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A new face of food security: A global perspective of the COVID-19 pandemic

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ABSTRACT

COVID-19 has impacted the world economy and food system in many aspects. We conducted a comprehensive examination of global food security during the COVID-19 pandemic by considering the food security index and its four key pillars (affordability, availability, quality and safety, and natural resources and resilience) for 102 countries. In addition to the fixed effect panel data estimator, the Method of Moments Quantile regression is useful for disaggregating the impact of the COVID-19 pandemic in relation to inflation, economic growth, urbanization, and agricultural land on global food security among countries with different levels of food security. We found that COVID-19 has negatively affected food security globally, especially in countries with a low food security level. The effect of income per capita and urbanization rate on the food security index is positive and statistically significant across all quantiles. Inflation rate and agricultural land, however, adversely affect food security, and this effect is stronger for countries with lower levels of food security. The results of affordability, availability, quality, and safety, and natural resources and resilience models provide meaningful implications for governments and policymakers to build resilience in food systems and to be better prepared for future crises and disruptions in the food supply.

1. Introduction

The COVID-19 pandemic has impacted the world economy tremendously, disrupting trade flow, causing labor shortage, and affecting food security in many countries [21,55]. Whenever food-importing countries face shocks they tend to consider implementing policies that bolster domestic food production and improve food security and national security. Most of the countries depending on food imports are poorly endowed with natural resources such as water, cropland and fertile soils [25]. Misallocation and depletion of water resources often occurred when domestic production is favored. For instance, Saudi Arabia's domestic wheat production policy has led to the depletion of groundwater. While phasing out a policy takes years, often decisions to shift to domestic production of food are faster and based on perceptions rather than scientific evidence.

Some major food-producing countries occasionally impose export restrictions on staple foods to secure domestic demand first, causing global food prices to rise [16]. By March 2020, twenty-one countries had announced or introduced export restrictions on almost 4% of the caloric value of globally traded food, but most of these restrictions were lifted by July 2020 [36]. Despite these minor trade restrictions, several studies showed increases in agricultural import and export volumes (Kenya: [62]; China: [45]). Falkendal et al. [26] showed that grain export restrictions during the COVID-19 pandemic have caused food price spikes and increased the fragility of food security in many low and middle-income countries. According to Laborde et al. [43] since the onset of the pandemic, world food prices have been quite volatile, which may adversely impact both consumers and agricultural producers (see also foodsecurityportal.org).

This paper explores whether COVID-19 has resulted in a heightened fragility of the global food trade system that justifies protective policies and increased domestic food production in countries with limited natural resources. We examine the effect of the COVID-19 pandemic on food security, with a focus on factors of affordability, availability, quality and safety, and natural resources and resilience from 2012 to 2020 for 102 countries. The effect of other explanatory variables, such as economic growth, agricultural land, urbanization and inflation rate are also considered. In addition to the fixed effect panel data estimator, the

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Method of Moments Quantile regression was employed to test the effect of COVID-19 on food security in different quantile of food security.

The rest of the paper is organized as follows: Section 2 reviews the related studies. Section 3 explains models, methods, and data. The empirical results are reported in Section 4 and the last section concludes the paper and discusses the policy implications.

2. Literature review

The impacts of COVID-19 on food security are multi-dimensional. According to Laborde et al. [43], the pandemic had impacted food access, availability, and stability. The threats COVID-19 poses to food security due to losses of income and assets, rising food prices, decline in agricultural production, supply chain disruptions, and trade restrictions are outlined in what follows. We then provide an overview of the impact of COVID-19 on world food security.

The International Monetary Fund [39] estimated a 3.3% contraction in the world economy in 2020 and the IMF's food and beverage price index increased by 20% led by surging prices for staple foods. Income loss and food price shock disproportionally affect low-income households. Laborde et al. [44] projected a 20% global increase in extreme poverty, a 0.2% decrease in food consumption in developing countries, and a 2.5% decrease in food consumption in developed countries due to COVID-19. Mahler [49] found that the global GINI index has had a marked increase for the first time in three decades and the global extreme poverty increased for the first time in over two decades. These results infer that the impact of COVID-19 on food security was larger for the poor than the wealthy and larger for developing countries than developed countries.

