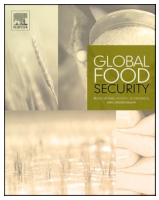
Global Food Security 45 (2025) 100848

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs



Why do epidemics cause more hunger even when global food production is unaffected?☆

Binlei Gong [a,1], Shouhan Dai [a,1], Shuo Wang [a,1], Xinjie Shi [a,1], Biao Huang [a,1], Kevin Z. Chen [a,b,1,*]

[a] School of Public Affairs, Zhejiang University, Hangzhou, China
[b] International Food Policy Research Institute, Washington D.C., USA

ARTICLE INFO

Keywords:
Epidemics
Infectious diseases
Hunger
Food security
Global food distribution

ABSTRACT

An apparent paradox is that, sufficient food is currently being produced to feed the global population, yet there has been a rising hunger in many parts of the world. An explanation that has been advanced in the literature lies in unfair food distribution within a specific region. However, empirical evidence regarding how infectious diseases influence people's food availability from a global food distribution perspective is still lacking. This paper aims to provide empirical evidence through investigating the effect of infectious diseases on hunger from the perspective of global food distribution. Using a panel data for 105 countries over the period of 1990–2016, we find that infectious diseases had no significant impact on overall global food production, but they caused more severe hunger in many countries or regions. How is that possible? The mechanism analysis shows that there was an increased flow of food from developing countries to developed countries during epidemics. Meanwhile, developing countries failed to compensate for this shortfall through either food stock or food aid, resulting in a reduced availability of food for domestic consumption. We find that epidemics caused higher domestic food prices and reduced affordability of food, which further exacerbated food insecurity and malnutrition in developing countries. To achieve the 2030 SDGs goal of Zero Hunger, it is critical to improve global food governance and enhance food distribution when facing a crisis such as epidemics.

1. Introduction

A world with zero hunger stands as one of the Sustainable Development Goals (SDGs), poised to yield far-reaching positive ramifications for global economies, health, education, equality, and social development. However, there are a staggering 828 million individuals being affected by hunger (UN Report, 2022). In a noteworthy contribution, Caparrós (2020) claims that the Earth's food production could feed all its inhabitants easily, yet hunger persists and proliferates in specific regions across the globe. Worse yet, the eruption of infectious diseases, such as the COVID-19 pandemic, has exacerbated this crisis, leading to a more severe hunger crisis, as highlighted by Dongyu Qu, the Director-General of FAO, on World Food Day in 2021. A similar conundrum unfolded during the Ebola virus outbreak in Africa. As Figuié (2016) elucidates, despite a limited decline in national rice production, the number of people facing hunger was rapidly increasing. Why is global food production sufficient while the number of people facing hunger has rapidly increased during the outbreak of infectious diseases? This paper aims to answer this question using historical epidemic and food security data.

The infectious diseases outbreak resulted in an upsurge of hunger, especially among low-income countries and vulnerable groups (Brown et al., 2020; Laborde et al., 2021). As depicted in Figs. 1 and 2, the number of people facing severe food insecurity has been increasing

☆ The work was supported by the financial support of the National Natural Science Foundation of China (No. 72161147001, 72173114, 71903172), the Major Project of Philosophy and Social Sciences by the Ministry of Education (2024JZDZ059), the National Social Science Foundation of China (21&ZD092), Humanities and Social Sciences Program of the Ministry of Education (22JJD790075), Mitigate+: Research for Low Emissions Food Systems, and Zhejiang University Global Partnership Fund.

* Corresponding author. School of Public Affairs, Zhejiang University, Hangzhou, China.
E-mail addresses: gongbinlei@zju.edu.cn (B. Gong), sh.dai@zju.edu.cn (S. Dai), lesleywang@zju.edu.cn (S. Wang), xjshi1990@zju.edu.cn (X. Shi), biaohuang@zju.edu.cn (B. Huang), K.Chen@cgiar.org (K.Z. Chen).

[1] All authors contributed equally.

https://doi.org/10.1016/j.gfs.2025.100848
Received 24 June 2024; Received in revised form 11 March 2025; Accepted 16 March 2025
Available online 16 April 2025

annually since 2014, especially in low-income countries and predominantly in sub-Saharan Africa and South Asia. Noteworthy outbreaks such as the 2014 Ebola crisis in Africa, the 2015 MERS outbreak in Asia, and the ongoing COVID-19 pandemic all appear to be associated with subsequent surges in the population experiencing food insecurity in the following years. FAO et al. (2022) also certified that as many as 828 million people were hit by hunger in 2021–46 million people more from a year earlier and 150 million more from 2019 due to COVID-19. In contrast, FAO data underscores that global food production remained stable, registering at 1525 million tons in 2019 and slightly edging up to 1537 million tons in 2020. Therefore, it is essential to figure out the relationship between infectious diseases and hunger from the perspective of global food distribution.

How have the infectious diseases led to hunger? Related studies have argued that hunger is largely attributed to factors such as inadequate food supplies, rising food prices, food production insufficiency, economic losses, caused by the infectious diseases such as Ebola and COVID-19 (Chavas et al., 2014; Gong et al., 2020; Kodish et al., 2019; Smith and Wesselbaum, 2020; Sumo, 2019; Wunderlich, 2021). The studies above are primarily focused on specific regions and countries. Yet, the world is characterized by abundant global food supply. With effective international food trade and fair food distribution, universal access to adequate food should be attainable. However, in the context of epidemics, some countries have restricted the food trade using export restriction, export quota management, export tariffs, export licenses, etc., to ensure domestic food supply (Falkendal et al., 2021). Notably, Chen & Mao (2020) contend that implementing trade restrictions as an instrument for preventing and controlling infectious diseases escalates the risk and instability of international agricultural markets and trade. Moreover, these trade restriction policies inevitably trigger fluctuations in global food prices, thereby precipitating food crises in specific regions (Dongyu et al., 2020).

Therefore, inspired by historical events like the Great Famine, a number of studies shifted their focus towards food distribution and found that food scarcity often stems from inequitable food distribution, driven by political decisions and trade entitlement failures, rather than inadequacies in global food supply (Meng et al., 2015; Sen, 1980; Waal, 1993). The same challenge occurred during epidemics, where food shortages frequently arise due to distortions within public food distribution systems, particularly in low-income nations (Laborde et al., 2020; Rohr et al., 2019). A large number of literatures have shown that the prolongation of epidemics and the control of food trade could disrupt global food distribution, consequently threaten global food security (Lin and Zhang, 2020; Varshney et al., 2020; Zurayk, 2020). Despite the extensive literature about the negative impacts of infectious diseases on food production and food supply, a compelling evidence of how infectious diseases influence people's food availability from a global food distribution perspective is still lacking. How infectious diseases have affected global food distribution and what food distribution decisions countries at different stages of development should make has not been addressed in the existing literatures.

This paper aims to identify the impact of infectious diseases on global hunger, with a specific emphasis on comparing disparities between developing and developed countries. We further delve deeper into the mechanisms through which infectious diseases may lead to hunger from the perspective of global food production and distribution. We aggregate the prevalence of 10 major infectious diseases at national level to characterize infectious disease outbreaks in 105 countries spanning from 1990 to 2016. Additionally, we also use datasets encompassing national nutritional status and food supply to investigate the effects of the infectious diseases on the nutritional well-being of vulnerable populations. We also analyze the impact of infectious diseases on the food supply of developed countries, developing countries and least developed countries from four key aspects: food production, food trade, food stock, and food aid (Barrett, 2010; Del Ninno et al., 2007; Devereux, 2007; Fraser et al., 2015). Our findings indicate that, while infectious diseases

