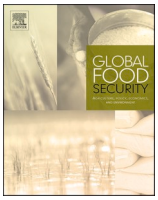
Global Food Security 35 (2022) 100659

Contents lists available at ScienceDirect

Global Food Security

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



Potential impacts of Ukraine-Russia armed conflict on global wheat food security: A quantitative exploration

Khondoker Abdul Mottaleb *, Gideon Kruseman, Sieglinde Snapp

Sustainable Agrifood Systems Program (SAS), International Maize and Wheat Improvement Center (CIMMYT), Carretera México-Veracruz Km. 45, El Batán, Texcoco, C.P. 56237, Mexico

ARTICLE INFO

JEL classification:
F61
Q18
F5
F52

Keywords:
Wheat
Consumption
Calories
Food security
Price
Elasticity
Armed conflict
Production
Export-import

ABSTRACT

Violent conflict is a major cause of acute food crises. In 2021, at least 155 million people in 10 countries were severely food insecure and eight of those countries were experiencing armed conflict. On February 24, 2022, an armed conflict between Russian Federation (Russia) and Ukraine escalated. As Russia and Ukraine are major wheat exporters, this will aggravate the already precarious food security situation in many developing countries by disrupting wheat production and export and by accelerating price hikes in import-dependent developing countries. This study examines the potential impacts of this ongoing armed conflict between Russia and Ukraine on wheat price, consumption, and calorie intake from wheat. In doing so, it applies the conditional mixed process estimation procedure using information collected from 163 countries and territories for the years 2016–2019 from online database of the Food and Agriculture Organization of the United Nations (FAO). The study shows that, on average, a 1% decrease in the global wheat trade could increase the producers' price of wheat by 1.1%, and a 1% increase in the producers' price could reduce the yearly per capita wheat consumption by 0.59%, daily calorie intake by 0.54% and protein intake by 0.64% in the sampled countries. Based on this, the study demonstrates that a 50% reduction in wheat exports by Russia and Ukraine could increase the producers' price of wheat by 15%, which would induce a reduction in wheat consumption and dietary energy intake by at least 8%. Since wheat export has reduced from both Russia and Ukraine, to avoid a food crisis in developing countries, policies are suggested, including near term improvement of domestic wheat production by promoting improved agronomic practices to close yield gaps to meet a substantial portion of wheat self-sufficiency goals. In the long run, countries in Africa, East Asia and South America can explore expanding wheat into new land area. International donor agencies can play a key role in supporting the ongoing wheat research and development activities.

1. Introduction

For the first time after 1990, the absolute number of poor and hungry people in world has started to increase (FAO et al., 2020; United Nations, 2022a; von Grebmer et al., 2021). In 1950, 63% of the world's population was extremely poor, living on less than US$ 1.90/day (Roser, 2019). In 1990, the portion of extremely poor was 35.9% (1895 million) and this was reduced to 20.8% (1352 million) by 2005 (World Bank, 2018). In 2015, out of a global population of 7.3 billion (World Bank, 2022), 654 million (8.9%) were estimated to be undernourished (FAO et al., 2020), and by 2019, 864 million persons (8.9% of the 7.68 billion world population) were considered undernourished (FAO et al., 2020).

The major drivers of hunger and food insecurity are climate shocks, outbreaks of crop diseases and pests, economic shocks, and war and conflicts (FAO et al., 2020). A report shows that in 2020, 155 million people globally were acutely food insecure, with 99.1 million of those living in 23 countries where war and conflicts were the chief causes of food security (von Grebmer et al., 2021). It indicates that war and conflicts is a major driver of hunger and food insecurity. When the world economy has been started to recover from the COVID-19 induced turmoil, on February 24, 2022, a fresh armed conflict between the Russian Federation (hereafter Russia) and Ukraine has escalated.

Both Russia and Ukraine are the major producers and exporters of wheat, maize, sunflower seeds, potassium, phosphorus and urea (46% nitrogen) fertilizers (FAO, 2022; Glauber and Laborde, 2022a; World Bank Group, 2022). In particular, 50 countries in Asia and Africa rely on Russia and Ukraine to fulfill 30% of their wheat food demand, and 26 countries meet 50% of their wheat demand through import from Russia

* Corresponding author.
E-mail addresses: k.mottaleb@cgiar.org (K.A. Mottaleb), G.KRUSEMAN@cgiar.org (G. Kruseman), S.SNAPP@cgiar.org (S. Snapp).

https://doi.org/10.1016/j.gfs.2022.100659
Received 19 April 2022; Received in revised form 11 October 2022; Accepted 13 October 2022
Available online 1 November 2022

and Ukraine (FAO, 2022). Sea ports in the Black Sea are the major gateway of the exports from Russia and Ukraine. Due to the armed conflict, ports in the Black Sea are unusable now. Grain transportation is disrupted due to the destruction of roads, bridges, and railways. The armed conflict between Russia and Ukraine has severely disrupted exports of crude oil, fertilizers, food grains including wheat (FAO, 2022).

As Russia and Ukraine are the source of more than a quarter of wheat traded in the global market, there is a consensus among researchers, think tanks, news agencies, and international donor agencies about the potential negative impacts of the ongoing armed conflict between Russia and Ukraine on the food security of developing countries (Abay et al., 2022; Bechdol et al., 2022; Bentley et al., 2022; Chikava, 2022; Douglas, 2022; FAO, 2022; Glauber and Laborde, 2022a; Headey and Hirvonen, 2022; Rattner and Barnett, 2022; Sabaghi, 2022). In 2021, 193 million people were acutely food insecure and at least 53 countries and territories required urgent assistance. According to FAO, there is a risk of pushing additional 11 to 19 million people to chronic hunger by 2023, due to the reduced exports of wheat and other commodities from Russia and Ukraine due to ongoing armed conflict (FAO, 2022).

Applying an econometric estimation process, the present study predicted the impacts of the ongoing Russia-Ukraine armed conflict on wheat consumption and the intake of calories and proteins from wheat in 163 countries. This is the first econometric study we are aware of to quantify the impacts of the armed conflict of Russia and Ukraine on food security. The rest of the study is organized as follows. Section 2 presents temporal changes in wheat production and consumption by major regions; Section 3 includes materials and methods; Section 4 presents major findings and Section 5 presents conclusions and policy implications.

