the view of challenges to fighting climate change.

There is no evidence directly linking the COVID-19 outbreak to climate change. However, COVID-19 is testing our resilience in responding to potential climate-related disasters. As such, the COVID-19 crisis can provide lessons about the vulnerability of our societies to high-impact global shocks and the critical role of

public policies in mitigating the risks by reducing greenhouse gas emissions and boosting investments in long-term resilience and prevention. Its global nature is also a reminder that global shocks – pandemics, economic crises, and climate-related disasters – are best overcome through coordinated international action and by following scientific advice. Recovery policies must be prepared to integrate economic, social, and climate change objectives. Over 100 countries have already adopted carbon neutrality goals for 2050, requiring a transformative change in many economic sectors. Careful preparation of recovery policies presents opportunities to simultaneously address recovery and climate objectives, which depend on actions and investments over the next decade. The COVID-19 crisis has reduced emissions but will not reduce climate change if emission reductions remain temporary. The lockdowns imposed across the globe and the associated collapse of economic activities have caused significant reductions in greenhouse gas emissions (along with life-shortening air pollutants) from transportation and industrial activity. For example, in China, industrial shutdowns are estimated to have caused a 25% drop in CO2 emissions in February 2020 compared with the same month in 2019.

9 Strategies for Reducing Food Loss and Waste

During the initial phase of the COVID-19 lockdown, food loss (production point up to retail) was mainly due to a shortage of labor, closure of SMEs, and restrictions on movement and border closures resulting in poor handling, storage, processing, and packaging. Also reduced demand for perishables, poor quality, the inability of consumers to purchase food, and the closure of public markets accentuated food loss. Policy responses like creating pooling platforms through the development of transport apps, building rural collection centers, and decentralizing storage sites along transport routes will help reduce food loss during handling, storage, and distribution. Demand-driven logistics and cold chain systems must be developed in place of traditional production-oriented fragmented multilayered channels. To reduce food waste (from retail to consumer), the promotion of alternative processing options in the supply chain (e.g., freezing vegetables) and good-quality packaging with improved capacity for sound postharvest technology, including solar drying of fruits and vegetables, need to be adopted.

10 Requisite Policies and Alignments: Toward Postpandemic Food and Nutritional Sustainability

The multifaceted efforts by the governance of different countries across the globe since the beginning of Covid-19 are trying to combat the loss. However, the past few complete shutdowns of all economic activities in several phases have had an adverse impact in the long run and have already reflected in absolute poverty. Even before the pandemic started, Kharas et al. (2018) estimated that extreme poverty (measured at the international poverty line of $1.9 per day per capita) would increase by

50 million globally. Per their prediction, in India, the extremely poor will increase by 10 million during the current decade.

Food security is a flexible socio-type, ecological, and conceptual framework, and interactions with the community determine an individual's survival strategies. Under great stress and hardest hit by the pandemic, multidimensional interventions, implementation, and policy innovations are the crux of agricultural development, food access, and current nonfarm economic options. Lockdown has jeopardized the system through failing income and work deficiencies for the monumental populace; therefore, short-term steps toward public food distribution programs must be strengthened along with respective long-term policies for agri-food sustainability. A COVID-19 pandemic-resilient framework for food security has been provided in Fig. 3.

India's subsidized food security under National Food Security Act (NFSA) and newly introduced Pradhan Mantri Garib Kalyan Yojana (PMGKY) are the most significant social safety network in the world, costing about 6% of the total budget. This scheme supplies free food grain to women, the poor, senior citizens, and farmers. During the first phase lockdown in India, PMGKY offered 5 kg of food grain and 1 kg of pulses per household to 80 crore individuals covered under NFSA until November 2020. Are all lower-rung populations covered and rightly exercised by NFSA, or are the damage, leaks, or procurement loss minimized?

NFSA scheme covers 67.22% population including migrant labors and agricultural wage workers across the states through different government schemes (NFSA+PMGKAY). However, these relief packages were insufficient to combat the deep economic breakdown under COVID-19, especially the malnutrition and poverty situations that have been downgraded among women and children. Holding sufficient procurement food stocks year-wise is a good reason for national security. Also, maximum release from the stock free of cost to the underprivileged in continual mode may be the win-win approach to feed the hungry and vulnerable, which ensures minimum procurement loss. Different NGOs, cooperatives, the Women Self Help Group (SHG), and volunteer organizations may be used under food distribution functionaries.