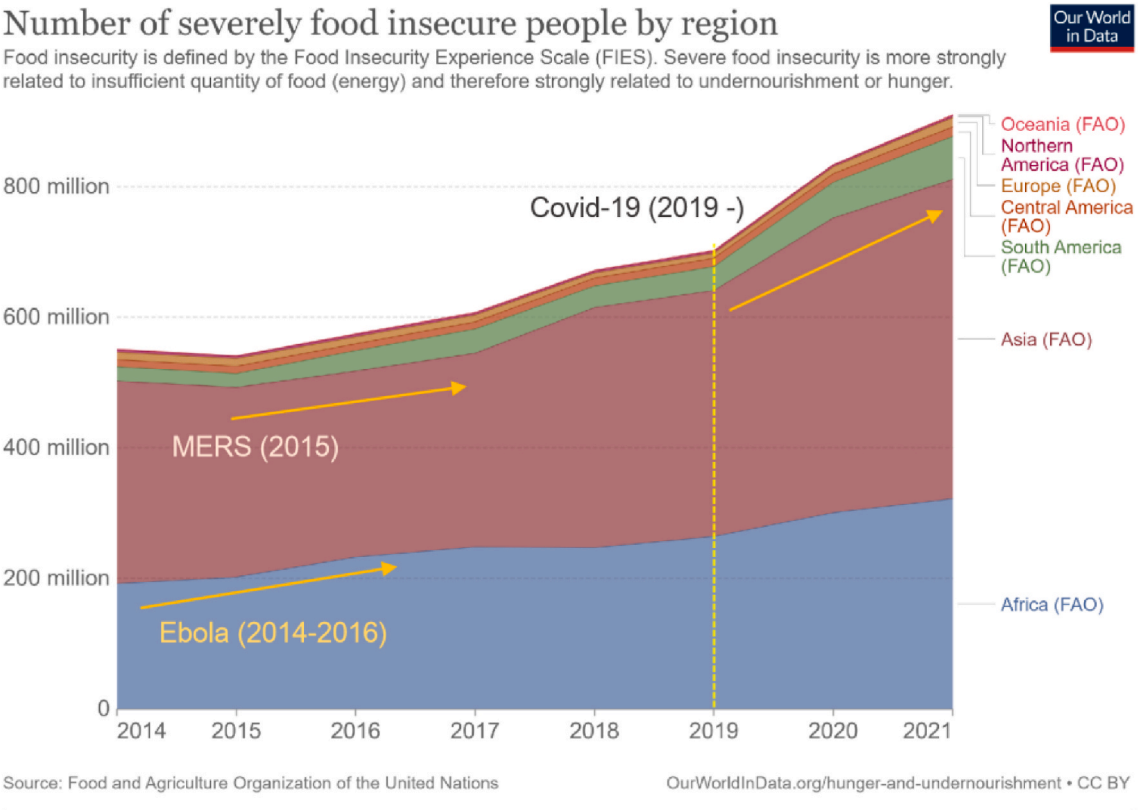


Fig. 1. The number of severely food insecure people by region.[12].

have an insignificant impact on food production and international food aid, they do influence international food trade and food stock. Moreover, the reduced stock is found to be inadequate to compensate for the loss of food trade. In the context of overall global food flows from developed to developing countries, our result reveals a reduced volume of agricultural products moving from developed countries to developing countries, which leads to inadequate food supply for the latter group during epidemics even if their domestic production remains stable. Furthermore, rising domestic food prices during epidemics further exacerbate malnutrition, as poor households cannot afford to buy the food.

This paper contributes to the literature in three aspects. First, the majority of existing studies concentrate on assessing the impact of a single infectious disease such as COVID-19 and Ebola, which usually have a severe social and economic impact and attracted global public attention. However, there are still many infectious diseases that are identified as ongoing threats by international authorities, continue to affect socioeconomic conditions and hunger. In contrast, this paper examines the collective impact of 10 major infectious diseases on food security, aiming to identify common characteristics of epidemic outbreaks and derive implications for future disease prevention measures, rather than focusing on a specific disease in isolation. Second, compared with existing studies that primarily focus on a single country or region, this paper investigates the global impact of major infectious diseases on food distribution using data from 105 countries in 27 years. Additionally, we delve into the food trade flows among countries at varying stages of development during epidemic outbreaks, finding that changes in food trade patterns during epidemics are the major reason for more severe hunger problems despite sufficient global food production. Third, this paper further identifies the mechanism of epidemic-induced hunger issues from the perspectives of both availability and affordability of food. On the one hand, we analyze the effect of infectious diseases on four food sources; on the other hand, we further investigate the effect on domestic food prices to gain insights into both availability and affordability.

The remainder of this paper is organized as follows. Section 2 discusses the background of this paper. The method is discussed in Section 3. Section 4 describes the dataset we used in the study. Section 5 reports the impact of infectious diseases on hunger issues and agricultural production, followed by mechanism analysis of the impact on food distribution in Section 6. Section 7 provides our conclusions.

2. Background

2.1. Infectious disease and global nutritional status

There are numerous instances in history where infectious diseases have triggered food shortages, famines, and other associated issues, such as the Justinian Plague and the Black Death (bubonic plague) (Roubík et al., 2022). In recent decades, infectious diseases have continued to impact the production and supply of food. The 2003 outbreak of SARS in China led to a decline in food production, which in turn affected the livelihoods of many small farmers (Gong et al., 2021). HIV/AIDS, particularly in sub-Saharan Africa, has led to significant reductions in agricultural productivity and food security due to illness and death of farmers, as well as reduced labor availability (UNAIDS, 2018). The Ebola outbreak in West Africa (2014–2016) led to food shortages and price

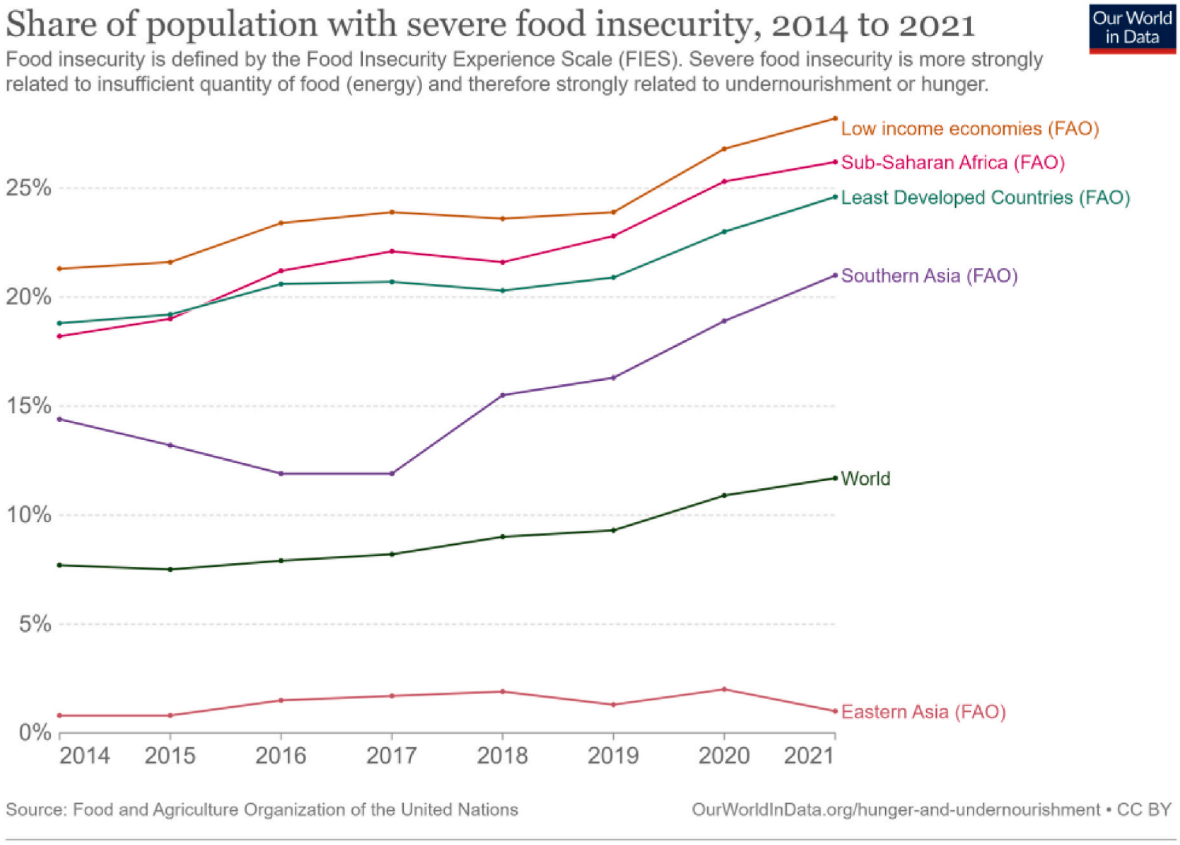


Fig. 2. Share of population with severe food insecurity from 2014 to 2021.

[2] Data from: Max Roser and Hannah Ritchie (2019) - "Hunger and Undernourishment". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/hunger-and-undernourishment' [Online Resource] original source: FAO.

increases due to restrictions on travel and trade, as well as loss of agricultural labor and disruption of farming activities (Kodish et al., 2019). In recent years, COVID-19 increased global food insecurity in almost every country by reducing incomes and disrupting food supply chains. The pandemic continues to create devastating effects on global hunger and poverty – especially in low-income countries and the most vulnerable populations, the number of severely food-insecure people has doubled from before the pandemic to 276 million people (USGLC, 2022). Fig. 3 shows that there is a strong correlation between major infectious diseases and hunger as well as malnutrition, where a high prevalence of infectious diseases is usually associated with a poor condition of undernourishment, especially in sub-Saharan Africa, Latin America, South and Southeast Asia.