2. Materials and methods

2.1. Data

This study relied on data from FAOSTAT (FAOSTAT, 2022a), a database administered by the Food and Agriculture Organization of the United Nations (FAO), as well as online data from the World Bank: the world development indicators (World Bank, 2022). The study also used the Global Hunger Index (von Grebmer et al., 2021) to group the sampled countries based on their food security situation. Country-level data for four years (2016–2019) on the yearly per capita wheat consumption (kg), daily calorie (kcal) and protein intake (grams) from wheat, wheat production, export, import, and international and producers' price of wheat (US$/ton) were collected from FAOSTAT. Data on the per capita GDP (US$), GDP growth rate, and share of the urban population (%) were collected from World Bank's world development indicators.

Using FAOSTAT data, our study calculated the international wheat price (US$/ton) as the total value of the exported wheat (US$) divided by the quantity of exports (tons). As wheat export information is not available for a few countries, we replaced the international wheat price with the import price, which was calculated as the total import value (US$) divided by the quantity of imports (tons). In calculating the international wheat price, the extreme values were replaced by taking the group average. The data on the producers' price of wheat (US$/ton) (annual average) was collected from FAOSTAT (FAOSTAT, 2022c). For a few countries, producers' price information was not available. In such a case, the producers' price was calculated as the international price plus transportation costs which were set at 30%.

In FAOSTAT, the information on per capita wheat consumption is available for 180 countries. For several countries and territories, data on GDP per capita (e.g., Cook Island, Equatorial Guinea); wheat consumption (e.g., Brunei Darussalam, Equatorial Guinea); wheat production (e.g., Guinea-Bissau, Eritrea); GDP growth rate (e.g., Venezuela, South Sudan, Palestine) are not available. After dropping the sampled countries with a lack of vital information, the study considered 163 countries as the sampled countries.

Based on the hunger severity scale, the Global Hunger Index 2021 classified the countries into normal (hunger score $\leq$9.9), moderate (hunger score 10.0–19.9), serious (20.0–34.9), alarming (35–49.9), and extremely alarming ($\geq$50.0) (von Grebmer et al., 2021). The share of wheat in per capita daily dietary energy intake for sampled countries is shown in Table 1A, based on the hunger severity scale (Table 1A, supplementary). As the number of countries in the last three groups (serious, alarming, and extremely alarming) are few in this study, these countries are merged into one group.

2.2. Econometric modeling process

Food represents 60–80% of total consumer expenditure in developing countries, compared to 10–20% in rich countries (Preckel and Hertel, 2007; Seale et al., 1904; UNCTAD, 2008). Consequently, many empirical studies agree that, at least in the short run, a hike in commodity prices hurts poor households, particularly in developing countries (Barrett and Dorosh, 1996; Ceballos et al., 2016; de Hoyos and Medvedev, 2011; Minot and Goletti, 2000; Ravallion, 1990). Studies have also confirmed that food price hikes can cause a net welfare loss and push households in developing countries into a poverty trap (Balagtas et al., 2014; Ivanic and Martin, 2008). A few researchers have argued for the possibility of gain in the long run (e.g., Aksoy and Isik-Dikmelik, 2008; Ivanic et al., 2012). The net gain or loss from commodity price hikes depends on a number of factors including the income distribution pattern in the society, the structure of the economy, and whether or not the household or the country is a net seller of the commodity (Hertel and Winters, 2006; Lokshin and Ravallion, 2004).

Another strand of the literature has propounded that food consumption is more responsive to price in low-income countries than in

Table 1
Wheat production, and trade-related information by the hunger status of the sampled countries.

	Country groups based on hunger status		
	Severe to extremely alarming (Group 1)	Moderate (Group 2)	Normal (Group 3)
Variables			
No. of sampled countries	40	30	93
Domestic production of wheat (MMT)	3.45	0.49	6.44
Domestic supply of wheat (MMT)	4.41	1.81	5.24
Wheat consumed (MMT)	3.84	1.27	3.32
Wheat imported (000, tons)	832.1	1399.9	1171.5
Value of imported wheat (million US$)	220.9	333.4	267.5
Wheat exported (000, tons)	12.8	4.8	2039.9
Value of wheat exported (million US$)	3.39	1.56	428.5
Wheat imported from Russia and Ukraine (000 tons)[a]	290.9	506.0	176.7
Share of imported wheat from Russia and Ukraine in total import (%)	33.5	36.2	13.8
Value of wheat imported from Russia and Ukraine (million US$)[a]	74.0	120.8	36.9
Share of the cost of wheat imports from Russia and Ukraine (%)	33.5	36.2	13.8
International price of wheat (US$/ton)	274.8	279.1	265.1
Producers' price of wheat (US $/ton)[b]	400.7	386.2	314.4

Sources: Authors' from FAOSTAT (2022b); [a]United Nations (2022b); [b]FAOSTAT (2022c); [c]World Bank (2022).

rich countries, thus any increase in food price can force households to reduce food consumption (D'Souza and Jolliffe, 2012; FAO, 2011; Green et al., 2013; Mazzocchi et al., 2012; Zaki et al., 2006). In some cases, to cope with rising food prices, households in low-income countries compromise food quality with quantity by moving away from nutritionally enriched food items to other cheaper food items (D'Souza and Jolliffe, 2012; Ulimwengu, 2009; Zaki et al., 2006).

Even prior to the Russia-Ukraine armed conflict, international food prices have risen and reached an all-time high in 2021, with higher costs of agricultural services, energy and fertilizers (FAO, 2022). The armed conflict between two major agricultural commodity exporting countries has sent a shockwave through the global commodity market. For example, crude oil price in 2021 was US$70.4/barrel, which has increased to US$100/barrel in the first quarter (Q1) of 2022, and it is projected to be US $92/barrel in Q12023 (World Bank Group, 2022). Similarly, in Q12022, urea price has increased by nearly 76% compared to 2021 price. (World Bank Group, 2022). In 2020, the international wheat price was US$ 232/ton, which increased to US$ 315/ton in 2021 (World Bank Group, 2022). In Q1 2022, the price of wheat increased by 42.7% to US$ 450/ton (World Bank Group, 2022). As many developing countries rely on cheap imported wheat from Russia and Ukraine to meet demand, how will this price hike affect wheat consumption and calorie intake?