The effects of COVID-19 on food security differ by products and countries/regions, varying on the degree of labor intensity in farm production and government mitigation efforts. For example, the aggregate volume of agricultural production in Southeast Asia was reduced by 3.11%, or 17.03 million tons during the first quarter of the year 2020 due to COVID-19 [31]. A community survey in Myanmar suggested COVID-19 adversely affected agricultural production and marketing with 68% of farmers expressing difficulties in selling their harvest due to COVID-19 [11]. The poverty rate in Kenya rose by 13% during the pandemic and 3–3.5 million people would be food insecure [65]. In contrast, agricultural production in China recovered quickly from the COVID-19 outbreak and resumed normal by April 2020 [59]. Cariappa et al. [14] found that agriculture was the only sector that witnessed positive growth in India during 2020–2021, demonstrating the resilience of the agricultural system. Food consumption and household dietary diversity are largely unchanged or even slightly increased by August 2020 in Addis Ababa of Ethiopia [34].

Several studies have conducted cross-country analyses on food security under the effect of COVID-19. Beckman et al. [6] used the USDA International Food Security Assessment (IFSA) model to estimate food consumption, food access, and food gaps in 76 developing countries. They projected that the economic shocks caused by the COVID-19 increased the number of food-insecure people by 211 million (or 27.8%). The Commonwealth of Independent States (CIS) (the largest changes are to Moldova and Tajikistan), Central and South Asia (CSA) (Afghanistan, Bangladesh, and Pakistan are the most impacted), and South East Asia (SEA) (Cambodia has the largest change) are projected to see the highest percentage increases in food insecurity in 2020. These predictions are overall in line with findings of Allee et al. [1] and O'Meara et al. [56]. Erokhin and Gao [24] studied the impacts of COVID-19 on food security in 45 developing countries from January to June 2020 using data from the WFP's Hunger Map portal, Trading Economics, and the United Nations Conference on Trade and Development (UNCTAD). They employed the autoregressive distributed lag method, Yamamoto's causality test, and variance decomposition analysis to show that COVID-19 affects both the food security and food supply stability in developing countries across the world. Furthermore, the effects are more significant in upper-middle-income economies than in the least developing countries (given the deeper integration in global supply chains and capital-intensity agricultural system). In lower-income developing countries, food security risks posed by COVID-19 are mainly related to economic access to the adequate food supply, whereas in higher-income developing countries, food security risks are due to trade restrictions and currency depreciation is more prevalent. Although many studies found increasing food insecurity amid the COVID-19 pandemic, there is also evidence of resilience in terms of food security in some countries, regions, or subpopulations [10]. For example, Béné et al. [11] reviewed the impacts of COVID-19 on food systems in 62 low and middle-income countries and found no clear evidence that the availability of food has been affected. They suggested that, overall, food systems have 'resisted' the pandemic, and no major episodes of severe food shortage were observed in 2020.

Some researchers investigated the impact of COVID-19 on food security at the household level. Egger et al. [23] conducted a survey on over 30,000 respondents in 16 original household surveys from nine countries in Africa, Asia and Latin America during the COVID-19 pandemic. They found that the median proportion of households experiencing reduced income across the sample countries is 67%, resulting in widespread food insecurity. Kansiime et al. [41] used online surveys to study how COVID-19 affected household food security in two East African countries – Kenya and Uganda. Results from Probit regressions showed that poor households and those dependent on labor income were more vulnerable to income shock and had poorer food consumption during the COVID-19 pandemic compared to other households. The proportion of food insecure respondents increased by 38% and 44% among the respondents of the survey in Kenya and Uganda respectively during the COVID-19 pandemic compared to a normal period before the pandemic. The stricter COVID-19 containment measures in Uganda might explain the difference. In contrast to the reduction in food security caused by COVID-19 in many countries, food supply chains in some countries have been resilient to the shock associated with the pandemic. For example, Hirvonen et al. [34] conducted food security surveys of households in Addis Ababa of Ethiopia, and found that food consumption and household dietary diversity are largely unchanged or even slightly increased by August 2020 compared to the same period in 2019. Aggarwal et al. [72] found no evidence of changes in food insecurity, as measured with a household dietary diversity score, a household hunger scale, and household food consumption associated with the COVID-19 pandemic in rural households of Liberia and Malawi. Changes in food insecurity associated with the COVID-19 pandemic may show geographic variation within countries. Ceballos et al. [15] presented mixed results across two Indian states, with households in Haryana experiencing large adverse changes in food insecurity, while households in Odisha experiencing no measurable increases in food insecurity associated with the COVID-19 pandemic.