2.2. Infectious disease outbreaks and global food supply

Numerous studies have specifically examined how infectious diseases such as H1N1, Ebola, and COVID-19 affect food production (Gatiso et al., 2018; Keogh-Brown et al., 2010; World Bank, 2015). In the context of infectious diseases, the severity of the disease and restrictive policies often lead to shortages of agricultural inputs, labor, and disruptions in the supply chain, resulting in reduced agricultural productivity (European Commission, 2015; Kakaei et al., 2022; Zhang et al., 2020). However, FAO (2022) pointed out that production data of primary crop and livestock in 2020 do not provide clear evidence for any impact of the COVID-19 pandemic at the global level. Consequently, study regarding global food distribution is of great significance. The study of the events of the Great Famine provides a new perspective on this issue. Famines often take place in situations of moderate to good food availability, without any significant decline in food supply per head (Sen, 1980). In this context, trade opportunities are highlighted because starvation is a matter of some people not having enough food to eat, and not a matter of there being not enough food(Sen, 1980). For example, control of trade was instrumental in creating famine in Ethiopia in the 1980s (Waal, 1993). Meng et al. (2015) found that during the 1959–1961 Great Chinese Famine, the average rural grain retention was much higher than the population subsistence needs. Remarkably, regions with higher per capita food production during this period had witnessed increased mortality rates. The main cause of the Great Famine was not the insufficiency of food production, but the unreasonable food distribution, which means the rigid food procurement system could not be adjusted according to the production situation. The studies above have focused on a specific country and found that the distortions of domestic food distribution is the reason for famine. Then, are there distortions in global food distribution during infectious disease outbreaks? Kakaei et al. (2022) indicates that there are disruptions in food distribution during infectious disease outbreaks, which can result in inadequate food supply in certain areas. In addition, food trade liberalization itself may also increase the risk of food insecurity, Mary (2019) argued that most developing countries may not benefit from freer agricultural trade and that liberalization may accentuate food insecurity. A 10 % increase in food trade openness would increase the prevalence of undernourishment by about 6 %. Under the epidemic context, a series of restrictive measures and policies, such as lockdowns, travel restrictions, and export limitations, are implemented, significantly impacting food supply chains and international trade (Mardones et al., 2020). These restrictive measures can cause interruptions in food supply, logistical issues, and transportation difficulties, thereby affecting food prices and global food distribution (Anderson, 2012).

3. Method

We adopt two approaches to estimate the effects of infectious diseases on nutrition as well as global food security. A conventional strategy that uses Ordinary Least Squares (OLS) is conducted as the following equation:

$$Y_{ct} = \alpha_0 + \alpha_1 \log\left(Prevalence_{ct}\right) + \delta_c + \theta_t + X_{ct}'\boldsymbol{\beta} + \varepsilon_{ct} \quad (1)$$

where Y_{ct} is either hunger-related or food-related outcomes of country c in the year t. $Prevalence_{ct}$ is the key independent variable, implying total cases per 100,000 population for 10 major infectious diseases in country c and year t. δ_c is the country fixed effect which removes country-specific unobservable factors and θ_t is the year fixed effect that incorporates common time-varying factors across countries. ε_{ct} is the error term with mean zero. X_{ct}' is a vector of control variables.

In this paper, the endogeneity problem may exist because of the reverse causal effect between infectious diseases and outcome factors such as nutritional status and food supply. For example, people with poor nutrition are more likely to catch infectious diseases (Gombart et al., 2020). The movement of people and goods generated by international trade can also lead to the spread of infectious diseases, while the import and export of food can also affect the availability of food, both of which affect the nutritional status of a country's people (Barrett and Maxwell, 2007). To address this potential problem, inspired by Gong and Sickles (2020, 2021) and Qian et al. (2021), we then use the lagged prevalence of major infectious diseases as instrumental variables (IV) and use Two Stage Least Squares (TSLS) method to estimate the impact.

A valid IV variable needs to meet two requirements, it is highly related to the endogenous variable but otherwise unrelated to the dependent variable. In other words, it affects the dependent variable only through its impact on the endogenous variable. The characteristics of infectious diseases make their lagged value a good IV. First, due to the infectiousness of these diseases, the prevalence of infectious diseases is highly related in two consecutive years. Second, unlike other disasters such as earthquakes and flood, infectious diseases do not damage physical capitals such as plants and equipment. As a result, once infectious diseases disappear, production and living activities can resume immediately, which implies that previous infectious diseases have no other major channels to affect production except their impact on current infectious diseases. This paper uses the following TSLS model to further identify the impact of infectious diseases with an endogeneity concern:

$$Prevalence_{ct} = \beta_0 + \beta_1 Prevalence_{ct-1} + \delta_c + \theta_t + X_{ct}'\boldsymbol{\beta} + \epsilon_{ct} \quad (2)$$

$$Y_{ct} = \pi_0 + \pi_1 \widehat{Prevalence}_{ct} + \delta_c + \theta_t + X_{ct}'\boldsymbol{\beta} + \mu_{ct} \quad (3)$$

where Equation (2) is the first stages, and Equation (3) is the second stages. $Prevalence_{ct-1}$ accounts for the total cases per 100,000 population for 10 major infectious diseases in country c and year t-1. $\widehat{Prevalence}_{ct}$ is predicted from Equation (2). Other notations have the same meaning as those in Equation (1). In order to account for the possible presence of simultaneity bias in other control variables, we substitute these variables with their lagged values in Equations (2) and (3).

4. Data

4.1. Infectious disease data

In terms of the measure of infectious diseases, this paper aggregates the prevalence rates for 10 major infectious diseases at country-level to proxy the outbreaks of infectious diseases during 1990–2016. These 10 diseases are Ebola, Zika, Dengue Fever, Yellow Fever, Leishmaniasis, AIDS/HIV, Malaria, Tuberculosis, African Trypanosomiasis Disease, and Meningitis. Prevalence rates of these 10 infectious diseases were collected from Global Burden of Disease Study (2017) Results (GDB, 2017) which estimated the burden caused by major diseases, injuries and risks in 195 countries and regions in the world from 1990 to 2016. The GBD, coordinated by the Institute for Health Metrics and Evaluation (IHME), is the most comprehensive global epidemiological observational study to date. Hence, it is as scientific as possible to use this

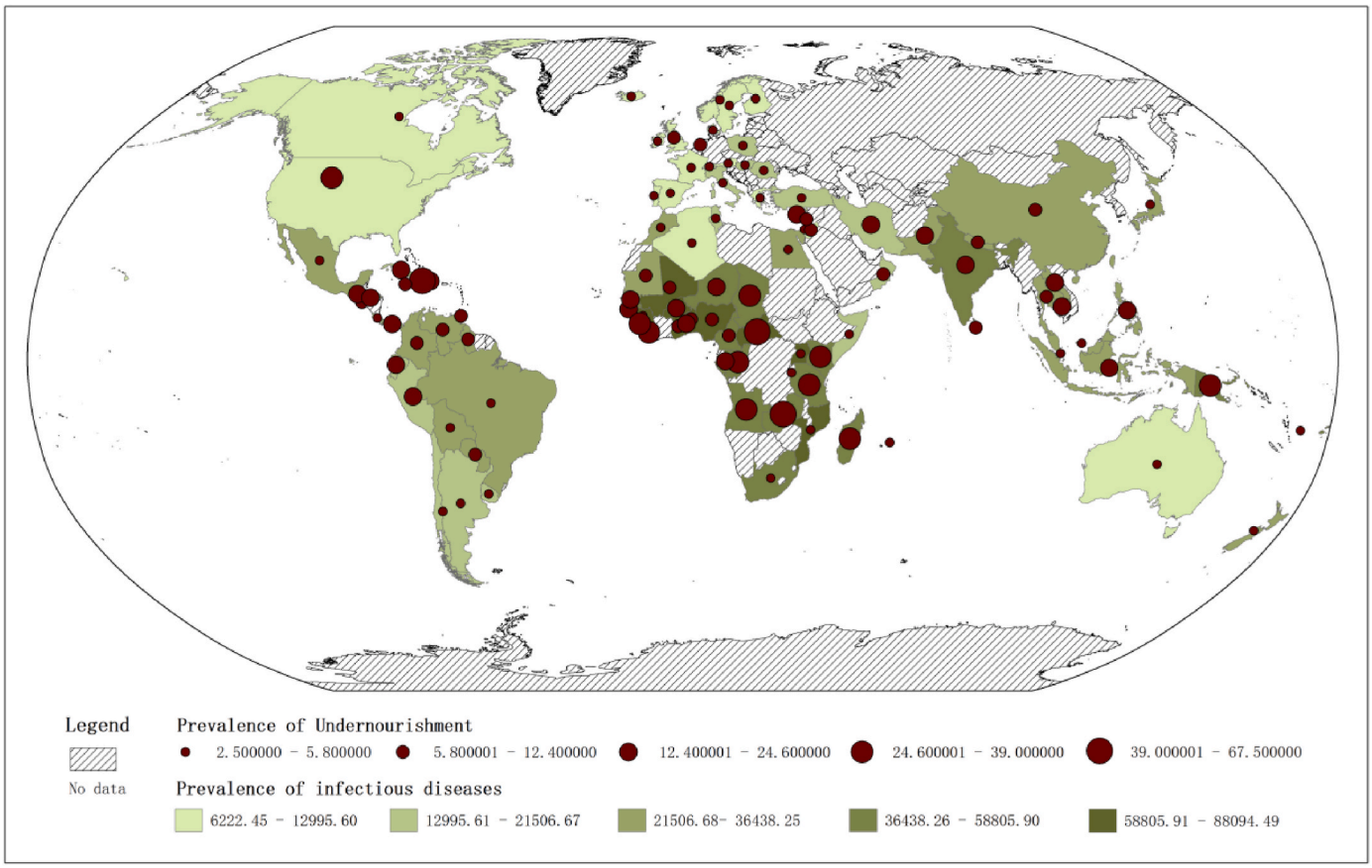


Fig. 3. Prevalence of infectious diseases and undernourishment around world during 1990–2016.

dataset for our study. In addition, in the process of data cleaning and analysis, we reference Roth et al. (2018), which has a comprehensive description of the metrics, data sources, and statistical modeling in GBD 2017. The reasons to choose these 10 diseases are described in Appendix A.1.