Based on the assumption that domestic markets are linked with international markets through trade, and price transmission is expected from international to domestic markets (Conforti, 2004; Minot, 2010; Mundlak and Larson, 1992; Quiroz and Soto, 1995). For example, Minot (2010) estimated that international prices could explain 16–97% of the changes in domestic prices in some developing countries. Ianchovichina et al. (2014) estimated that, on average, a 1% increase in international food prices increased domestic food prices by around 0.2–0.4% in sampled Middle East and North African countries. Greb et al. (2012) confirmed that, on average, 75% of the changes in the price of agricultural commodities in the international market transmitted to the domestic market, and that the domestic rice price was strongly linked to the international price. Baquedano and Liefert (2014), examined wheat, rice, maize, and sorghum prices and estimated that around 25% of the changes in the domestic prices of these commodities were linked to the changes in international prices. Ceballos et al. (2016) estimated that, on average, 17.2% of the changes in the domestic prices of maize, rice, sorghum, and wheat could be attributed to the changes in the international price. Using the AGLINK-COSIMO partial equilibrium modeling approach, Araujo-Enciso et al. (2017) demonstrated that an assumed reduction in Russian wheat exports by 15%, Kazakh wheat exports by 30%, and Ukrainian wheat exports by 38% below the baseline level, could lead to a reduction of wheat in the world market by 3% and could increase the wheat price in the world market by 7%.

Following the notion of Araujo-Enciso et al. (2017), the present study econometrically examines the potential impacts of the increase in wheat price due to export disruptions due to Russia-Ukraine armed conflict on wheat consumption in the sampled countries (Fig. 1). This study hypothesizes that producers' price of wheat in the sampled countries will be affected by the international wheat price through international trade (Fig. 1). Specifically, it is assumed that the domestic price is determined by the international price, trade, and domestic wheat production and that wheat production in all sampled countries is constant. Thus, it is assumed that over the near term there is no increase in wheat production to make up for recent losses in global supply. Furthermore, it is assumed that no extra export from other countries will make up the loss in exports from Russia and Ukraine, and there will be no substantive change in wheat consumption habit in the countries sampled. Based on our hypothesis, we have formulated the inverse demand function of the domestic wheat price as follows:

$$\ln\left(P_c^{PD}\right) = \alpha_2 + \gamma_1\, ln\,(Domestic\ production)_c + \gamma_2\,(Trade)_c + \gamma_3 ln\,(Intl.\ \ price)_c + + \sum_{yd=1}^{3} \varphi_{d1}(TD)_{d1} + \varepsilon_1 \quad (1)$$

Where:

$\ln(P_c^{PD})$ = natural log of producers' price of wheat (US$/ton);
$ln\,(Domestic\ production)_c$ = natural log of wheat domestically produced in the country (tons);
Trade = Export + import of wheat (million metric tons);
$ln\,(Intl.\ price)_c$ = natural log of the international wheat price (US $/ton);
$(TD)_{d1}$ = Year 2017, 2018, and 2019 dummies where the base is the year 2016.

Finally, to examine how changes in the domestic price affect wheat consumption and calorie and protein intake from wheat, Eq. (2) is developed as follows:

$$\ln\,(y_c^k) = \alpha_3 + \varnothing 1\,(SFIS)_i + \varnothing 2(MFIS)_c + \varnothing 3\,\ln\left(P_c^{PD}\right) + \varnothing 4(GDPC)_c + \varnothing 5(GDGR)_c + \varnothing 6\,(URB)_c + \sum_{yd=1}^{3} \varphi_{d2}(YD)_{d2} + \varepsilon_2 \quad (2)$$

Where:

$\ln\,(y_c^k)$ = a vector of dependent variables including a natural log of

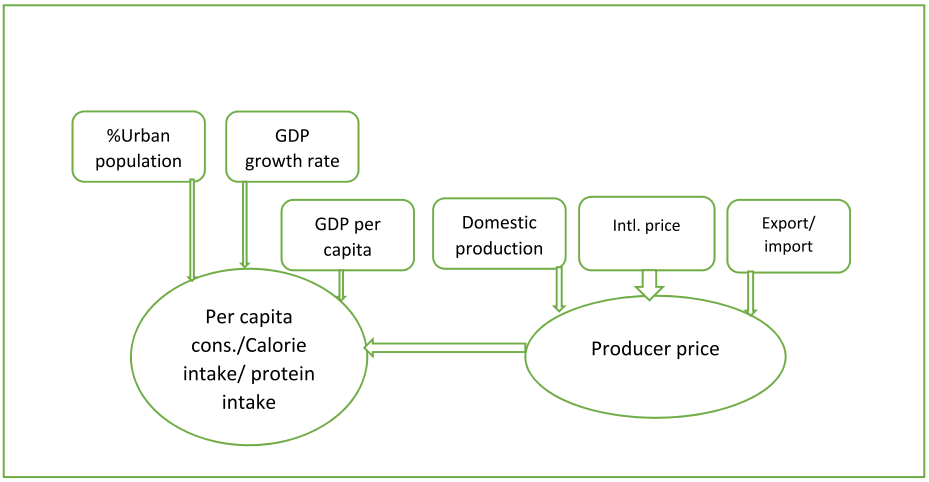


Fig. 1. Schematic diagram on the relationship between export-import price, producer price, and wheat consumption. Source: Authors.

yearly per capita wheat consumption (kg) and daily per capita calorie and protein intake from wheat;

$(SFIS)_i$ = dummy for the countries with hunger levels from serious to extremely alarming (yes = 1);
$(MFIS)_c$ = dummy for the countries with moderate hunger levels (yes = 1);
$\ln(P_c^{PD})$ = natural log of the producer's price of wheat (US$/ton);
$ln\ (GDPC)_c$ = per capita GDP (000, US$);
$(GDGR)_c$ = the annual GDP growth rate (%); and
$(URB)_c$ = the share of urban population (%).

In Eq. (1) and Eq. (2), c denotes the sampled countries (c = 1–163), α_i are the scalar parameters, ε_i are the error terms, and β_i , γ_i, $\varnothing\ i$ and φ_{di} are the parameters to be estimated. In estimating Eqs. (1) and (2), c Details about the estimation process can be seen in Roodman (2011).

3. Findings

3.1. Summary statistics

In terms of land allocation and international trade, wheat is the most widely cultivated crop in the world. In the triennium average ending 2020 (TE2020), wheat was cultivated in at least 124 countries on 216 million ha. At the same time, maize was cultivated in at least 167 countries on 198 million ha, and rice was cultivated in 115 countries on 164 million ha (FAOSTAT, 2022a). In TE2019, the total world wheat production was 757.4 million metric tons (MMT), of which 31% was exported. At the same time, maize and rice production were around 1138 MMT and 754 MMT respectively, of which 16% (181.5 MMT) of maize and 8.9% (67 MMT) of rice were exported (FAOSTAT, 2022a).

In Table 1, the current state of wheat production, consumption, and trade are presented by the countries sampled. In the first group of countries (group 1), where the hunger situation is severe to extremely alarming, the domestic production of wheat (3.45 MMT) cannot meet the consumption demand (3.84 MMT). The countries in this group are net importers of wheat, and on average each country in the group had imported more than 832 thousand tons of wheat worth US$ 221 million (Table 1). Importantly, on average, a country in group 1 imported 299.4 thousand tons of wheat from Russia and Ukraine in TE2019 worth US$ 74 million. The share of imported wheat from Russia and Ukraine was 33%. The international wheat price for the sampled countries in group 1, was US$275 ton and the producers' price in the domestic market was US $400/ton (Table 1).