The impacts of COVID-19 on food security in many countries have been observed with mixed results. A comprehensive global level analysis is needed to shed light on the impact of the COVID-19 pandemic on world food security. Béné et al. [8] assessed COVID-19's impacts on food security for 62 low and middle-income countries and found that food systems resisted and adapted to the crisis without major food shortages. In our study, we provided a more in-depth analysis that fills the gap in "COVID-19–food security" literature by examining the effect of COVID-19 pandemic across 102 countries of all income and food security levels (low, middle, and high) on affordability, availability, quality and safety, and natural resources and resilience pillars of food security in the global context.

3. Methodology

The index is a dynamic quantitative and qualitative benchmarking model, constructed from 59 unique indicators that measure the drivers of food security in developing and developed countries. The overall food

security index weights up of 32.4% of affordability, 32.4% of availability, 17.6% of quality and safety, and 17.6% of natural resources and resilience. Food security is defined as the state in which people at all times have physical, social, and economic access to sufficient and nutritious food that meets their dietary needs for a healthy and active life. Affordability measures the ability of consumers to purchase food, their vulnerability to price shocks and the presence of programmes and policies to support customers when shocks occur. Availability measures the sufficiency of the national food supply, the risk of supply disruption, national capacity to disseminate food, and research efforts to expand agricultural output. Quality and safety examine the diversity and nutritional value of typical diets as well as food safety. Lastly, Natural Resources and Resilience evaluate a nation's exposure to climate change impacts, sensitivity to resource risks, and response to these risks.[1]

To test the effect of COVID-19 and other explanatory variables on food security, the following cross-sectional regression model is first used in this paper:

$$FSI_i = \alpha_0 + \alpha_1 IF_i + \alpha_2 GDP_i + \alpha_3 AGL_i + \alpha_4 URB_i + \alpha_5 DCOVID_i + \varepsilon_i \quad (1)$$

Where i is country ith. FSI is a proxy of overall food security. IF is the inflation rate (annual %), GDP is real GDP per capita (constant 2010 US $), AGL is agricultural land (% of land area). URB is the urbanization rate (% of total population), DCOVID is the dummy variable that assumes a value of 0 for the pre-coronavirus period (i.e. 2012–2018) and 1 for the coronavirus period (i.e. 2019–2020), and ε_i is an i.i.d error term. We estimate Eq. (1) for the food security index (FSI) and also each of the four pillars of food security, including; availability index (AVI), natural resources and resilience (NRI), affordability index (AFI) and quality and safety index (QUI). The overall food security index and its four sub-indexes are normalized on a scale of 0 (the least favorable) to 100 (the most favorable). Datasets of FSI, AVI, NRI, AFI and QUI are collected from 2012 to 2020 for 102 countries, (see Appendix 1), from the Global Food Security Index database.[2] The data of IF, GDP, AGL, and URB were collected from World Development Indicators, World Bank.

3.1. Preliminary tests

Before estimating the research model, a set of pre-estimation procedures was considered. These tests include normality, unit root, cointegration, and cross-sectional dependence tests. Im, Pesaran and Shin [38] (IPS) unit root test which is specific to unbalanced panel data, was used in this study. Four tests of Breusch-Pagan Lagrange Multiplier (LM), Pesaran scaled LM, Bias-corrected scaled LM, and to determine if each panel data is cross-sectionally independent, we apply the cross-sectional dependence (CD) test developed by Pesaran [57] to the variables that were investigated. We employed the Westerlund cointegration test developed by Westerlund and Edgerton [67] to evaluate the presence of cointegration.