4.2. Nutrition and food supply data

We obtain the nutrition and food supply dataset from FAOSTAT. Following the description on the website,[3] the nutrition dataset includes prevalence of undernourishment, anemia among women of reproductive age, low birthweight, children under 5 years who are stunted, and children under 5 years affected by wasting. Details about the definition are listed in Appendix A.2.

Food supply data includes growth rate in agricultural production, agricultural trade surplus, food stock, and food aid. Agricultural production contains total agriculture production, crop production and livestock production. The growth rates are calculated by the data in the database. The agricultural trade surplus is calculated by subtracting the import quantity from the export quantity of agricultural products. Food stock data is collected from FAO Food Balances dataset, which comprises changes in stocks occurring during the reference period at all levels between the production and the retail levels.[4] Food aid data contains total food aid and cereals aid.[5] Food price data is also collected from FAO dataset, with the prices indexed to 2015 as the base period. The original data is monthly data, and the price variables are obtained by taking the arithmetic mean of the monthly data. In terms of the control variables, we describe the data source in Appendix A.3.

4.3. Descriptive statistics

By matching the infectious diseases dataset, the nutrition dataset and the food supply dataset from FAO, we ended up with a database, covering 105 countries[6] from 1990 to 2016. Table 1 is the descriptive statistics of the variables involved in the analysis below.

5. Empirical results

5.1. Results on hunger

Table 2 presents the estimated impact of infectious diseases on undernourishment. On the one hand, columns (1) and (2) report the OLS and IV estimation for all countries, respectively, and the results are robust. The prevalence rate of infectious diseases significantly increases the incidence of undernourishment. More specifically, a 10 % increase in the number of infections per 10,000 people is associated with a 0.791 percent point increase of the prevalence of malnutrition based on the IV estimates. On the other hand, columns (3) and (4) provide IV

[3] FAOSTAT. https://www.fao.org/faostat/en/#data.

[4] In the database, net increases in stocks (add to stock) are generally indicated by the sign "-", no sign denotes net decreases from stock.We change the variation of stock to absolute variation of stock by adding the absolute value of minimum amount of stock at first year and accumulate variation year by year. Detail description can be found in the website: https://www.fao.org/faostat/en/#data/FBS.

[5] The total food aid is the aggregate of cereals aid and non-cereals aid. Cereals aid contains blended and mix bulgur, wheat total, wheat and wheat flour, rice total, coarse grains.

[6] The 105 countries are listed in Appendix A.4. Additionally, we have also discussed the issue of data attributes in this section.

Table 1
Descriptive statistics.

VARIABLES	Obs	Mean	Std. Dev	Min	Max
Dependent Variables					
Nutrition related Dependent Variables					
Prevalence of Undernourishment (3-year Average) (%)	1497	12.273	12.161	0	69
Prevalence of Anemia among Women of Reproductive Age (15–49 Years) (%)	1377	34.394	12.979	9.9	65.3
Prevalence of Low Birthweight (%)	1024	12.307	4.434	3.8	27.2
Percentage of Children under 5 Years Who are Stunted (%)	325	27.683	13.929	1.8	64
Percentage of children under 5 Years affected by wasting (%)	319	6.869	4.740	0.3	24.4
Food Supply related Dependent Variables					
Growth in Agricultural Production	2781	0.021	0.075	−0.890	0.547
Growth in Crop Production	2678	0.021	0.107	−0.656	0.725
Growth in Livestock Production	2678	0.022	0.062	−0.970	0.698
Trade Surplus in Agriculture (Million tons)	2341	0.217	10.530	−30.298	99.661
Stock Variation of Nine Cereals (Million tons)	2341	67.176	3.693	0.001	104.968
Total Aid (Million tons)	1281	65.337	119.683	0.027	1752.133
Aid of Cereals (Million tons)	1358	54.141	109.139	0.008	1729.024
Food Price related Dependent Variables					
Food Price Inflation	1382	7.963	15.215	0.002	383.654
Independent Variables					
Prevalence Rate (Cases per 100,000 Population from 10 Diseases)	2781	10.108	0.690	8.696	11.431
Control Variables					
Trade Ratio (total trade volume of agricultural products to agricultural output)	2781	0.899	0.825	0	2.841
R&D to-output ratio (ratio of R&D stock to agricultural output)	2781	0.113	0.099	0	0.359
Number of regional conflicts	2781	31.682	151.282	0	2790
Rainfall (mm/year)	2781	1266.542	728.640	23.44	3250
Temperature Standard Deviation(°c)	2781	0.571	0.277	−0.32	1.8
Local currency units per USD	2781	789.410	2851.306	0.120	31558.91

Note: The data of nutritional status are averaged over three years. The descriptive statistics of nutrition data for the 4 vulnerable groups only contain developing countries, for the analysis in that part only focuses on developing countries.

estimations for two sub-samples, including developed countries and developing countries, respectively. The results show that the outbreaks of infectious diseases have significantly increased the prevalence of undernourishment in developing countries, but have no significant impact in developed countries. Moreover, column (5) shows that among developing countries, the subgroup of least developed countries suffers from a more severe negative impact on nutrition due to infectious diseases.

To further verify that infectious disease outbreaks indeed pose a threat to the nutrition status in developing countries, we further conducted a detailed analysis of the impact of infectious diseases on undernourishment among vulnerable populations. Vulnerable groups such as women, pregnant women, newborns, and children under five years old are at a higher risk of health problems stemming from malnutrition and other health challenges. For instance, pregnant women and newborns require special attention, as the mother's health and nutritional status during pregnancy significantly influence the health and well-being of the infant. Newborns are particularly vulnerable to malnutrition and other health issues due to their underdeveloped immune systems and susceptibility to infections (Beluska-Turkan et al., 2019). To address these challenges and ensure that key populations receive the care they need, governments, NGOs, and international organizations, often focus on targeted interventions, such as nutrition programs,[7] maternal and child health services,[8] and healthcare outreach programs,[9] that are tailored to the unique needs of these populations. We focus on developing countries given that developed countries experienced no significant impact on nutritional status during epidemics.

The results are shown in column (1)–(5), respectively, in Table .3. It is clear that the prevalence rate of infectious diseases significantly increases the incidence of anaemia, low birth weight, stunting and wasting. The estimated coefficients of interest are all statistically significant at the 1 %, in which the impact on children who are stunted is the largest, reached 1.328 percent point with 10 % increase in prevalence of infectious diseases per 10,000 people. These findings further confirm that infectious disease outbreaks will exacerbate hunger in developing countries.

5.2. Results on agricultural production

Once we find that infectious diseases cause more hunger problems, a reasonable guess is that agricultural production may be negatively affected by epidemics and hence leads to insufficient food supply. Table .4 reports the relationship between infectious diseases and agricultural productions. Panel A shows the impact on the growth rate of agricultural production, which is then decomposed into growth rate of crop production and livestock production in Panel B and C, respectively. There is an insignificant impact of infectious diseases on global agricultural production in developing countries as well as the subgroup of least developed countries. For developed countries, however, we even witness a slight increase in agricultural production during epidemics, which is a joint result of more crop production and less livestock production.

6. Mechanism analysis

The previous section shows that infectious diseases did not exert a significant impact on agricultural production but led to more severe hunger issues in developing countries. How is that possible? It is worth noting that food production is not equal to food consumption. Besides

[7] World Food Programme. (n.d.). Nutrition. https://www.wfp.org/nutrition.
[8] UNICEF. (n.d.). Maternal and child health. https://www.unicef.org/health/maternal-and-child-health.
[9] Health for All. (n.d.). Our approach. https://healthforallint.org/about-us/our-approach/.

Table 2
The effect of infectious diseases on Prevalence of undernourishment.

	Dependent Variable (Y)				
	Prevalence of Undernourishment				
	All Countries	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	OLS	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)
Prevalence Rate(log)	9.312***	7.908***	0.006	5.531***	20.038***
	(1.615)	(1.671)	(0.064)	(1.921)	(4.839)
Controls	Yes	Yes	Yes	Yes	Yes
Country Fixed Effect	Yes	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes
Under-identification test	–	1285.81	254.45	1039.18	297.61
Weak identification test	–	1.7e+04	1.0e+04	1.3e+04	3.4e+03
Sample Size	1,426[a]	1426	300	1126	271

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression. Column (1) is the OLS estimate and column (2)–(5) are the IV estimates. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency. Underidentification test provides the Anderson canon. corr. LM statistic and weak identification test provides the Cragg-Donald Wald F statistic. The first and second stage result are respectively showed in Appendix Table B.1.

[a] The data on nutritional status are averaged over three years, and in the FAOSTAT database, the nutritional status from 1990 to 2000 is the three-year average data, so when analyzing the impact of the epidemic on nutritional status, we also average the prevalence rate, which is also more conducive to alleviating endogenous problems.