The countries in the second group (hereafter group 2), where the hunger situation is moderate, are also generally net importers. On average, a country in group 2 produced 0.49 MMT of wheat but consumed 1.27 MMT of wheat and to make up the deficit imported around 1.4 MMT of wheat in TE2019 (Table 1). A group 2 country imported, on average, 506 thousand tons of wheat from Russia and Ukraine, which was 36% of the total wheat imported (Table 2). The sampled countries in group 3, where the hunger situation was normal, were generally net wheat exporters (Table 1). Nonetheless, on average, a country in group 3 imported 177 thousand tons of wheat from Russia and Ukraine in TE2019, which was 14% of the total imported (Table 1). The international wheat price (US$/ton) and the producers' wheat price (US$/ton) are also reported in Table 1. In our econometric modeling process, the domestic price of wheat (US$/ton) was estimated and included in the functions explaining wheat consumption in the sampled countries.

Regarding wheat exports and wheat exporting countries, Russia and Ukraine are the top exporters (Fig. 2). Of 2021 global wheat export, totaling 199 MMT, Russia and Ukraine's share was 25% (49.9 MMT) (Fig. 2). Egypt, Indonesia, and China are the world's top wheat importing countries in 2021, purchasing a total of 32.5 MMT of wheat, 16% of the world total wheat exports (Fig. 3).

Taken together, these findings indicate the importance of imported wheat, particularly wheat exports from Russia and Ukraine, in countries where the hunger situation is extremely alarming to moderate (Figs. 2 and 3). Thus, any disruption in the wheat supply due to the ongoing armed conflict can significantly affect the hunger situation in countries with precarious food security and widespread hunger.

Wheat is a major staple grain in the world (Dixon, 2007; Dixon et al., 2009; Erenstein et al., 2022; Shiferaw et al., 2013). In 2019, wheat was consumed in at least 180 countries; the per capita wheat consumption in TE2019 was 66.7 kg, which was 38% of the per capita total cereal consumed (174.7 kg) in the same year (FAOSTAT, 2022a). The per capita wheat consumption in the countries where the hunger situation was severe to extremely alarming was 42 kg in TE2019, more than 28% of the total cereal consumed annually (Table 2). In the countries where the hunger situation was moderate, the TE2019 per capita wheat consumption was 45 kg, 25% of the total cereal consumed by a person in a year (Table 2). In the countries where the hunger situation was normal, the TE2019 per capita wheat consumption was 96 kg, 70% of the total cereal consumption by a person in a year (Table 2).

In TE2019, wheat supplied 14% of a person's daily dietary energy and 16% of their daily total protein intake in the countries with a severe to extremely alarming hunger situation (Table 2), and 13% of a person's daily dietary energy and 14% of their daily total protein intake in the countries with a moderate hunger situation (Table 2). In the third group of countries, where the hunger situation was normal, wheat supplied 24% of a person's daily dietary energy intake and 23% of their daily total protein intake (Table 2).

Interestingly, due to the increase in population, per capita income, and urbanization, wheat consumption in Africa and South Asia has been increasing (Mason et al., 2015; Mottaleb et al., 2018a, 2018b; Nagarajan, 2005). It is projected that the global average per capita wheat consumption may increase from 67 kg per capita in TE2019 to 70 kg by 2030 and to 75 kg by 2050 (Mottaleb et al., 2021). In addition, millions of resource-poor farmers in Asia and Africa rely on wheat cultivation for their livelihood and income (Erenstein et al., 2021; Shewry, 2009). This suggests that the importance of wheat as a major staple will continue in the future.

In Table 3, some of the important macroeconomic indicators are presented by the hunger status of the sampled countries. On average, the yearly per capita GDP of a country in the group with a severe to

Table 2
Wheat consumption and nutrition intake from wheat by the food security status of the sampled countries.

Variables	Country groups based on hunger status		
	Severe to extremely alarming	Moderate	Normal
Wheat consumption (yearly/capita/kg)	42.1	45.4	96.0
%Share of wheat in total cereal consumption	28.4	24.9	69.4
Calorie intake from wheat (daily/capita/kcal	346.2	363.9	761.9
%Share of calorie intake from wheat to the daily per capita total calorie intake	14.3	13.3	24.0
Protein intake from wheat (daily/capita/grams)	10.0	10.3	22.5
%Share of protein intake from wheat to daily per capita total protein intake	16.4	14.3	23.5

Source: Authors based on FAOSTAT (2022b).

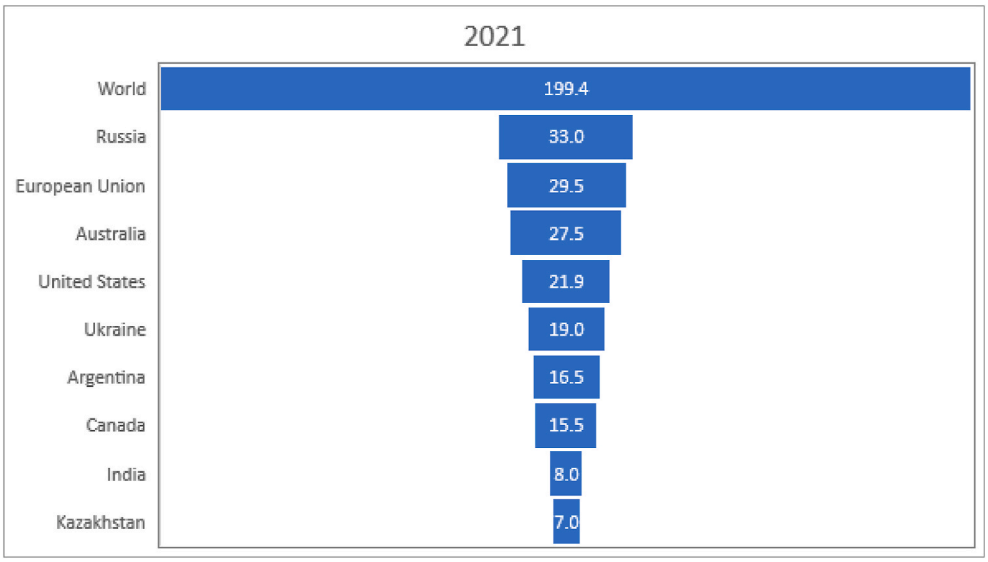


Fig. 2. Total wheat export in million metric ton and top nine wheat exporting countries in 2021/22. Source: USDA (2022).