3.2. The method of moments quantile regression

In the current study, we used the Method of Moments Quantile Regression (MMQR) to identify the possibility that the effects of the determinants of food security can differ across the conditional distribution of food security, which reflects nations' food security levels. The MMQR is employed to examine the sectoral and heterogeneous impact across quantiles [61]. Quantile regressions estimate more reliable predictions compared with simple regressions. Especially when there doesn't seem to be any relationship between the two parameters [9]. To further improve the model estimations, this study applied the MMQR with a static impact in line with Machado [48]. Quantile regression is insensitive to a variety of undetected heterogeneity [13,42]. The MMQR technique allows for the efficient detection of partial heterogeneous covariance effects in a simple and straightforward manner. The MMQR is a useful method when there are multiple outcomes resulting from human activities and multiple endogenous response variables. The MMQR approach is not only straightforward but also easy to use because it offers non-crossing predictions of the regression quantiles. For estimating the contingent quantiles $Q_Y((\tau/X)$, the estimate is given by:

$$Y_{it} = \alpha_i + X_{it}\beta + (\delta_i + Z_{it}\gamma)U_{it} \quad (2)$$

And the probability P $\{\delta_i + Z_{it}'\gamma > 0\} = 1$. $(\alpha, \beta', \delta, \gamma')'$ is estimated based on the coefficients i. (α_i, δ_i), $i = 1\ldots\ldots$, n, represents the individuals I fixed impact and Z is the k-vector of recognised factor of X which are differentiable alterations with component l given by:

$$Z_1 = Z_1(X), 1 = 1\ldots.k \quad (3)$$

Where, *Xit* is the proxy of any fixed *i* is independent across time (t). *Uit* is a proxy distributed across individuals (i) and across time (t) which are normalized to satisfy the moment situation but does not imply limit as indicates in the following equation:

$$Q_Y\left(\frac{\tau}{X_{it}}\right) = \left(\alpha_i + \delta_{iq}(\tau)\right) + X_{it}\beta + Z_{it\gamma q}(\tau) \quad (4)$$

Our empirical model in the framework of MMQR is as follows.

$$Q_{Yit}\left(\frac{\tau_k}{\alpha_i, X_{it}}\right) = \alpha_i + \alpha_{1\tau} IF_i + \alpha_{2\tau} GDP_i + \alpha_{3\tau} AGL_i + \alpha_{4\tau} URB_i + \alpha_{5\tau} DCOVID_i \quad (5)$$

Where the variables are defined before.

4. Results

4.1. Normal distribution test

Before attempting to estimate the empirical research model, the normality test was used to determine whether the data was normally distributed. This is an important step in the analysis of econometric models because a data set with a non-normal distribution produces spurious results, leading to misleading conclusions. The data should be normally distributed to ensure that the results show the exact relationship between the explanatory variables of the research, such as DCOVID with food security. Several tests were used to evaluate the normality of the variables. The results of the various tests used to determine whether the variables were normal are shown in Table 1. The null hypothesis for the Shapiro-Wilk and Kolmogorov-Smirnov (k) tests is that a variable is normally distributed. As the results of Table 1 show, the null hypothesis of both tests is rejected, which indicates that all the variables of this research are non-normal, and these results are also confirmed by Skewness and Kurtosis tests. As a result of this evidence, we can conclude that the data is generally not normally distributed, and the

Table 1
Test of normal distribution.

Variables	Skeweness	Kurtosis	Shapiro-Wilk test		Kolmogorov-Smirnov (k) test	
			Statistics	Sig.	Statistics	Sig.
FSI	−0.193	1.878	8.617	0.000	0.065	0.000
AVI	−0.506	1.924	5.916	0.000	0.042	0.032
NRI	0.767	3.354	8.397	0.000	0.083	0.000
AFI	−0.506	1.924	10.320	0.000	0.126	0.000
QUI	−0.208	1.825	8.917	0.000	0.095	0.000
IF	16.446	335.600	15.585	0.000	0.333	0.000
GDP	1.633	4.919	7.389	0.000	0.081	0.000
AGL	−0.102	2.215	6.458	0.000	0.057	0.009
URB	−0.272	2.057	7.521	0.000	0.076	0.009

[1] The details of indicators and sub-indicators and their weights can be found at https://impact.economist.com/sustainability/project/food-security-index/

[2] https://impact.economist.com/sustainability/project/food-security-index/

quantile regression model is regarded as suitable for this study.

4.2. Cross-sectional dependence, unit root and cointegration tests

The Cross-sectional Dependence (CD) test was used to determine whether the dataset is impacted by the spillover effect. The CD test is shown in Table 2. As a result of Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD, we reject the null hypothesis and conclude that the spillover effect exists among countries. In fact, changes in research variables in one country may affect another country.