Table 3
The effect of infectious diseases on nutrition in developing countries.

	Dependent Variable (Y)				
	All People	Women of Reproductive Age (15–49 Years)	Pregnant Women and Newborns	Children under 5 Years	Children under 5 Years
	Prevalence of Undernourishment	Prevalence of Anemia	Prevalence of Low Birthweight	Percentage of children who are stunted	Percentage of children affected by wasting
	(1)	(2)	(3)	(4)	(5)
Prevalence Rate (log)	7.762***	12.660***	2.280***	13.284***	3.476***
	(1.716)	(0.712)	(0.253)	(1.183)	(0.512)
Controls	Yes	Yes	Yes	Yes	Yes
Country Fixed Effect	Yes	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes
Under identification test	1285.81	1299.91	958.23	324.61	318.62
Weak identification test	1.7e+04	2.2e+04	1.4e+04	2.5e+05	2.5e+05
Sample Size	1369	1377	1024	325	319

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency. Underidentification test provides the Anderson canon. corr. LM statistic and weak identification test provides the Cragg-Donald Wald F statistic.

food production, the amount of food available for consumption also depends on international trade, food stock change, and international food aid. For example, the overall agricultural production is smaller than the overall agricultural consumption in developing countries, and net imports of agricultural products as well as food aid from developed countries play an important role in balancing food supply and demand. Even if epidemics do not decrease agricultural production, as long as net import and food aid decline, hunger issues will become more severe in developing countries. As a result, it is necessary to identify the channels through which infectious diseases affect hunger given production unchanged.

6.1. Main reason of insufficient food supply: international trade flows

Table 5 reports the impact of infectious diseases on international trade surplus for agricultural products. During infectious disease outbreaks, developed countries experience a reduction in their trade surplus in agricultural trade, whereas developing countries have an incline in international trade surplus for agricultural products. In the context of overall global food flows from developed to developing countries, this result shows that fewer agricultural products flow from developed countries to developing countries during the outbreaks of infectious diseases, which leads to insufficient food supply for the latter group even if domestic production remains stable. It is worth noting that this change in global food flows can either be the result of more export from developing countries or less export from developed countries. On the one hand, the rising international food price due to epidemics may motivate developing countries to export more food to earn foreign exchange to pay off international debts or to purchase other imported goods. For example, at the beginning of 2020, India exported a lot of rice and wheat, although India itself faced food shortages. This has led to higher domestic food prices. On the other hand, developed countries may reduce their food exports to ensure domestic food security. This is because domestic food supply is crucial for maintaining the health and

Table 4
The effect of infectious diseases on output growth.

	Dependent Variable (Y)			
	Growth Rate of Production			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Panel A: Growth Rate in Agricultural Production				
Prevalence	0.001	0.115*	−0.002	0.043
Rate (log)	(0.023)	(0.065)	(0.025)	(0.045)
Panel B: Growth Rate in Crop Production				
Prevalence	0.006	0.354**	0.003	0.082
Rate (log)	(0.032)	(0.146)	(0.034)	(0.060)
Panel C: Growth Rate in Livestock Production				
Prevalence	−0.010	−0.128***	−0.011	−0.026
Rate (log)	(0.018)	(0.042)	(0.021)	(0.037)
Controls	Yes	Yes	Yes	Yes
Country Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Sample Size	2678	546	2132	664

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. The dependent variable of column (1)–(3) remains the same and refers to the growth in agricultural output. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

Table 5
The effect of infectious diseases on trade surplus in agriculture.

	Dependent Variable (Y)			
	Agricultural Trade Surplus			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence	3.928***	−19.619***	5.523***	0.322***
Rate (log)	(0.877)	(5.935)	(0.788)	(0.108)
Controls	Yes	Yes	Yes	Yes
Country Fixed effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Sample Size	2242	469	1773	519

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. The dependent variable of column (1)–(3) remains the same and refers to trade surplus to GDP. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

well-being of their citizens, especially during times of crisis. Furthermore, the disruption of global supply chains and trade restrictions imposed by some countries may also contribute to a decrease in food exports. We further investigate the impact of infectious diseases on the import and export of agricultural products respectively, the results confirm the conclusion above (see Appendix Table B2a and B2b). To summarize, although infectious diseases do not change global agricultural production, international trade is significantly affected and hence developing countries have less food for consumption.

6.2. Potential remedies: food stock and food aid

Even if international trade leads to insufficient food supply for developing countries, there are two remedies to compensate for the loss. Domestically, developing countries can increase food supply if they have enough food in stock. Internationally, developing countries can increase food supply if they receive more food aid. Next, we analyze the impact of outbreak of infectious diseases on food stock and food aid.

Table 6 shows the stock change of nine cereals due to infectious diseases in different country groups. For the analysis in all countries, when infectious diseases break out, countries alleviate food shortages in the form of lower stock and food to market. However, there are differences between country groups. For developed countries, food stock even increased during epidemics. This is consistent with our previous findings that developed countries produce more food and reduce their trade surplus. For developing countries, we do witness a decline in food stock to compensate for the insufficient food supply. However, a 1 % increase in prevalence of infectious diseases per 10,000 people only reduces 0.319 % of cereals stock. According to FAO,[10] annual cereals stock in developing countries averaged about 350 million tons in 2004–2016, with an average of 2.69 million tons per country. Based on our results, when the prevalence rate increases by 1 %, the average food shortage due to international trade in developing countries is 54,320 tons, while the reduced food stock is about 8581 tons (2.69×0.319 %), which is far from enough to compensate for the food losses caused by trade. To make matters worse, for least developed countries that suffered more from hunger, the stock change is economically insignificant, which means they cannot bring more food for consumption from their stocks.

Table 7 shows the effect of infectious diseases on food aid. Since developed countries do not have food aid data, we only focus on developing countries as well as their subgroup of least developed countries. The result indicates that international food aid, including both total aid and cereals aid, fails to increase when the prevalence of infectious diseases increases.

6.3. Add insult to injury: domestic food inflation

Our analysis has demonstrated that infectious diseases do not significantly affect food production in developing countries. However, disruptions in international trade flows of food result in inadequate

Table 6
The effect of infectious diseases on stock change of nine cereals.

	Dependent Variable (Y)			
	Stock Variation of Nine Cereals (Log)			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence	−0.322***	0.402**	−0.366***	−0.005**
Rate (log)	(0.092)	(0.198)	(0.106)	(0.003)
Controls	Yes	Yes	Yes	Yes
Country Fixed effect	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes
Sample Size	2242	469	1773	519

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. The dependent variable of column (1)–(3) remains the same and refers to logarithmic stock change of nine cereals. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

[10] FAO. Crop Prospects and Food Situation. https://www.fao.org/giews/reports/crop-prospects/en/.

Table 7
The effect of infectious diseases on food aid.

	Dependent Variable (Y)			
	Food Aid (Log)			
	Total Aid		Aid of Cereals	
	Developing Countries	Least Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence Rate (log)	−0.453	0.091	−0.254	0.007
	(0.463)	(0.501)	(0.526)	(0.565)
Controls	Yes	Yes	Yes	Yes
Country Fixed effect	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes
Sample Size	1218	581	1287	599

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. The dependent variable of column (1)–(2) are the total aid of food, which is the aggregate of cereals aid and non-cereals aid, and of column (3)–(4) are the aid of cereal. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

domestic food supply, and this shortfall is not effectively mitigated by changes in food reserves and food aid. As a result, the availability of food in developing countries cannot be guaranteed. Moreover, food security also includes food affordability. When food prices increase, poor families cannot afford food and still suffer from hunger even if domestic food supply is sufficient. As a result, extra attention should be paid to domestic food inflation.

Table 8 reports the impact of infectious disease on domestic food price inflation. Overall, infectious diseases slightly increase food inflation globally. However, this increasing inflation is predominantly observed in developing countries, whereas the inflation is not significant in developed countries. When food supply decreases, if food prices increase, rich families can afford to buy enough food, and the shortage of food is only experienced by the poor, leading to a larger share of food shortage for vulnerable groups and therefore leads to more severe hunger issues. This fact is just as described by the ancient Chinese poet Du Fu: "The vermilion gates reek of wine and meat, while on the road lie frozen bones of the dead."

Table 8
The Effect of infectious diseases on Food Inflation.

	Dependent Variable (Y) Food Price Inflation			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence Rate (log)	0.375*	3.787	0.978***	−0.412
	(0.438)	(4.117)	(0.510)	(0.669)
Controls	Yes	Yes	Yes	Yes
Country Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Sample Size	1382	260	1122	322

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

7. Discussion and policy implications

From a global perspective, it is reported that food production is sufficient to meet the demands of the population (UN Report, 2022; Caparrós, 2020). However, due to uneven food distribution, large populations in some regions continue to suffer from hunger. This paper presents empirical evidence on the impact of infectious diseases on global hunger. Importantly, we investigate the mechanisms through which infectious diseases may lead to hunger from the perspective of global food distribution, which includes food production, food trade, food stock, and food aid. Additionally, we emphasize the differences between developing and developed countries and pay special attention to the impact of infectious diseases on vulnerable populations.