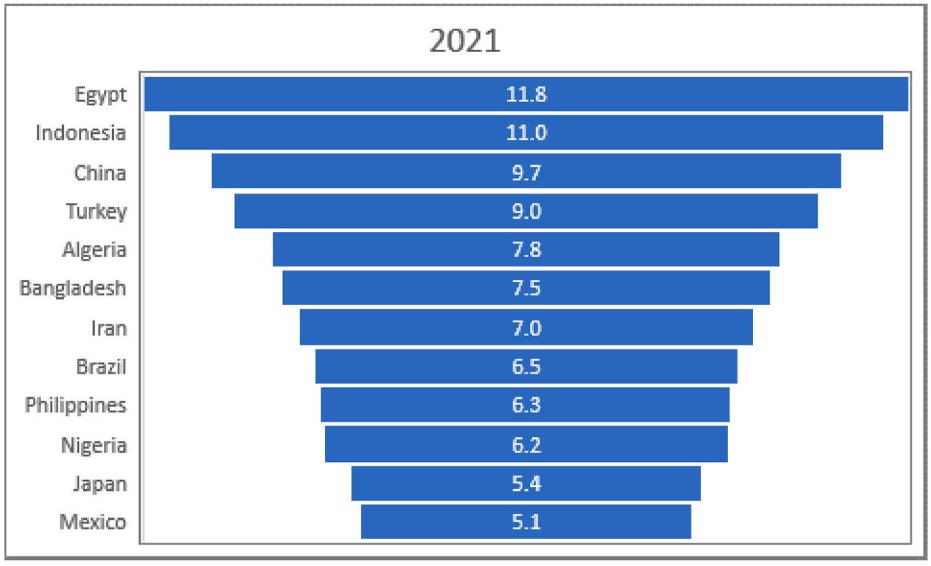


Fig. 3. Top 12 wheat importing countries in 2021/22 (million metric ton). Source: USDA (2022).

Table 3
Important macroeconomic indicators by the hunger groups of the sampled countries.

Variables	Country groups based on hunger level		
	Severe to extremely alarming	Moderate	Normal
GDP per capita (US$)	1664.4	4355.4	23284.1
GDP growth rate (%)	0.99	2.69	2.13
Share of urban population (%)	40.1	48.4	70.4

Source: Authors' based on World Bank (2022).

extremely alarming hunger situation was US$ 1664.4, which was 2.6 times lower than the per capita GDP of the countries with a moderate hunger situation (US$ 4355.4), and 14 times lower than the per capita GDP of the countries with a normal hunger situation (US$ 23284.1) (Table 3). The average GDP growth rate was 0.99% per annum for the countries with a severe to extremely alarming hunger situation, 2.69% for the countries with a moderate hunger situation and 2.13% for the other countries (Table 3).

Forty per cent (40%) of the total population in the countries with a severe to extremely alarming hunger situation, 48.4% of the population in the countries with a moderate hunger situation, and 70% of the population in the countries with a normal hunger situation reside in the urban areas (Table 3). In the empirical estimation process, the GDP per capita, the annual GDP growth rate, and the share of the urban population (%) are used as regressors in estimating the yearly per capita wheat consumption and the daily dietary energy and protein intake from wheat.

In Table 4, the pairwise correlation coefficients are presented for the yearly per capita wheat consumption in kg, the daily per capita calorie (kcal) and protein intake (grams) from wheat, and the producers' and the international prices of wheat. All variables are converted into the natural log form (Table 4). As is expected, the relationship between the international and the producers' prices of wheat are negatively and significantly correlated with yearly per capita wheat consumption (-0.36, $p < 0.00$) and daily per capita calorie (-0.35, $p < 0.00$) and

Table 4
Pairwise correlation matrix explaining the relationship between international and domestic prices of wheat and the consumption, calorie, and nutrient intake from wheat in the sampled countries.

Variables	1	2	3	4	5
1. ln (consumption/ capita/kg)	1.00				
2. ln(daily calorie intake)	0.99*** (0.00)	1.00			
3. ln(daily protein intake)	0.99*** (0.00)	0.99*** (0.00)	1.00		
4. ln(producers' price of wheat)	−0.36*** (0.00)	−0.35*** (0.00)	−0.37*** (0.00)	1.00	
5. ln (international wheat price)	−0.27*** (0.00)	−0.26*** (0.00)	−0.28*** (0.00)	0.73*** (0.00)	1.00

Note: P-values are in the parenthesis. *** indicate significance at the 1% level.
Source: Authors calculation.

protein intake (−0.37, $p < 0.00$) from wheat. Furthermore, the relationship between the international and the producers' wheat prices is +0.73 ($p < 0.00$). The findings in Table 4 show that an increase in international wheat prices is predicted to increase producers' prices and negatively affect wheat consumption and nutrition intake.

A simple relationship between variables is indicated. The correlation coefficients are not calculated considering the influences of other variables, and the correlation coefficients cannot be used for inference purposes (Table 4). To infer how a change in international price affects the producers' price of wheat, and how a change in the producers' price can affect wheat consumption and calorie intake from wheat, Eqs. (1) and (2) are estimated and reported next.

3.2. Empirical findings

The estimated functions specified in Eqs. (1) and (2), explaining producers' prices and wheat consumption, are presented in Table 5. The first column of Table 5 presents the estimated function explaining the (ln) yearly per capita wheat consumption (kg), the second column presents the (ln) daily per capita calorie intake from wheat (kcal), and the third column presents the (ln) daily per capita protein intake from wheat (grams).

The last segment in Table 5 presents the estimated functions explaining the producers' price of wheat. The domestic production of wheat is negative and highly statistically significant ($p < 0.00$) in explaining the producers' price of wheat. It shows that a 1% increase (decrease) in domestic production can reduce (increase) producers' prices by 0.018%. This finding suggests that to smooth out the influence of global price hikes, it is necessary to enhance domestic production in the countries where this is possible. The international wheat price and producers' price of wheat are positively and highly statistically significant ($p < 0.00$). On average, a 1% increase in international wheat prices increases producers' prices in the sampled countries by 0.89% and vice versa (Table 5). Similar to the findings of Minot (2010); Ianchovichina et al. (2014); Greb et al. (2012); Baquedano and Liefert (2014), and Ceballos et al. (2016), the findings of the present study are consistent with global commodity prices as transmitting into domestic markets, which has severe consequences for purchasing power and food security..