In this COVID catastrophe, medium and long-term interlinked challenges and alleviative measures rely on eco-regional planning for production sufficiency, particularly for high-value commodities and agricultural pricing policy. There is an urgency for functional governance of the food market and prices with a total capacity to prevent price volatility across the seasons. Cheaper information technology and software, Aadhar-based beneficiary identification, and tracking are also opportunities for the modernization of the supply chain. Due to the high unemployment rate, economic nourishment must be prioritized by ensuring direct, optimal payment to the growers for farm produce and proper functioning of government food and nutritional programs.

Negative ramifications of farm labor shortage must be rectified by facilitating more machinery involvement through custom hiring centers (CHCs) and Farmer Producer Organizations (FPOs) soon. NREGA scheme may be effectively linked with rural agriculture to reduce farmers' monetary load and secure labor income. The major portion of all livestock components is devoid of established marketing networks, resulting in a lack of feed availability and unsold or half-priced milk and meat from the farmers. They must be considered for immediate credit assistance

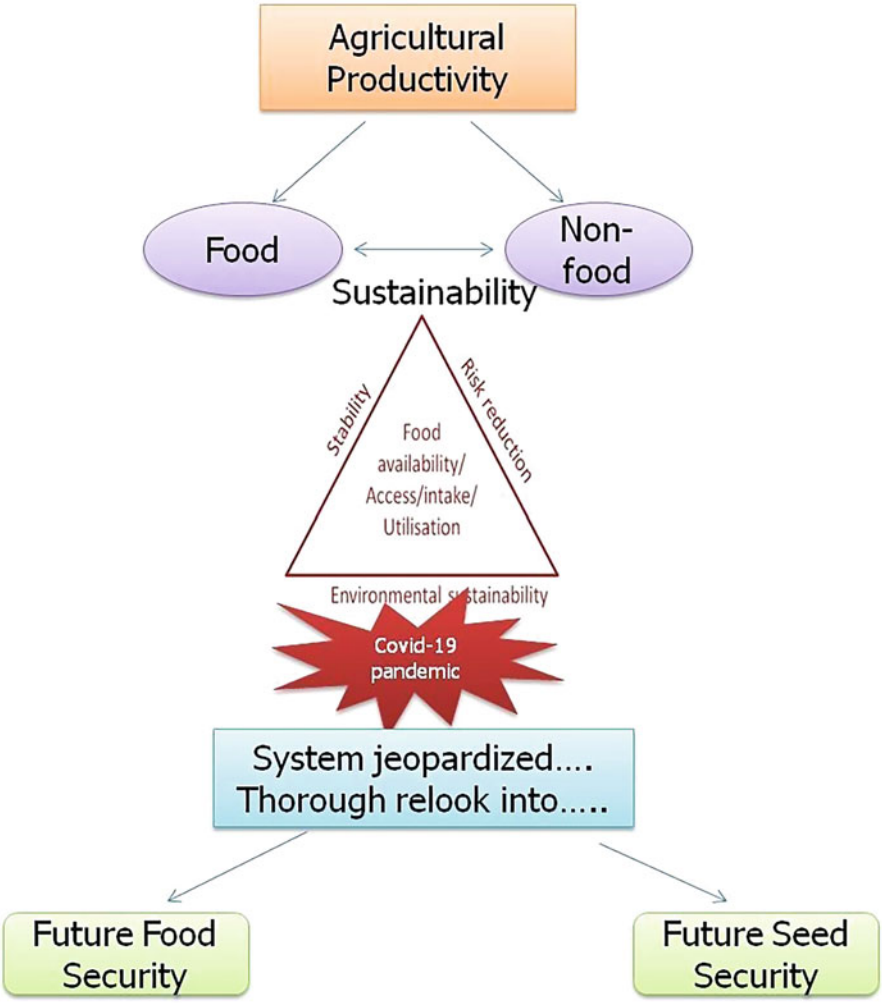

Fig. 3 COVID-19 pandemic-resilient framework for food security

and more targeted help. Cooperatives, farmers' clubs, and enterprises should be boosted with crop loans.