Our results indicate that infectious diseases mainly exacerbate hunger among populations in developing and least developed countries. Besides, vulnerable populations, such as women and children, are more severely affected. Mechanism analysis suggests that as the impact of infectious diseases expands, the flow of agricultural products from developed countries to developing countries through international trade gradually decreases. This leads to insufficient food supply in the latter group even if domestic food production remains stable. Meanwhile, developing countries are unable to fill this gap through their food reserves or food aid, resulting in reduced food available for consumption. Furthermore, due to the rise in food prices, vulnerable groups cannot afford food, thus suffering from more severe food shortages.

This paper has several important policy implications. Firstly, by exploring the relationship between infectious disease outbreaks and hunger, we provide insights into ensuring food security at the global level when dealing with external shocks that may disturb international food distribution. Hunger issues in developing and least developed countries are more severely affected during infectious disease crises. Meanwhile, vulnerable groups such as pregnant women and children may experience worsened hunger issues. The heterogeneity provides guidance for the formulation of policies relevant to addressing the impact of external shocks on hunger issues.

Secondly, the mechanism analysis shows more insightful implications. Our analysis indicates that during infectious disease crises, the trade surplus of developed countries decreases, while that of developing countries increases. Considering the situation where domestic food production remains basically stable in both developed countries and developing countries, it suggests that global food distribution has changed under the impact of infectious diseases. Not only that, further analysis find that imported food in developing countries has decreased, and the amount of exported food has increased. With stable domestic food production, developing countries are urged to prioritize enhancing domestic food distribution efficiency to ensure sufficient food supply and prevent excessive exports. Likewise, developed countries ought to refrain from hoarding excessive food during infectious disease outbreaks to maintain a balanced global food distribution, ensuring uninterrupted food flow to developing countries. However, changing these strategies in the short term poses a challenge, so it is also necessary to strengthen domestic food self-sufficiency of developing countries. The focus should be on improving the efficiency of domestic producers and fostering resilience to crises, even though these actions may conflict with WTO perspectives. In view of this, developing countries must strive to establish robust food reserves to alleviate food shortages during infectious disease crises and compensate for potential food losses related to trade.

Thirdly, our findings indicate that there has been no increase in food aid during infectious disease crises. This underscores the importance of further enhancing the targeting of international food assistance. Measures should be taken by relevant international organizations to support countries and vulnerable groups facing severe hunger issues. Additionally, our results show that the epidemic has led to an increase in food prices. On the one hand, this provides evidence for the increase in food exports from developing countries during the pandemic, as higher food

prices enable these countries to gain more revenue and foreign exchange through food trade, resulting in a reduction in domestic food supply. On the other hand, this further diminishes the accessibility and affordability of domestic food. The policy implication is that the rise in domestic food prices highlights the necessity to further stabilize and optimize global food distribution. Cooperation with other countries in food trade should be pursued to ensure a stable food supply.

8. Conclusions

We find consistent and robust evidence that the past infectious diseases had not led to a severe impact on overall global food production, but changed global food distribution and resulted in more hunger among vulnerable populations, especially in developing and the least developed countries. Our result shows that fewer agricultural products flow from developed countries to developing countries during epidemics, leading to insufficient food supply for the latter group even if their domestic production remains unchanged. At the same time, developing countries are not able to fill this gap through their food stock or food aid, resulting in less food for consumption. To add insult to injury, since domestic food prices increase during epidemics, vulnerable groups cannot afford to buy food and hence suffer more from food shortage, leading to more severe hunger. Our results show that hunger is often not a food production problem but a distribution problem, and highlight the critical significance of measures and initiatives to enhance both international and domestic food distribution.

CRediT authorship contribution statement

Binlei Gong: Writing – review & editing, Supervision, Investigation, Data curation, Conceptualization. **Shouhan Dai:** Writing – original draft, Visualization, Software, Resources, Methodology, Funding acquisition, Formal analysis, Data curation. **Shuo Wang:** Resources, Data curation. **Xinjie Shi:** Conceptualization, Data curation, Supervision. **Biao Huang:** Data curation, Supervision, Writing – review & editing. **Kevin Z. Chen:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

We declare that we have no relevant or material financial interests that relate to the research described in this paper.

Appendix A

A.1 Reasons for the selection of 10 diseases

We select these 10 diseases based on three rules. First, we find a list of infectious diseases that have historically caused Public Health Emergency of International Concern (PHEIC)[11], which is defined by the WHO. PHEIC was declared by the Emergency Committee, which operates under the International Health Regulations (IHR) 2005 and is composed of international experts. The Committee was set up after the SARS outbreak in 2002–2003. Since 2009, there have been six public health emergencies of international concern: H1N1 influenza in 2009, poliomyelitis in 2014, zika virus disease in 2015–2016, Ebola virus disease in 2018–2019, and coronavirus in 2020. Second, WHO Report on Global Surveillance of Epidemic-prone Infectious Diseases 2000 [12] provided nine infectious diseases that are emerging or unstable or pose a major threat to public health, all of which have a high epidemic potential and most of which are increasing in incidence, including yellow fever, plague, cholera, meningococcal, dengue fever, influenza, African trypanosomiasis disease, AIDS, and leishmaniasis. Third, nine emerging pathogens which were considered highly likely to cause serious outbreaks and public health emergencies with no or insufficient prevention and treatment in the near future were prioritized by WHO research and development blueprint in 2015. According to the R&D blueprint, the nine diseases are Crimean-Congo hemorrhagic fever, Ebola viral disease, Marburg viral disease, Lassa fever, MERS-CoV, SARS, Nipah and Henipaviral diseases, Rift Valley fever, and Zika disease. It also clarified that although dengue, yellow fever, AIDS, tuberculosis, malaria, influenza, smallpox, cholera, leishmaniosis, West Nile virus, and plague are not currently within the scope of the blueprint, these diseases continue to pose major public health problems. We juxtapose all the infectious diseases listed above and combine them with the data recorded in the GDB 2017, then we finally obtain prevalence rates of the 10 infectious diseases that have occurred since the beginning of the 1990s as independent variables in this paper.

A.2 Definition of variables in nutrition dataset

The prevalence of undernourishment expresses the probability that a randomly selected individual from the population consumes amounts of calories that are insufficient to cover her/his energy requirement for an active and healthy life. The indicator is computed by comparing a probability distribution of habitual daily dietary energy consumption with a threshold level called the minimum dietary energy requirement. Both are based on the notion of an average individual in the reference population. According to the definition from FAOSTAT, prevalence of anemia among women of reproductive age refers to the combined prevalence of both non-pregnant with hemoglobin levels below 12 g/dL and pregnant women with hemoglobin levels below 11 g/dL. Low birthweight is defined as a weight at birth of less than 2500 g (less than 5.51 lbs), regardless of gestational age. Children under 5 years who are stunted is defined as percentage of stunting (height-for-age less than −2 standard deviations of the WHO Child Growth Standards median) among children aged 0–59 months. Percentage of children under 5 years affected by wasting (percent) means that weight-for-height is more than two standard deviations below the median for the international reference population aged 0–59 months.

A.3 Data source for control variables

We follow Gong (2020) to include trade ratio, and R&D to-output ratio when studying agricultural conditions at nation-level. Trade ratio refers to the total trade volume of agricultural products to agricultural output that is collected from the NBER-UN database and the CEPII-BACI database. R&D

[11] According to WHO, PHEIC is an official statement which refers to unusual events that pose a public health risk to other countries through the international spread of the disease and may require a coordinated international response. The event statement will be activated in three circumstances when it is serious, suddenly unusual or unexpected, and the public health impact extends beyond the borders of the affected country, and it may require immediate international action.

[12] World Health Organization, Department of Communicable Disease Surveillance and Response. https://apps.who.int/iris/bitstream/handle/10665/66485/WHO?sequence=1.

to-output ratio is defined as the ratio of R&D stock to agricultural output, which measures agricultural R&D intensity of a country. We also followed the methodology provided by Gong (2020) to obtain data from the Agricultural Science and Technology Indicator (ASTI) and the Gross Domestic Expenditure on Research and Development (GERD) by the OECD. We converted investment flows to stocks using Perpetual Inventory Method (PIM). Simultaneously, the eruption of regional conflicts could exacerbate the spread of infectious diseases and directly disrupt the food distribution system, consequently triggering hunger issues. Hence, in line with the approach of (Raleigh et al., 2023), we incorporate conflict-related factors into our analysis using data from the Armed Conflict Location & Event Data Project (ACLED).[13] Specifically, we quantify the occurrences of Battles and Riots at the national level to reflect the condition of regional conflicts. Additionally, with reference to the "5C" framework (Conflicts, Covid-19, China, Climate Change, and Currency) proposed by Maruejols et al. (2023), we incorporate climate and currency-related factors into our analysis. To capture potential climate variability, we include temperature change on land from FAOSTAT and National Rainfall Index (NRI) data from the World Bank' s Climate Change Knowledge Portal. These variables are included in all regressions to control for shocks to agricultural production caused by climate fluctuations. While climate change is not the primary focus of our paper, its inclusion strengthens the validity of our results. Furthermore, we control for exchange rates from FAOSTAT. This variable captures how currency fluctuations erode purchasing power, particularly in import-dependent countries, thereby reducing access to affordable food even when global supply remains stable.