The variable trade, which is the sum of wheat exports and imports (MMT) is negative and statistically significant ($p < 0.00$) in explaining the producers' wheat price (Table 5). Based on the findings, a 1% increase in exports and imports can reduce the international wheat price by 1.1% (Table 5). Alternatively, a 1% decrease in trade can increase the international wheat price by 1.1% (Table 5). This indicates that an undisrupted and increased international wheat trade can smooth out the domestic wheat price in the long run.

The first segment of Table 5 demonstrates that after controlling for the influence of other variables, the average yearly per capita wheat consumption (kg), and the daily calorie and protein intake from wheat is at least 0.96%–1% lower in the countries where the hunger situation is extreme or seriously alarming (Table 5). Similarly, in the sampled countries where the hunger situation is moderate (yes =), wheat consumption and calorie and protein intake from wheat are lower by 0.75–0.78% compared to the base countries where the hunger situation

Table 5
Estimated functions applying the Conditional (recursive) mixed process estimator with multilevel random effects and coefficients explaining the consumption of wheat (yearly/capita/kg), calorie intake from wheat (daily/capita/kcal), and protein intake from wheat (daily/capita/grams).

	ln(Wheat consumption (yearly/capita/kg))	ln(Calorie intake (daily/capita/kcal))	ln(Protein intake (daily/capita/grams))
Food security status dummies (base country: hunger situation is normal = 0)			
Dummy for the country where hunger situation is serious/alarming/ extremely alarming (yes = 1)	−1.00*** (0.18)	−0.98*** (0.19)	−0.96*** (0.19)
Dummy for the country where hunger situation is moderate (yes = 1)	−0.78*** (0.15)	−0.75*** (0.15)	−0.77*** (0.15)
ln(producers' price, US $/ton)	−0.59*** (0.20)	−0.54*** (0.18)	−0.64*** (0.18)
GDP per capita (000, US$)	−0.001 (0.00)	−0.001 (0.00)	0.0003 (0.00)
GDP growth rate (%)	−0.01 (0.01)	−0.01 (0.01)	−0.01 (0.01)
% Urban population	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Year dummies (base year 2016 = 0)			
Year 2017 dummy	0.05** (0.03)	0.05** (0.02)	0.05** (0.03)
Year 2018 dummy	0.06** (0.03)	0.06** (0.03)	0.07** (0.03)
Year 2019 dummy	0.04 (0.03)	0.04* (0.02)	0.05* (0.03)
Constant	7.40*** (1.17)	9.22*** (1.10)	6.22*** (1.09)
Dependent variable	**ln of producers' price (US$/ton)**		
ln(Domestic production of wheat, tons)	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)
Export + import of wheat (MMT)	−0.01*** (0.00)	−0.01*** (0.00)	−0.01*** (0.00)
ln(International wheat price ton/USD)	0.89*** (0.07)	0.89*** (0.07)	0.89*** (0.07)
Year dummies (base year 2016 = 0)			
Year 2017 dummy	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Year 2018 dummy	0.03** (0.01)	0.03** (0.01)	0.03** (0.01)
Year 2019 dummy	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Constant	0.97** (0.40)	0.95** (0.39)	0.99** (0.40)
lnsig_1	−0.37*** (0.08)	−0.37*** (0.07)	−0.35*** (0.07)
lnsig_2	−1.20*** (0.10)	−1.20*** (0.10)	−1.20*** (0.10)
atanhrho_12	0.29** (0.14)	0.27** (0.14)	0.31** (0.14)
No. of observations	652	652	652
Wald $chi^2(15)$	1350.2	1370.9	1428.8
Prob > chi2	0.00	0.00	0.00
Log pseudolikelihood	−802.9	−800.7	−811.4

Values in parentheses are clustered standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

is normal (Table 5). Importantly, following the law of demand, findings are consistent with the following: a 1% increase in producers' wheat price reduces wheat consumption by 0.59%, calorie intake by 0.54%, protein intake by 0.64%, and vice versa (Table 5). The positive and weakly significant year dummies indicate that over time, in general, wheat consumption and dietary nutrition intake from wheat have been increasing in the sampled countries (Table 5).

The estimated functions reported in Table 5 are based on pooled data. One might argue that the results are just spurious regression. In Table2A in Annexure A, the model is estimated using only 2018 data. The estimated coefficients reported in Table 2A are the same as those reported in Table 5, indicating the robustness of our findings. In addition, the significant orthogonality test coefficients in Table 5 indicate the suitability of the application of the conditional mixed process estimation with the multilevel random effects estimation process.

4. Discussion

This study demonstrates econometrically how changes in producers' prices can affect the consumption of wheat, where the producers' wheat price is a direct function of domestic wheat production, the international wheat price, and trade (exports + imports). Findings demonstrate that a 1% increase in the international wheat trade can reduce domestic wheat prices by 1.1%, larger than some earlier studies and with severe consequences for food security in some countries (Table 5). In 2020, the total wheat export around the globe was 192.6 MMT, worth US$ 44796.3 million. In the same year, total wheat exports by Russia and Ukraine were 53.3 MMT, which was 28.7% of the total wheat export, worth US$ 11512.5 million (United Nations, 2022b).

Due to the armed conflict that started in March 2022 between Russia and Ukraine, Ukraine banned exports of oats, wheat, and other food items to prevent an internal food crisis (The Associated Press, 2022). In 2020, Ukraine exported 18.1 MMT of wheat, which was 9.4% of the global exports and worth US$ 3594.2 million (United Nations, 2022b). Let us assume that 50% of Russian and Ukrainian wheat −14.4% of the total world exports — will not be available in the international market due to the current armed conflict. Based on our estimated elasticities, in such a case other thing remaining the same, the global average producers' price of wheat will increase by 15% (1.04648 × 0.1436). Keeping other things constant, this increase in the producers' price of wheat will force consumers to reduce the yearly per capita wheat consumption (kg) by 8.9% (0.15 × 0.59), the daily per capita calorie intake from wheat by 8.1% (0.15 × 0.54), and the daily per capita protein intake from wheat by 9.6% (0.15 × 0.64). This finding is similar to the findings of Araujo-Enciso et al. (2017), which estimated that a reduction in Russian wheat exports by 15%, Kazakh wheat exports by 30%, and Ukrainian wheat exports by 38% below the projected baseline level, could lead to a reduction of wheat in the world market by 3%, and that consequently the wheat price in the international market would increase by 7%.