Multifaceted challenges during pandemics have brought urgency to look forward toward commercialized and diversified agricultural produce with more prominence on natural resource management and crop improvement technologies. Promotion and marketing framework for organic farming, pulses, coarse cereals, and value addition will be the key to achieving regional food security and economic resilience. In these ways, with a comprehensive and systematic policy framework, regional planning, and executions, we can manage the SDG target for eliminating extreme poverty and nutritional security by 2030.

11 Conclusion

COVID-19 is now becoming the most unprecedented and unfolding life threat globally. Its health, economic and social consequences, and vulnerabilities have been compounded, prompting severe panic and disruption in daily livelihood. Climate change, economic breakdown, poverty, inequality, and malnutrition are further threatening issues to aggravate the disease potential (see Sect. 2). Food systems and nutrition are exigent for restraining the food catastrophe amid this pandemic, unique region-specific policy design, intelligibility, and synergism for allover agriculture. Potential public and private mechanisms, innovations for securing cultivating networks during imminent agrarian seasons, streamlining value chains, and better accessibility together with market price stability have to be prosecuted for tackling the crisis. The crucial thresholds for every opportunity, precedence, and scheme must be mutually achieved toward nutritional nourishment for healthy lives, resource-based ecosystem sustainability for future balance, and productive investment for a resilient agrarian rural economy. Spirited endeavors, concerted development assistance, and awareness pushed by empathy and feelings for our society's poorest and fragile segment are the absolute urgency to reach scale-neutral nationwide food security.

References

Abi-Habib, M., & Yasir, S. (2020, March 30). For India's laborers, Coronavirus lockdown is an order to starve. *The New York Times*. https://www.nytimes.com/2020/03/30/world/asia/coronavirus-india-lockdown.html. Accessed 12 July 2021.

Aday, S., & Aday, M. S. (2020). Impact of COVID-19 on the food supply chain. *Food Quality and Safety, 4*, 167–180.

Adhikari, J., Timsina, J., Khadka, S. R., Ghale, Y., & Ojha, H. (2021). COVID-19 impacts on agriculture and food systems in Nepal: Implications for SDGs. *Agricultural Systems, 186*, 102990.

Allard, L., Ouedraogo, E., Molleville, J., Bihan, H., Giroux-Leprieur, B., Sutton, A., Baudry, C., Josse, C., Didier, M., & Deutsch, D. (2020). Malnutrition: Percentage and association with prognosis in patients hospitalized for coronavirus disease 2019. *Nutrients, 12*, 3679.

Almeida, V., Barrios, S., Christl, S., Poli, S. D., Tumino, A., & van der Wielen, W. (2021). The impact of COVID-19 on households' income in the EU. *The Journal of Economic Inequality, 19*, 413. https://doi.org/10.1007/s10888-021-09485-8

Alonso, E., Gregory, J., & Field, F. (2007). Material availability and the supply chain: Risks, effects, and responses. *Environmental Science and Technology, 41*, 6649–6656.

Alvi, M., & Gupta, M. (2020). Learning in times of lockdown: How Covid-19 is affecting education and food security in India. *Food Security, 12*, 793–796.

APEDA. (2016). *Indian Agri Exports, Study on difficulties faced by the exporters in the supply chain of agriculture product, 2016*. APEDA. Retrieved from https://apeda.gov.in/apedawebsite/Announcements/APEDA_REPORT_22_Sep_16.pdf

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control, 39*, 172–184.

Badia-Melis, R., Mishra, P., & Ruiz-García, L. (2015). Food traceability: New trends and recent advances. A review. *Food Control, 57*, 393–401.

Barling, D. (2020). Challenges to the food supply in the UK: Collaboration, value and the labour force. *Agriculture and Human Values, 37*, 561–562.

Barrett, C. B. (2020). Actions now can curb food systems fallout from COVID-19. *Nature Food, 1*, 319.