A.4 Discussion on Data Attrition

The 105 countries in our sample including: Algeria, Angola, Argentina, Australia, Austria, Belgium-Luxembourg, Benin, Bolivia, Brazil, Burkina Faso, Burundi, Côte d'Ivoire, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Congo, Congo DR, Costa Rica, Cuba, Cyprus, Denmark, Dominican, Republic, Ecuador, Egypt, El Salvador, Ethiopia, Fiji, Finland, France, Gabon, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea, Republic, Laos, Lebanon, Liberia, Madagascar, Malaysia, Mali, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Senegal, Sierra Leone, Singapore, Somalia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia.

The missing data primarily result from the unavailability of our key dependent variable, Nutrition-related Dependent Variables (e.g., Prevalence of Undernourishment). Our key explanatory variable, Prevalence Rate (Cases per 100,000 Population from 10 Diseases), covers almost all countries in the world. Therefore, we focus our discussion on the impact of missing data in the dependent variable. We fully acknowledge this concern and have conducted a comprehensive analysis to address it. Below, we present two key findings that demonstrate the robustness of our results despite data limitations.

a). Balanced Distribution of Missing Countries Across Income Groups

To rigorously evaluate this issue, we conduct comparative analyses across two distinct grouping frameworks (income levels and food supply quartiles) and demonstrate that our final sample of 105 countries retains a distribution highly consistent with the full population.

First, in terms of the income group distribution (World Bank classification), our analysis demonstrates that the income group distribution in our final sample (31.43 % high-income, 43.81 % middle-income, 20.95 % low-income) closely aligns with the global distribution of all countries with available disease data (29.11 %, 46.94 %, and 21.02 %, respectively). This near-uniform attrition pattern—with no group disproportionately excluded—indicates no systematic bias against countries with weaker governance or data collection capacity.

Second, to further assess sample validity, we classified countries into quartiles by Food Supply Quantity (kg/capita/year). The distribution of our final sample aligns closely with the full population across all quartiles, particularly at the extremes: the Lower Quartile (25.74 % in sample vs. 25.62 % in full population) and Top Quartile (26.87 % vs. 24.96 %) exhibit near-identical proportions. This consistency in distribution confirms that our sample retains the global heterogeneity of food supply systems, mitigating concerns about selection bias tied to nutritional data availability.

b). Statistical Comparison of Included vs. Missing Countries

To further assess potential selection bias, we conducted t-tests comparing key economic variables related to our analysis between included and missing country samples using data from FAOSTAT. The results are presented in Table A1. Overall, there are no significant differences between included and missing countries in key economic variables such as GDP per capita, food supply, domestic production, and food price inflation. This suggests that sample attrition does not introduce systematic bias, ensuring the robustness of our analysis.

Table A1
Sample Distribution by Income Group

Variable	Unit	Sample Mean		Difference
		Included Sample	Missing Sample	
GDP per capita	USD	10092.97	10249.11	−156.15
		(297.44)	(365.44)	(466.25)
Food supply quantity	(kg/capita/yr)	20.75	20.52	0.23
		(0.53)	(0.71)	(0.87)
	(kcal/capita/day)	143.92	147.81	−3.89
		(3.63)	(4.91)	(5.99)
Food production	kg/capita	176.49	188.11	−11.61
		(7.14)	(6.49)	(10.02)
Consumer price indices	Food price inflation (%)	7.07	7.18	−0.11
		(0.11)	(0.15)	(0.18)

[13] ACLED is a disaggregated conflict collection, analysis and crisis mapping project. It collects the dates, actors, types of violence, locations, and fatalities of all reported political violence and protest aevents. More details can be obtained from the ACLED website: https://acleddata.com/data-export-tool/.

***Notes*:** All data are sourced from the FAOSTAT database. Standard errors are reported in parentheses. Food production per capita represents the total amounts of eight major agricultural products: wheat, rice (milled equivalent), barley, maize, rye, oats, millet, sorghum, and other cereals.

Appendix B

Table B1
2SLS result of Baseline

	Dependent Variable (Y)		
	Prevalence of Undernourishment	Prevalence Rate(log)	Prevalence of Undernourishment
	All Countries	All Countries	All Countries
	OLS	First Stage	Second Stage
	(1)	(2)	(3)
Prevalence Rate(log)	9.312***		7.908***
	(1.615)		(1.671)
L.Prevalence Rate(log)		0.963***	
		(0.005)	
Controls	Yes	Yes	Yes
Country Fixed Effect	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes
Underidentification test	–	–	1285.81
Weak identification test	–	–	1.7e+04
Sample Size	1426	1426	1426

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

Table B2a
The Effect of infectious diseases on Export Quantity of Agriculture

	Dependent Variable (Y)			
	Export Quantity of Agriculture Products			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence Rate (log)	1.918***	−8.666*	2.941***	−0.155***
	(0.717)	(5.247)	(0.617)	(0.042)
Controls	Yes	Yes	Yes	Yes
Country Fixed effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Sample Size	2242	469	1773	519

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

Table B2b
The Effect of infectious diseases on Import Quantity of Agriculture

	Dependent Variable (Y)			
	Import Quantity of Agriculture Products			
	All Countries	Developed Countries	Developing Countries	Least Developed Countries
	(1)	(2)	(3)	(4)
Prevalence Rate (log)	−2.010***	10.953***	−2.582***	−0.478***
	(0.417)	(1.944)	(0.430)	(0.099)
Controls	Yes	Yes	Yes	Yes
Country Fixed effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Sample Size	2242	469	1773	519

Notes: Asterisks *, **, and ***indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively. Standard errors are clustered at country level. Each column represents a separate regression with IV estimates. Controls include control variables including trade ratio, R&D to-output ratio, number of regional conflicts, rainfall, temperature, and currency.

Data availability

Data will be made available on request.

References

Anderson, K., 2012. Government trade restrictions and international price volatility. Global Food Secur. 1 (2), 157–166. https://doi.org/10.1016/j.gfs.2012.11.005.

Barrett, C.B., 2010. Measuring food insecurity. Science 327 (5967), 825–828. https://doi.org/10.1126/science.1182768.

Barrett, C.B., Maxwell, D., 2007. Food Aid after Fifty Years: Recasting its Role. Routledge.

Beluska-Turkan, K., Korczak, R., Hartell, B., Moskal, K., Maukonen, J., Alexander, D.E., Salem, N., Harkness, L., Ayad, W., Szaro, J., Zhang, K., Siriwardhana, N., 2019. Nutritional gaps and supplementation in the first 1000 days. Nutrients 11 (12), 2891. https://doi.org/10.3390/nu11122891.

Brown, C.S., Ravallion, M., Van de Walle, D., 2020. *Can The World's Poor Protect Themselves From the New Coronavirus?* (W27200). National Bureau of Economic Research. https://doi.org/10.3386/w27200.

Caparrós, M., 2020. Hunger: the oldest problem. Melville House.

Chavas, J.-P., Hummels, D., Wright, B.D., 2014. The Economics of Food Price Volatility. University of Chicago Press. https://doi.org/10.7208/chicago/9780226129082.001.0001.

Chen, K.Z., Mao, R., 2020. Fire lines as fault lines: increased trade barriers during the COVID-19 pandemic further shatter the global food system. Food Secur. 12 (4), 735–738. https://doi.org/10.1007/s12571-020-01075-2.

Del Ninno, C., Dorosh, P.A., Subbarao, K., 2007. Food aid, domestic policy and food security: contrasting experiences from South Asia and sub-Saharan Africa. Food Policy 32 (4), 413–435. https://doi.org/10.1016/j.foodpol.2006.11.007.

Devereux, S., 2007. The impact of droughts and floods on food security and policy options to alleviate negative effects. Agric. Econ. 37 (s1), 47–58. https://doi.org/10.1111/j.1574-0862.2007.00234.x.

Dongyu, Q., Ghebreyesus, Adhanom, Azevedo, R., 2020. Mitigating impacts of COVID-19 on food trade and markets. https://www.fao.org/geneva/news/detail/en/c/1269529/.

European Commission, 2015. Impact of the West African Ebola Virus Disease Outbreak on Food Security—Sierra Leone. ReliefWeb. https://reliefweb.int/report/sierra-leone/impact-west-african-ebola-virus-disease-outbreak-food-security.

Falkendal, T., Otto, C., Schewe, J., Jägermeyr, J., Konar, M., Kummu, M., Watkins, B., Puma, M.J., 2021. Grain export restrictions during COVID-19 risk food insecurity in many low- and middle-income countries. Nature Food 2 (1), 11–14. https://doi.org/10.1038/s43016-020-00211-7.

FAO, 2022. Agricultural production statistics 2000–2020. In: FAOSTAT Analytical Brief Series No. 41. Rome, Italy. ISSN 2709-0078 [Online].

FAO, IFAD, UNICEF, WFP, WHO, 2022. The State of Food Security and Nutrition in the World 2022: Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable. FAO, IFAD, UNICEF, WFP, WHO. https://doi.org/10.4060/cc0639en.