The IPS test was employed in this study to determine the presence of a single root in the research variables. The unit root test results reveal that all variables are either integrated of order I(0) or I(1) (see Table 3). FSI, QUI, IF, GDP, AGL, and GE are of order I(0), while AVI, NRI, and URB are of order I(1), implying that cointegration is required to be checked.

The first generation of cointegration tests cannot produce reliable results in light of the evidence for cross-sectional dependence among the units. To deal with cross-sectional dependence, Westerlund and Edgerton [67] introduced the Westerlund panel cointegration test. The results of the Westerlund cointegration test are shown in Table 4. This suggests that there is evidence of the existence of cointegration between all variables in the five research models. It means that there is a long-term relationship between the variables in the models.

4.3. Multicollinearity tests

A multicollinearity test was applied to independent variables. As shown in Table 5, there is not significant multicollinearity between explanatory variables because the variance inflation factor (VIF) statistics for all variables are <10. The independent variables we take into account are therefore not redundant.

4.4. An overview of the estimated results

Eq. (1) is estimated using the Method of Moments Quantile Regression, and the fixed effect panel data estimator was also used to compare the results, as in the studies of Ike et al. [37]. Table 6 displays the results.

In panel A, FSI (overall food security index) is the dependent variable. The results of the fixed effect estimator indicate that (1) the inflation rate reduces the food security index, so a one-unit increase in the inflation rate will decrease food security by 0.07 points. (2) real GDP per capita and urbanization have statistically significant positive effects on food security, and an increase in real GDP per capita will improve food security by 8.3 units, while an increase in urbanization will improve food security by 1.1 units. A one-point increase in agricultural land will decrease food security by around 0.2 points. A dummy variable of COVID-19 has a negative and statistically insignificant effect on the overall food security index.

To measure the conditional median or a variety of different quantiles of the response variables, we used the Method of Moments Quantile Regression. Furthermore, since the employed normality tests indicated that most of the variables in Eq. (1) are non-normally distributed, there are some possibilities that the non-normal distribution of variables affects the results of the fixed effect estimator and calculated residuals. To control for non-normal distribution, the quantile regression model is applied, which is robust with respect to the non-normality of estimated residuals. The results of estimated coefficients for quantiles 0.1, 0.3, 0.5, 0.7, and 0.9 are presented in panel A Table 5. The panel quantile regression estimates show that the effect of COVID-19 on the total food security index is negative and statistically significant for the three first quantiles. This implies that the negative effect of COVID-19 on the total food security index is stronger in countries below the median (i.e. 1st, 3rd, and 5th) which are countries with less food security levels, and the coefficients get smaller from the 1st to the 3rd quantiles (countries with higher food security level).

The effect of income captured by GDP per capita on the food security index is positive and statistically significant across all quantiles. The results show that the effect of the inflation rate on food security is negative and statistically significant for all the quantiles and is stronger for countries below the median (countries with less food security levels) and getting weaker for countries above the median (countries with higher food security levels). The quantile results show a negative and significant effect of agricultural land on the total food security index across all the quantiles. At higher quantiles (i.e. 7th, 9th) however, this

Table 2
Cross-sectional dependence test.

Models	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
Model A	11,977.75	50.670	41.337	14.285
P-value	0.000	0.000	0.000	0.000
Model B	11,677.78	47.980	38.647	2.495
P-value	0.000	0.000	0.000	0.000
Model C	15,410.70	81.460	72.126	2.075
P-value	0.000	0.000	0.000	0.037
Model D	9350.697	27.109	17.776	13.159
P-value	0.000	0.000	0.000	0.000
Model E	10,918.89	41.174	31.840	2.727
P-value	0.000	0.000	0.000	0.000

Table 3
IPS panel unit-root test.

	Level		First difference	
Variables	Statistic	P-value	Statistic	P-value
FSI	−3.999	0.000	–	–
AVI	−1.148	0.125	−5.258	0.000
NRI	−1.418	0.960	−9.555	0.000
AFI	−7.291	0.000	–	–
QUI	−2.342	0.009	–	–
IF	−4.210	0.000	–	–
GDP	−9.320	0.000	–	–
AGL	−16.187	0.000	–	–
URB	14.369	1.000	−7.516	0.000

Table 4
Westerlund panel cointegration test.