Since 1990, the absolute number of hungry and poor people in the world has started to increase globally (United Nations, 2022a; von Grebmer et al., 2021). In 2020, around 720–811 million people went to bed with a hungry stomach, which was higher by 118–161 million people compared to the previous year (FAO et al., 2020). While climate shocks, outbreaks of crop diseases and pests, and economic shocks are all global drivers of food insecurity, war and conflicts are the main drivers of food insecurity and hunger in the world (FAO et al., 2020). According to von Grebmer et al. (2021) in 2020, 155 million people globally were acutely food insecure, with 99.1 million of those living in 23 countries where war and conflicts were the main reason for food insecurity. Furthermore, the COVID-19 pandemic has intensified the food insecurity situation in many countries of the world. Considering the issues, von Grebmer et al. (2021) predicted that at least 47 countries are off course in achieving the United Nations, 2022a zero hunger goal (von Grebmer et al., 2021).

Despite tremendous progress in crop yields and production, prices have been continuously increasing in the world since 2004, mainly due to the increase in demand stemming from growth in population and incomes (FAO et al., 2020). The Russia and Ukraine armed conflict has contributed to escalating food prices to an unprecedented level. There is a consensus that the current crisis can increase food prices, which in turn reduces affordability and real incomes, with severe consequences for food security, particularly in developing countries.

A search in the United Nations online database on commodity trading (Comtrade) revealed that in 2020, at least 89 countries imported wheat from Russia, and at least 63 countries imported wheat from Ukraine (United Nations, 2022b). Our study shows that in the sampled countries where the current hunger status is severe to extremely alarming, wheat supplies 14% of the daily dietary energy and protein intake per person. These countries secure at least 33% of their imported wheat from Russia and Ukraine, and any potential disruption of this wheat supply could seriously undermine the overall food security situation of these countries, where the food security situation is already precarious. The findings of this study confirm quantitatively that a 50% reduction in wheat exports from Russia and Ukraine could increase the average domestic price of wheat (producers' price) by 15%, and that this price increase could reduce per capita wheat consumption, thus reducing daily calorie and protein intake per capita by at least 8%. The findings of this study is similar to the findings of Araujo-Enciso et al. (2017), which asserted that a reduction in Russian wheat exports by 15%, Kazakh exports by 30% and Ukrainian wheat export by 38% below the projected baseline level, can lead to a reduction of wheat in the world market by 3% and it will result in an increase of wheat price by 7% in the world market.

High reliance on imports for any commodity to meet food demand cannot not be a sustainable solution, as major commodity exporting countries may stop exporting in the face of any crisis, prioritizing their own requirement in a critical time. For example, during commodity price hikes in 2007–08, India banned rice exports (Government of India, 2007), and in 2019, India banned onion exports (Gettleman et al., 2019). Finally, India, the second largest wheat producing county in the world, following a harvest reduced by excess heat, also banned wheat export on May 13, 2022 (Menon, 2022).

A related issue highlighted here is that of fertilizer price shocks. Both Russia and Ukraine are major producers and exporters of potassium, phosphorus and urea (46% nitrogen) fertilizers (FAO, 2022; Glauber and Laborde, 2022a; World Bank Group, 2022). Because of the ongoing armed conflict and rising crude oil price, in the first quarter of 2022, urea fertilizer price has increased by nearly 76% compared to 2021 price, and it is projected to be 55% higher in the first quarter of 2023 than 2021. Urea is the chief nitrogen source relied upon for high yields and is essential to producing high-protein wheat in particular which is important for bread production. There are crop production consequences of the confluence of price spikes in fertilizer and grain, but more importantly, these have long-term sustainability consequences. Both short and long-term strategies are needed that encompass fertilizer and other input costs, address yield gaps and consider the entire value chain, so as to ensure wheat production is sufficient at both a country, local scale, and a global scale.

5. Conclusion and policy implications

Currently, 864 million persons- 8.9% of the world population, suffer from hunger (FAO et al., 2020) and at least 77 million are severely food insecure due to war and conflicts (von Grebmer et al., 2021). For the first time since 1990, the number of absolutely poor people in the world has started to increase and COVID-19 induced economic turmoil has exacerbated the situation. At least 47 countries are expected to fall short of the United Nations, 2022a zero hunger goal (von Grebmer et al., 2021).

The findings of this study warn the consequences of the ongoing armed conflict between Russia and Ukraine including reduced yearly per

capita wheat consumption and calorie and protein intakes from wheat. This will worsen the already precarious food and nutritional security of the countries where food security situation is already extremely alarming. Rising wheat prices, particularly in countries that rely on imported wheat, can lead to violence and social unrest, as occurred during 2007–11 (Clapp and Cohen, 2009; Kliger, 2008; Kron, 2011; Sneyd et al., 2013; Zerbe, 2009).

Based on the findings, first and foremost we urge international donor agencies to mobilize resources to ensure alternative sources of affordable wheat for import-dependent, resource-poor countries. To avoid crisis in the future, steady public funding is needed for basic and adaptive research to improve agronomic management and genetic gains for wheat production. This is essential given the crop's central role in staple foods for the 9.7 billion, highly-urbanized world population expected by 2050 (World Bank, 2021).

To avoid a potential disaster, this study suggests enhancing domestic wheat production as well as substituting alternate crops for wheat to the extent feasible, particularly in Asia and Africa to lessen the reliance of these on imports. Also, to increase exportable surplus, wheat production in India, China, United States, Argentina, and other major wheat producing countries should be enhanced immediately.

In the long run, expansion of improved agronomic practices and seeds in Asia and Africa can contribute substantially to avoid potential crisis and achieving towards self-sufficiency in wheat. The average wheat yield in Africa in TE2020 was 2.73/ton, and in Asia it was 3.40 ton/ha, whereas the global average yield was 3.78 ton/ha. In particular, the large wheat yield gap in Africa points to a great opportunity to increase wheat production in the continent(Silva et al., 2021) Closing the yield gap by research and investment can be instrumental in achieving towards self-sufficiency in wheat and overall food security in Africa (Baudron et al., 2019; Bentley et al., 2022).

Exploring the possibility of land expansion for wheat, in the long run, could be another option to avoid a disaster. While in South Asia the possibility of expanding the cropland is very limited, in East Asia around 100 million ha of cropland is potentially available (Bruinsma, 2009). Deininger et al. (2011), and Fischer and Shah (2010) also indicated that a total of 295 million ha of land could be made available to use as cropland, conditional on a negligible investment in infrastructure. A study commissioned by the International Maize and Wheat Improvement Center (CIMMYT), Mexico indicated that vast areas of land in Nigeria, Tanzania, DR Congo, Angola, Kenya, and Madagascar, had high potential for wheat cultivation. Policies that facilitate access to improved agronomy, along with modern, high-yielding varieties, could significantly improve wheat production in these areas. Converting land to cropland entails environmental costs (IPCC et al., 2019; WBGU, 2020). Keeping this in mind, a careful expansion of the wheat areas in East Asia and Africa could significantly improve the wheat supply and could be achieved through doubling cropping and intercropping in some areas to minimize pressure on land (Bentley et al., 2022). In addition, it is imperative to expand social protection programs, and support policies for income growth particularly for the poor in the countries where food security situation is precarious. International donor agencies can play a significant role by supporting wheat research and development through ensuring a continuous and steady supply of research funds. Furthermore, one policy that could be considered is strengthening global trade rules to prohibit countries from banning exports of staple foods at the time of crisis, unless absolutely necessary (e.g., Glauber and Laborde, 2022b; Smaller, 2022).