Figuié, M., 2016. Impact of the Ebola virus disease outbreak on market chains and trade of agricultural products in West Africa. Report for FAO REOWA (Resilience, Emergencies and Rehabilitation in West Africa) 3 (1), 7–8.

Fraser, E.D.G., Legwegoh, A., Kc, K., 2015. Food stocks and grain reserves: evaluating whether storing food creates resilient food systems. Journal of Environmental Studies and Sciences 5 (3), 445–458. https://doi.org/10.1007/s13412-015-0276-2.

Gatiso, T.T., Ordaz-Németh, I., Grimes, T., Lormie, M., Tweh, C., Kühl, H.S., Junker, J., 2018. The impact of the Ebola virus disease (EVD) epidemic on agricultural production and livelihoods in Liberia. PLoS Neglected Trop. Dis. 12 (8), e0006580. https://doi.org/10.1371/journal.pntd.0006580.

Gombart, A.F., Pierre, A., Maggini, S., 2020. A review of micronutrients and the immune system-working in harmony to reduce the risk of infection. Nutrients 12 (1), 236. https://doi.org/10.3390/nu12010236.

Gong, B., 2020. New growth accounting. Am. J. Agric. Econ. 102 (2), 641–661. https://doi.org/10.1002/ajae.12009.

Gong, B., Sickles, R.C., 2020. Non-structural and structural models in productivity analysis: study of the British Isles during the 2007–2009 financial crisis. J. Prod. Anal. 53 (2), 243–263. https://doi.org/10.1007/s11123-019-00571-8.

Gong, B., Sickles, R.C., 2021. Resource allocation in multi-divisional multi-product firms. J. Prod. Anal. 55 (2), 47–70. https://doi.org/10.1007/s11123-020-00595-5.

Gong, B., Zhang, S., Yuan, L., Chen, K.Z., 2020. A balance act: minimizing economic loss while controlling novel coronavirus pneumonia. Journal of Chinese Governance 5 (2), 249–268. https://doi.org/10.1080/23812346.2020.1741940.

Gong, B., Zhang, S., Liu, X., Chen, K.Z., 2021. The Zoonotic diseases, agricultural production, and impact channels: evidence from China. Global Food Secur. 28, 100463. https://doi.org/10.1016/j.gfs.2020.100463.

Kakaei, H., Nourmoradi, H., Bakhtiyari, S., Jalilian, M., Mirzaei, A., 2022. Effect of COVID-19 on food security, hunger, and food crisis. COVID-19 and the Sustainable Development Goals 3–29. https://doi.org/10.1016/B978-0-323-91307-2.00005-5.

Keogh-Brown, M.R., Smith, R.D., Edmunds, J.W., Beutels, P., 2010. The macroeconomic impact of pandemic influenza: estimates from models of the United Kingdom, France, Belgium and The Netherlands. Eur. J. Health Econ. 11 (6), 543–554. https://doi.org/10.1007/s10198-009-0210-1.

Kodish, S.R., Bio, F., Oemcke, R., Conteh, J., Beauliere, J.M., Pyne-Bailey, S., Rohner, F., Ngnie-Teta, I., Jalloh, M.B., Wirth, J.P., 2019. A qualitative study to understand how Ebola Virus Disease affected nutrition in Sierra Leone—a food value-chain framework for improving future response strategies. PLoS Neglected Trop. Dis. 13 (9), e0007645. https://doi.org/10.1371/journal.pntd.0007645.

Laborde, D., Martin, W., Swinnen, J., Vos, R., 2020. COVID-19 risks to global food security. Science 369 (6503), 500–502. https://doi.org/10.1126/science.abc4765.

Laborde, D., Martin, W., Vos, R., 2021. Impacts of COVID-19 on global poverty, food security, and diets: insights from global model scenario analysis. Agric. Econ. 52 (3), 375–390. https://doi.org/10.1111/agec.12624.

Lin, B., Zhang, Y.Y., 2020. Impact of the COVID-19 pandemic on agricultural exports. J. Integr. Agric. 19 (12), 2937–2945. https://doi.org/10.1016/S2095-3119(20)63430-X.

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. Front. Vet. Sci. 7, 578508. https://doi.org/10.3389/fvets.2020.578508.

Maruejols, L., et al., 2023. Using machine learning to identify the important Features for global trade of cereals: conflicts, covid-19, China, climate change, and currency ("5C"). Paper Presentation at the 63nd Annual Conference of the GEWISOLA (German Association of Agricultural Economics).

Mary, S., 2019. Hungry for free trade? Food trade and extreme hunger in developing countries. Food Secur. 11 (2), 461–477. https://doi.org/10.1007/s12571-019-00908-z.

Meng, X., Qian, N., Yared, P., 2015. The Institutional causes of China's great famine, 1959-1961. Rev. Econ. Stud. 82 (4), 1568–1611. https://doi.org/10.1093/restud/rdv016 (293).

Qian, Z., Yuan, L., Wang, S., Zhang, Q., Gong, B., 2021. Epidemics, convergence, and common prosperity: evidence from China. China World Econ. 29 (6), 117–138. https://doi.org/10.1111/cwe.12397.

Raleigh, C., Kishi, R., Linke, A., 2023. Political instability patterns are obscured by conflict dataset scope conditions, sources, and coding choices. Humanit Soc Sci Commun 10, 74. https://doi.org/10.1057/s41599-023-01559-4.

Rohr, J.R., Barrett, C.B., Civitello, D.J., Craft, M.E., Delius, B., DeLeo, G.A., Hudson, P.J., Jouanard, N., Nguyen, K.H., Ostfeld, R.S., Remais, J.V., Riveau, G., Sokolow, S.H., Tilman, D., 2019. Emerging human infectious diseases and the links to global food production. Nat. Sustain. 2 (6), 6. https://doi.org/10.1038/s41893-019-0293-3.

Roth, G.A., Abate, D., Abate, K.H., Abay, S.M., Abbafati, C., Abbasi, N., Abbastabar, H., Abd-Allah, F., Abdela, J., Abdelalim, A., 2018. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 392 (10159), 1736–1788. https://doi.org/10.1016/S0140-6736(18)32203-7.

Roubík, H., Lošťák, M., Ketuama, C.T., Procházka, P., Soukupová, J., Hakl, J., Karlík, P., Hejcman, M., 2022. Current coronavirus crisis and past pandemics—what can happen in post-COVID-19 agriculture? Sustain. Prod. Consum. 30, 752–760. https://doi.org/10.1016/j.spc.2022.01.007.

Sen, A., 1980. Famines. World Dev. 8 (9), 613–621. https://doi.org/10.1016/0305-750X(80)90053-4.

Smith, M.D., Wesselbaum, D., 2020. COVID-19, food insecurity, and migration. J. Nutr. 150 (11), 2855–2858. https://doi.org/10.1093/jn/nxaa270.

Sumo, P.D., 2019. Impacts of Ebola on supply chains in MRB countries: using Liberia as a case study. International Journal of Research in Business and Social Science 8 (3), 122–139. https://doi.org/10.20525/ijrbs.v8i3.264 (2147-4478).

UN Report, 2022. UN Report: global hunger numbers rose to as many as 828 million in 2021. https://www.who.int/news/item/06-07-2022-un-report–global-hunger-numbers-rose-to-as-many-as-828-million-in-2021.

UNAIDS, 2018. Miles to go: closing gaps, breaking barriers, righting injustices. In: Global AIDS Update.

Usglc, U., 2022. COVID-19 Brief: Impact on Food Security. USGLC. https://www.usglc.org/coronavirus/global-hunger/.

Varshney, D., Roy, D., Meenakshi, J.V., 2020. Impact of COVID-19 on agricultural markets: assessing the roles of commodity characteristics, disease caseload, and market reforms. In: Gupta, I., Das, M. (Eds.), Contextualizing the COVID Pandemic in India: A Development Perspective. Springer Nature, pp. 249–271. https://doi.org/10.1007/978-981-99-4906-9_12.

Waal, A. de, 1993. War and famine in Africa. IDS Bull. 24 (4), 33–40. https://doi.org/10.1111/j.1759-5436.1993.mp24004004.x.

World Bank, 2015. *Giving New Life To Farms In Ebola-Affected Countries* [Text/HTML]. World Bank. https://www.worldbank.org/en/news/feature/2015/06/15/giving-new-life-to-farms-in-ebola-hit-countries.

Wunderlich, S.M., 2021. Food supply chain during pandemic: changes in food production, food loss and waste. International Journal of Environmental Impacts: Management, Mitigation and Recovery 4 (2), 101–112. https://doi.org/10.2495/EI-V4-N2-101-112.

Zhang, S., Wang, S., Yuan, L., Liu, X., Gong, B., 2020. The impact of epidemics on agricultural production and forecast of COVID-19. China Agric. Econ. Rev. 12 (3), 409–425. https://doi.org/10.1108/CAER-04-2020-0055.

Zurayk, R., 2020. Pandemic and food security: a view from the global South. Journal of Agriculture, Food Systems, and Community Development 9 (3), 3. https://doi.org/10.5304/jafscd.2020.093.014.