BBC (British Broadcasting Corporation). (2020). *Coronavirus: Five ways the outbreak is hitting global food industry* [Online]. https://www.bbc.com/news/world-52267943. Accessed 12 July 2021.

Beal, T., Massiot, E., Arsenault, J. E., Smith, M. R., & Hijmans, R. J. (2017). Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLoS One, 12*(4), e0175554.

Bernton, H. (2020). In French fry heaven, spring turns bitter. *The Seattle Times*. Available online: https://www.seattletimes.com. Accessed 21 July 2020.

Bhalla, N., & Wuilbercq, E. (2020). No bed of roses: East Africa's female flower workers lose jobs as coronavirus hits exports. *Reuters*. Retrieved from: https://tinyurl.com/y7yvm69h. Accessed 11 July 2021.

Bhavani, R. V., & Rampal, P. (2018). *Review of agriculture – Nutrition linkages in South Asia*. Retrieved from http://www.cabi.org/cabreviews. Accessed 25 Apr 2020.

Ceballos, F., Kannan, S., & Kramer, B. (2020). Impacts of a national lockdown on smallholder farmers' income and food security: Empirical evidence from two states in India. *World Development, 136*, 105069.

CIHEAM (International Center for Advanced Mediterranean Agronomic Studies). (2020). *The COVID-19 pandemic: Threats on food security in the Mediterranean region*. https://www.ciheam.org/agendas/threats-on-food-security. Accessed 13 July 2021.

Dandage, K., Badia-Melis, R., & Ruiz-García, L. (2017). Indian perspective in food traceability: A review. *Food Control, 71*, 217–227.

Deaton, A. (2021). *COVID-19 and global income inequality* (National Bureau of Economic Research Working Paper 28392). Retrieved on July 13, 2021 from https://www.nber.org/system/files/working_papers/w28392/w28392.pdf

FAO, IFAD, UNICEF, WFP, & WHO. (2020). *The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets*. FAO. https://doi.org/10.4060/ca9692en

Food and Agriculture Organisation of United Nations (FAO). (2015a). Global initiative on food loss and waste reduction of the FAO: Pilot activities and measurements conducted during an FAO Technical Cooperation Project: TCP\RAS\3502, Reduction of post-harvest Losses in horticultural supply chains in SAARC Countries.

Food and Agriculture Organisation of United Nations (FAO). (2015b). *Climate change and food security: Risks and responses*. FAO. ISBN:978-92-5-108998-9. Retrieved from http://www.fao.org/3/i5188e/I5188E.pdf

Food and Agriculture Organisation of United Nations (FAO). (2018). *World food and agriculture – statistical pocketbook*. FAO. 254 pp. Retrieved from http://www.fao.org/3/CA1796EN/ca1796en.pdf

Food and Agriculture Organisation of United Nations (FAO). (2019). *India at a glance*. FAO. Retrieved from http://www.fao.org/india/fao-in-india/india-at-a-glance/en/

Food and Agriculture Organisation of United Nations (FAO). (2020a). *COVID-19 and the role of local food production in building more resilient local food systems*. Retrieved from http://www.fao.org/documents/card/en/c/cb1020en/

Food and Agriculture Organisation of United Nations (FAO). (2020b). *Responding to the impact of the COVID-19 outbreak on food value chains through efficient logistics* [Online]. Retrieved from http://www.fao.org/3/ca8466en/CA8466EN.pdf

Food and Agriculture Organisation of United Nations (FAO). (2020c). *COVID-19 and the risk to food supply chains: How to respond?* [Online]. Retrieved from http://www.fao.org/3/ca8388en/CA8388EN.pdf

Gadgil, S., Abrol, Y. P., & Rao Seshagiri, P. R. (1999). On growth and fluctuation of Indian food grain production. *Current Science, 76*(4), 548–556.

Galimberti, A., Cena, H., Campone, L., Ferri, E., Dell'Agli, M., Sangiovanni, E., Belingheri, M., Riva, M. A., Casiraghi, M., & Labra, M. (2020). Rethinking urban and food policies to improve citizens safety after COVID-19 pandemic. *Frontiers in Nutrition, 7*, 569542.