Tests	Statistic	P-value
Model A		
Variance ratio	9.637	0.000
Model B		
Variance ratio	10.297	0.000
Model C		
Variance ratio	12.123	0.000
Model D		
Variance ratio	11.384	0.000
Model E		
Variance ratio	12.306	0.000

Table 5
Multicollinearity tests.

Variables	VIF	Tolerance
IF	1.17	0.851
GDP	3.85	0.259
AGL	1.12	0.893
URB	3.68	0.271
DCOVID	1.07	0.934
Mean VIF	2.18	–

Table 6
Estimation results of eq. (1) using fixed effect panel data estimator and the Method of Moments Quantile Regression.

Model A: Food Security Index

Covariates	FE-OLS		MMQR quantile = 0.10		quantile = 0.25		quantile = 0.50		quantile = 0.75		quantile = 0.90	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
IF	-0.075	0.000	−0.091	0.012	−0.084	0.005	−0.075	0.004	−0.067	0.016	−0.061	0.053
GDP	8.397	0.000	8.185	0.006	8.274	0.001	8.401	0.000	8.519	0.000	8.596	0.001
AGL	−0.190	0.031	−0.217	0.036	−0.206	0.018	−0.190	0.011	−0.175	0.029	−0.165	0.071
URB	1.163	0.000	1.110	0.000	1.132	0.000	1.164	0.000	1.193	0.000	1.212	0.000
DCOVID	−0.804	0.596	−1.095	0.032	−0.973	0.023	−0.799	0.030	−0.636	0.108	−0.531	0.241
Intercept	−33.318	0.000	−30.318	0.006	−31.573	0.001	−33.365	0.000	−35.041	0.000	−36.123	0.000

Model B: Availability Index

Covariates	FE-OLS		MMQR quantile = 0.10		quantile = 0.25		quantile = 0.50		quantile = 0.75		quantile = 0.90	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
IF	-0.023	0.578	−0.035	0.555	−0.031	0.545	−0.023	0.582	−0.016	0.703	−0.013	0.786
GDP	8.160	0.059	4.539	0.415	5.954	0.208	8.376	0.032	10.360	0.011	11.481	0.010
AGL	-0.263	0.150	−0.248	0.208	−0.254	0.129	−0.264	0.056	−0.272	0.059	−0.276	0.082
URB	0.857	0.000	0.839	0.003	0.846	0.000	0.858	0.000	0.868	0.000	0.873	0.000
DCOVID	-1.797	0.568	−0.547	0.797	−1.035	0.566	−1.872	0.208	−2.557	0.099	−2.944	0.085
Intercept	-15.437	0.368	−6.073	0.792	−9.733	0.618	−15.996	0.320	−21.125	0.207	−24.022	0.194

Model C: Natural resources and resilience index

Covariates	FE-OLS		MMQR quantile = 0.10		quantile = 0.25		quantile = 0.50		quantile = 0.75		quantile = 0.90	
	Coefficient	P-value	Coefficient	*P*-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
IF	0.050	0.035	0.060	0.128	0.056	0.099	0.050	0.088	0.043	0.197	0.039	0.297
GDP	2.858	0.229	1.025	0.750	1.685	0.544	2.799	0.245	4.122	0.130	4.740	0.127
AGL	−0.199	0.048	−0.159	0.330	−0.173	0.220	−0.198	0.105	−0.227	0.101	−0.240	0.127
URB	0.936	0.000	0.970	0.000	0.958	0.000	0.937	0.000	0.913	0.000	0.902	0.000
DCOVID	0.566	0.744	2.982	0.075	2.112	0.145	0.644	0.609	−1.098	0.438	−1.913	0.237
Intercept	−11.375	0.229	−10.871	0.379	−11.052	0.302	−11.359	0.220	−11.722	0.263	−11.892	0.319