Gillespie, S., & Haddad, L. (2001). *Attacking the double burden of malnutrition in Asia and the Pacific*. Asian Development Bank Press and International Food Policy Research Institute.

GoI. (2017a). *Pulses in India, retrospect and prospects*. Directorate of Pulses Development; Ministry of Agriculture & Farmers Welfare, 2017, Government of India.

GoI. (2017b). *Report of the expert committee on "strategy for doubling farmers income' by 2022", 2017* (Vol. 1 & 2). MOA&FW, Government of India.

GoI. (2018). *Agricultural statistics at a glance*. Ministry of Agriculture, Department of Agriculture and Cooperation, Directorate of Economics and Statistics. Retrieved from http://agricoop.gov.in/sites/default/files/agristatglance2018.pdf

GoI. (2019). *Food and nutrition security analysis*. WFP and Ministry of Statistics & Programme Implementation, 2019. Government of India.

Golan, E., Krissoff, B., Kuchler, F., Nelson, K., Price, G., & Calvin, L. (2004). *Traceability in the US food supply: Economic theory and industry studies* (Agricultural Economic Report No. 830). US Department of Agriculture, Economic Research Service.

Goncalves, T. J. M., Goncalves, S. E. A. B., Guarnieri, A., Risegato, R. C., Guimaraes, M. P., Cabral de Freitas, D., Razuk-Filho, A., Junior, P. B. B., & Parrillo, E. F. (2020). Prevalence of obesity and hypovitaminosis D in elderly with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). *Clinical Nutrition, 40*, 110–114.

Gulati, A., Kumar, A. G., Sreedhar, G., & Nandkumar, T. (2012). Agriculture and malnutrition in India. *Food and Nutrition Bulletin, 33*(1), 74–86.

Harris, J., Depenbusch, L., Pal, A. A., Nair, R. M., & Ramasamy, S. (2020). Food system disruption: Initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Security, 12*, 841–851.

Havice, E., Marschke, M., & Vandergeest, P. (2020). Industrial seafood systems in the immobilizing COVID-19 moment. *Agriculture and Human Values, 37*, 655–656.

Headey, D., Heidkamp, R., Osendarp, S., Ruel, M., Scott, N., Black, R., Shekar, M., Bouis, H., Flory, A., Haddad, L., & Walker, N. (2020). Impacts of COVID-19 on childhood malnutrition and nutrition-related mortality. *The Lancet, 396*(10250), 519–521.

Hindu Business Line. (2018). *NCDs account for 53% of the disease burden in India: study*. Retrieved from https://www.thehindubusinessline.com/news/science/ncds-account-for-53-of-the-disease-burden-in-india-study/article9187723.ece

Hirvonen, K., Bai, Y., Headey, D., & Masters, W. A. (2020). Affordability of the EAT–lancet reference diet: A global analysis. *The Lancet Globalization and Health, 8*(1), e59–e66.

ICRISAT. (2015). *Meso level data for India, 1966–2011: Collected and compiled under the project on Village Dynamics in South Asia. 2015*. Retrieved from http://vdsa.icrisat.ac.in/vdsa-mesodoc.aspx

IFPRI. (2016). International Food Policy Research Institute, global nutrition report 2016: From promise to impact: Ending malnutrition by 2030, Washington, DC.

ILO (International Labour Organization). (2020). *COVID-19 and the impact on agriculture and food security* [Online]. Retrieved from https://www.ilo.org/wcmsp5/groups/public/%2D%2D-ed_dialogue/%2D%2D-sector/documents/briefingnote/wcms_742023.pdf

ILO Monitor. (2020, April 7). *COVID-19 and the world of work. Second edition updated estimates and analysis*. International Labour Organization.

International Organization for Migration (IOM). (2020). *Migrants and global food supply* (COVID-19 Analytical Snapshot #18). Retrieved from https://tinyurl.com/y7ocan7d

Jaacks, L. M., Veluguri, D., Serupally, R., Roy, A., Prabhakaran, P., & Ramanjaneyulu, G. V. (2021). Impact of the COVID-19 pandemic on agricultural production, livelihoods, and food security in India: Baseline results of a phone survey. *Food Security, 13*, 1323. https://doi.org/10.1007/s12571-021-01164-w

Kharas, H., Hamel, K., & Hofer, M. (2018). *The start of a new poverty narrative*. Brookings Institution.