Model D: Affordability index

Covariates	FE-OLS		MMQR quantile = 0.10		quantile = 0.25		quantile = 0.50		quantile = 0.75		quantile = 0.90	
	Coefficient	P-value	Coefficient	*P*-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
IF	−0.250	0.000	−0.290	0.005	−0.270	0.001	−0.246	0.000	−0.228	0.000	−0.217	0.001
GDP	12.885	0.001	15.682	0.040	14.308	0.015	12.601	0.004	11.350	0.009	10.560	0.029
AGL	-0.150	0.353	−0.265	0.272	−0.209	0.260	−0.139	0.320	−0.087	0.526	−0.054	0.719
URB	1.665	0.000	1.885	0.000	1.777	0.000	1.643	0.000	1.544	0.000	1.482	0.000
DCOVID	−0.959	0.731	−0.102	0.916	−0.523	0.482	−1.047	0.062	−1.430	0.010	−1.673	0.006
Intercept	−74.655	0.000	−97.682	0.000	−86.369	0.000	−72.320	0.000	−62.019	0.000	−55.513	0.001

Model E: Quality and safety index

Covariates	FE-OLS		MMQR quantile = 0.10		quantile = 0.25		quantile = 0.50		quantile = 0.75		quantile = 0.90	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
IF	0.01925	0.487	0.020	0.664	0.020	0.616	0.019	0.574	0.018	0.615	0.017	0.665
GDP	5.914	0.033	4.532	0.186	5.104	0.077	5.940	0.016	6.745	0.011	7.219	0.016
AGL	−0.116	0.322	−0.215	0.151	−0.174	0.167	−0.114	0.289	−0.056	0.625	−0.022	0.863
URB	1.033	0.000	1.064	0.000	1.051	0.000	1.033	0.000	1.015	0.000	1.004	0.000
DCOVID	0.035	0.986	4.036	0.088	2.380	0.232	−0.037	0.982	−2.368	0.194	−3.739	0.070
Intercept	−11.907	0.281	−7.962	0.562	−9.595	0.406	−11.979	0.225	−14.277	0.177	−15.629	0.192

effect is less pronounced. The effect of urbanization on the total food security index is positive and statistically significant at a 1% significance level across all the quantiles.

In panels B, C, D, and E of Table 5, we present the estimation results of Eq. (1) using panel fixed effect and quantile regression where availability index, natural resources and resilience index, affordability index, and quality and safety index are dependent variables, respectively. According to the fixed effect estimator results, COVID-19 doesn't have any significant effect on all the sub-indexes of food security (i.e. availability, natural resources, affordability, and quality and safety indexes). However, looking at the results of quantile regressions indicate that COVID-19 has a negative and significant effect on the affordability index in the above median quantiles, such as 5th, 7th, and 9th, and on the availability index in the 7th, and 9th quantiles. The negative effect of COVID-19 on the availability index in the countries with higher food security is in line with Deaton and Deaton's [20] findings that COVID-19 raises concerns about the food system in Canada. COVID-19 has a positive and statistically significant effect on the quality and safety index only in the first quantiles (countries with the least quality and safety index) and has a statistically negative impact in the 9th quantile (countries with the highest quality and safety index).

Furthermore, our quantile results confirm that the inflation rate has a negative and statistically significant effect on total food security and affordability indexes. The effect of urbanization on total food security and on all the sub-indices of food security is positive and statistically significant in almost all the quantiles. In all quantiles of food security, agricultural land has a statistically significant negative impact on total food security. Additionally, the results show that agricultural land decreases food availability in the high quantiles, such as the 5th, 7th, and 9th quantiles (countries above the median).

5. Discussion

In summary, our study shows that countries with lower food security were more vulnerable to economic shocks such as the pandemic and inflation, compared to countries with higher food security level. Our results are in line with findings in the existing literature. For example, Vos et al. [66] found that income shocks and supply disruptions have affected food security more where supply chains were poorly integrated. Bundervoet et al. [12] found that the COVID-19 pandemic has led to large job and income losses and increased food insecurity in 31 developing countries. The prevalence rate of undernourishment increased significantly in Africa and Southern Asia from 2019 to 2020 compared to the world average [17], while COVID-19 did not have severe impacts on the food security of high-income countries [18,55]. Furthermore, our quantile results confirm that the inflation rate has a negative and statistically significant effect on total food security and affordability indices. This result is in line with the findings of Peter Timmer and Dawe [58], Gustafson [32], and Zhou et al. [71]. Compared to other commodities and services, food prices rise alongside inflation. It puts a burden on the finances of low-income households and increases their vulnerability to price shocks. A low purchasing power caused by high inflation reduces food security and affordability.