Kim, K., Kim, S., & Park, C. Y. (2020). *Food security in Asia and the Pacific amid the COVID-19 pandemic* (ADB (Asian Development Bank) Brief, 139). ADB.

Kinsey, E. W., Kinsey, D., & Rundle, A. G. (2020). COVID-19 and food insecurity: An uneven Patch work of responses. *Journal of Urban Health, 97*, 332–335.

Kohlmeier, M. (2020). Avoidance of vitamin D deficiency to slow the Covid-19 pandemic. *BMJ Nutrition, Prevention & Health, 3*, e000096.

Kumar, P., Mruthyunjaya, & Dey, M. M. (2007). Long-term changes in Indian food basket and nutrition. *Economic & Political Weekly, 42*(35), 3567–3572.

Kumar, P., Joshi, P. K., & Mittal, S. (2016). Demand vs supply of food in India-Futuristic projection. *Proceedings of the Indian National Science Academy, 82*(5), 1579–1586.

Laborde, D., Martin, W., & Vos, R. (2020). *Estimating the poverty impact of COVID-19: The MIRAGRODEP and POVANA frameworks* (IFPRI Technical Note (IFPRI, 2020)). https://tinyurl.com/y9fazbzf. Accessed 13 July 2021.

Mahendra Dev, S. (2018, November 1–3). *Transformation of Indian agriculture? Growth, inclusiveness and sustainability.* Presidential address delivered at the 78th annual conference of the Indian Society of Agricultural Economics, New Delhi.

Mardones, F. O., Rich, K. M., Boden, L. A., Moreno-Switt, A. I., Caipo, M. L., Zimin-Veselkoff, N., Alateeqi, A. M., & Baltenweck, I. (2020). The COVID-19 pandemic and global food security. *Frontiers in Veterinary Science, 7*, 578508.

Marti, L., Puertas, R., & García-Álvarez-Coque, J. M. (2021). The effects on European importers' food safety controls in the time of COVID-19. *Food Control, 125*, 107952.

Moran, D., Cossar, F., Merkle, M., & Alexander, P. (2020). UK food system resilience tested by COVID-19. *Nature Food, 1*, 242.

Murphy, K., Hoagland, L., Reeves, P., & Jones, S. (2008). *Effect of cultivar and soil characteristics on nutritional value in organic and conventional wheat*. In Proceedings of the 16th IFOAM Organic World Congress 4, Modena, Italy, 16–20 June 2008.

Narayanan, S. (2015). Food security in India: The imperative and its challenges. *Asia & The Pacific Policy Studies, 2*(1), 197–209.

National Statistical Office. (2019, May). *Periodic labour force survey: July 2017–June 2018*, Ministry of Statistics and Programme Implementation, Government of India.

New Zealand Herald. (2020). *Covid-19 coronavirus: Courgette prices jump 74pc to all-time high*. Retrieved from https://www.nzherald.co.nz/business/covid-19-coronavirus-courgette-prices-jump-74pc-to-all-time-high/R3RATB3EWT6VB4FAT5LKNC4Q5U/

Niles, M. T., Bertmann, F., Belarmino, E. H., Wentworth, T., Biehl, E., & Neff, R. (2020). The early food insecurity impacts of COVID-19. *Nutrients, 12*, 2096.

NSSO (National Sample Survey Organization). (2012). Consumption and expenditure survey (various rounds), 50th (1993–94), 61st (2004–05), 66th (2009–10) and 68th (2011–12). New Delhi: Government of India.

Petetin, L. (2020). The COVID-19 crisis: An opportunity to integrate food democracy into postpandemic food systems. *European Journal of Risk Regulation, 11*, 326–336.

PIB. (2016, August 9). *Press Information Bureau: Information given to the Lok Sabha*.

Pingali, P., Aiyar, A., Abraham, M., & Rahman, A. (2019). Indian food systems towards 2050: Challenges and opportunities. In *Transforming food Systems for a rising India. Palgrave studies in agricultural economics and food policy.* Palgrave Macmillan. https://doi.org/10.1007/978-3-030-14409-8_1

Reardon, T., Mishra, A., Nuthalapati, C. S. R., Bellamare, M. F., & Zilberman, D. (2020). COVID-19's disruption of India's transformed food supply chains. *Economic and Political Weekly, 55*(18) Retrieved 11, July 2021, from https://www.epw.in/journal/2020/18/commentary/covid-19s-disruption-indias-transformed-food.html

Rivera-Ferre, M. G., López-i-Gelats, F., Ravera, F., Oteros-Rozas, E., di Masso, M., Binimelis, R., & El Bilali, H. (2021). The two-way relationship between food systems and the COVID19 pandemic: Causes and consequences. *Agricultural Systems, 191*, 103134.

Rodriguez-Leyva, D., & Pierce, G. N. (2021). The impact of nutrition on the COVID-19 pandemic and the impact of the COVID-19 pandemic on nutrition. *Nutrients, 13*, 1752.

Shahi, R. B., & Gautam, H. (2020, September 2). Food shortage looming large in Mugu, Dolpa districts of Karnali Province. *The Kathmandu Post*. https://kathmandupost.com/karnali-province/2020/09/02/food-shortage-looming-large-in-mugu-dolpa-districts-of-karnali-province. Accessed 13 July 2021.

Shupler, M., Mwitari, J., Gohole, A., Anderson de Cuevas, R., Puzzolo, E., Čukić, I., Nix, E., & Pope, D. (2021). COVID-19 impacts on household energy & food security in a Kenyan informal settlement: The need for integrated approaches to the SDGs. *Renewable and Sustainable Energy Reviews, 144*, 111018.

Singh, B., Shirsath, P. B., Jat, M. L., McDonald, A. J., Srivastava, A. K., Craufurd, P., Rana, D. S., Singh, A. K., Chaudhari, S. K., Sharma, P. C., Singh, R., Jat, H. S., Sidhu, H. S., Gerard, B., & Braun, H. (2020). Agricultural labor, COVID-19, and potential implications for food security and air quality in the breadbasket of India. *Agricultural Systems, 185*, 102954.

Souza-Monteiro, D. M., & Hooker, N. H. (2013). Food safety and traceability. In *US programs affecting food and agricultural marketing* (pp. 249–271). Springer.

Summerton, S. A. (2020). Implications of the COVID-19 pandemic for food security and social protection in India. *Indian Journal of Human Development, 14*(2), 333–339.

Swinnen, J., & Vos, R. (2021). COVID-19 and impacts on global food systems and household welfare: Introduction to a special issue. *Agricultural Economics, 52*(3), 365–374.

Torero, M. (2020). Without food, there can be no exit from the pandemic. *Nature, 580*, 588–589.

UN. (2019). *The Sustainable Development Goals report*. UN. Available online at: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

UN General Assembly. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development* (21/10/2015, A/RES/70/1). https://www.refworld.org/docid/57b6e3e44.html

Vogel, H. J., Eberhardt, E., Franko, U., Lang, B., Ließ, M., Weller, U., Wiesmeier, M., & Wollschläger, U. (2019). Quantitative evaluation of soil functions: Potential and state. *Frontiers in Environmental Science, 7*, 164.

WFP. (2020). *Chief warns of hunger pandemic as COVID-19 spreads; News releases on 21 April 2020 Statement to UN Security Council, World Food Programme*. Retrieved from https://www.wfp.org/news/wfp-chief-warns-hunger-pandemic-COVID-19-spreads-statement-un-security-council

WFP. (2021). *Food security and COVID-19*. Retrieved from https://www.worldbank.org/en/topic/agriculture/brief/food-security-and-covid-19.print

Zdruli, P., Lal, R., Cherlet, M., & Kapur, S. (2017). New world atlas of desertification and issues of carbon sequestration, organic carbon stocks, nutrient depletion and implications for food security. *Carbon management, technologies, and trends in mediterranean ecosystems*, 13–25.