The effect of urbanization on total food security and on all the sub-indices of food security is positive and statistically significant in almost all the quantiles. Rapid urbanization is widely acknowledged to increase food quality and security demands [33], diversify global agriculture [52], increase market access to neighboring rural regions [3], develop infrastructure [2], increase technical guidance, train farmers, and promote the development of smart agriculture [47].

In all quantiles of food security, agricultural land has a statistically significant negative impact on total food security. Additionally, the results show that agricultural land decreases food availability in the high quantiles, such as the 5th, 7th, and 9th quantiles (countries above the median). In line with Allee et al. [1], this result supports their claim that the agricultural land of a nation does not predict food security at a cross-national level.

The adverse impacts of COVID-19 on agricultural production were mainly due to the labor shortage, lockdown policies [5] and movement restrictions [27,63,64,70]. A range of household coping strategies included decreasing the frequency of grocery shopping, shifting to online shopping, improving practices in home vegetable gardening, reducing consumption of high price commodities, reducing junk food consumption, and increasing the consumption of protein and nutrient-rich food items [29,50,51,70]. Moreover, government policies have played important roles in ensuring food access during the pandemic. Strategies such as food and cash safety nets, support mechanisms for food production and businesses, and relaxed trade policies for food products have proven to be effective in reducing the adverse effects of COVID-19 on food security [19,40]. The development of infrastructure might possibly buffer the adverse effect of COVID-19 on the food security [18,55]. For example, several studies [22,53,60] have found dramatic increases in online grocery shopping and food ordering during COVID-19 that had positive effects on food and nutrition consumption. Furthermore, due to the reduced dependence on intermediate inputs (energy, seeds, fertilizer, and pesticides) and fixed capital, developed countries might be less affected by shocks to the supply chains due to COVID-19 [68].

6. Conclusions and Policy implications

COVID-19 has impacted the world economy and food system in many aspects. Higher food prices combined with reduced income inevitably posed risks to food security, meaning that many households had to lower the quality and quantity of their food consumption [69]. The result indicated that the impact of COVID-19 on the food security index is detrimental and statistically significant in nations with lower levels of food security, while the detrimental effect is less pronounced in nations where food security is higher. Food systems involve different factors along the supply chain, where the impacts of COVID-19 are multi-dimensional, including labor shortages, input shortages, production disruptions, trade restrictions, and economic recessions. Some of these factors may be more or less resilient to COVID-19's impacts than others. Furthermore, COVID-19's impacts and government measures for food insecurity prevention may be factor or region specific. Therefore, a comprehensive multi-national analysis is necessary for combating food insecurity globally. The paper compares the global food security situation after and before the COVID-19 outbreak by estimating how COVID-19 as a dummy variable affects the food security index and its four key pillars (affordability, availability, quality and safety, and natural resources and resilience) for 102 countries. Our study found that countries with low food security were more vulnerable to economic shocks, such as the pandemic and inflation, compared to countries with higher food security levels. The results of our study provide meaningful implications for policymakers in different countries and international organizations to build resilience in food systems and to be better prepared for future crises and disruptions in the food supply.

Contributions

Behnaz Saboori and Slim Zekri conceived the original idea, wrote the introduction and derived the model. Reza Radmehr analyzed the data and interpreted the results. Yu Yvette Zhang wrote the literature review. All authors provided critical feedback, helped shape the research, discussed the results and developed the policy implications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

List of the selected countries.

Algeria, Angola, Argentina, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belgium, Benin, Bolivia, Botswana, Brazil, Bulgaria, Burkina, Faso, Burundi, Cambodia, Cameroon, Canada, Chad, Chile, China, Colombia, Costa Rica, Côte d'Ivoire, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Germany, Ghana, Greece, Guatemala, Guinea, Haiti, Honduras, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Lao PDR, Madagascar, Malawi, Malaysia, Mali, Mexico, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria,Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines,

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Poland,Portugal, Qatar, Romania, Russian Federation, Rwanda, Saudi Arabia, Senegal, Serbia, Singapore, Slovak Republic, South Africa, Korea, Spain, Sri Lanka, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Vietnam, Yemen, and Zambia.

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