While this study provides a firsthand potential impact of the ongoing armed conflict between Russia and Ukraine on wheat consumption, there are several limitations of the study. Crude oil price, fertilizer price, and global production determine international wheat price, and international wheat price transmits into domestic market and affects producers' price. Producers' price affects retail price which affects consumption. For simplicity, this study modeled potential impacts considering two step procedures, based on a cross-section panel dataset. Assumptions included no change in other variables, such as international price, consumption pattern and GPD per capita. In reality, any change of these variables can affect wheat consumption and calorie intake from wheat differently. To understand the complete impacts of the ongoing armed conflict between Russia and Ukraine more deeply, it is imperative to conduct country level case studies. In particular, many Middle-Eastern and African countries, where wheat is the major staple, heavily rely on imported wheat to meet their demand. In this study, we have grouped sampled countries based on their food security situation. However, grouping of countries based on their geographic location may provide additional and different perspectives on the potential impacts of the current Russia-Ukraine armed conflict on the global food security. Future research may examine potential impacts by grouping countries based on geographic locations. Finally, in addition to wheat, Russia and Ukraine are also the major exporters of sunflower seeds, barley, maize, and chemical fertilizers. Future research should consider export, import and consumption/utilization of these commodities in quantifying the impacts of the ongoing armed conflict between Russia and Ukraine.

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.

Acknowledgements

This study was conducted by the foresight team of the agri-food systems program (SAS) at the International Maize and Wheat Improvement Center (CIMMYT) and financially supported by the One CGIAR initiative on Foresight and Metrics for the Transformation of Food, Land and Water Systems (FMI). CGIAR is a global research partnership for a food-secure future, dedicated to transforming food, land, and water systems in a climate crisis. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: https://www.cgiar.org/funders/.

Annexure- A

Table 1A
Sampled countries grouped based on the food security status and share of wheat (%) in daily total energy intake (kcal) per capita.

Countries by food security situation and wheat share in daily total dietary energy per person (%)					
Serious, alarming, extremely alarming	Wheat share (%)	Moderately food insecure	Wheat share (%)	Food secure	Wheat share (%)
Afghanistan	61.0	Bangladesh	6.1	Albania	29.9
Angola	9.9	Bolivia	18.3	Algeria	40.1
Benin	4.3	Cabo Verde	12.7	Antigua and Barbuda	24

(*continued on next page*)

Table 1A (*continued*)

Countries by food security situation and wheat share in daily total dietary energy per person (%)					
Serious, alarming, extremely alarming	Wheat share (%)	Moderately food insecure	Wheat share (%)	Food secure	Wheat share (%)
Botswana	15.9	Cambodia	1	Argentina	27.7
Burkina Faso	3.6	Cameroon	7.8	Armenia	25.7
Burundi	3.5	Ecuador	13.4	Australia	17.9
Cote d'Ivoire	6.3	Egypt	35.3	Austria	19
Chad	1.1	Eswatini	12.7	Azerbaijan	49.9
Congo	17.3	Gabon	16.7	Barbados	21.3
The Democratic Republic of the Congo	1.9	The Gambia	14.8	Belarus	18.4
Djibouti	35.4	Ghana	4	Belgium	18.3
Ethiopia	13.4	Guatemala	11.3	Belize	17.7
Guinea	5.3	Guyana	13	Bosnia and Herzegovina	21.4
Haiti	11.2	Honduras	10	Brazil	11.6
India	20.0	Lao People's Democratic Republic	0.7	Bulgaria	26.2
Indonesia	7.8	Malaysia	11.4	Canada	16.7
Iraq	45.9	Mauritius	27.8	Chile	29.5
Kenya	12.9	Myanmar	3.4	China, Hong Kong SAR	13.6
Lesotho	8.1	Nepal	14	China, Macao SAR	14.8
Liberia	4.4	Nicaragua	8.4	China, mainland	17.3
Madagascar	5.9	Oman	19.8	Colombia	7.9
Malawi	1.9	Philippines	8.6	Costa Rica	10.8
Mali	5.0	Senegal	12.6	Croatia	23.3
Mauritania	32.5	Solomon Islands	8.9	Cuba	12.1
Mozambique	7.6	South Africa	16.6	Cyprus	31.6
Namibia	16.9	Sri Lanka	12	Denmark	17.3
Niger	1.2	Suriname	17.6	Dominican Republic	6.9
Nigeria	7.6	Tajikistan	43.6	El Salvador	13.3
Pakistan	35.2	Thailand	4.5	Estonia	15
Papua New Guinea	13.4	Viet Nam	3.8	Fiji	21.4
Rwanda	3.4	Group average	13.0	Finland	20.5
Sierra Leone	4.3			France	25.4
Sudan	20.7			Georgia	36.2
The Syrian Arab Republic	39.6			Germany	19.4
Togo	5.4			Greece	23.8
Uganda	2.7			Grenada	18.4
United Republic of Tanzania	5.5			Hungary	25.6
Yemen	45.8			Iceland	19.1
Zambia	2.8			Iran (the Islamic Republic of)	42.1
Group average	14.0			Ireland	23.5
				Israel	23.1
				Italy	29.3
				Jamaica	21.5
				Japan	14.3
				Jordan	30.8
				Kazakhstan	25.3
				Kuwait	25.2
				Kyrgyzstan	37.2
				Latvia	15.8
				Lebanon	35.9
				Libya	33.7
				Lithuania	26.7
				Luxembourg	25.5
				Maldives	20.4
				Malta	28
				Mexico	7.6
				Mongolia	25.9
				Montenegro	28
				Morocco	40.7
				Netherlands	17.8
				New Caledonia	27.5
				New Zealand	21.5
				North Macedonia	23.3
				Norway	26.2
				Panama	10.1
				Paraguay	9.3
				Peru	12.5
				Poland	24.7
				Portugal	19.9
				Republic of Korea	11.8
				Republic of Moldova	29.4
				Romania	27
				Russian Federation	32.7
				Saint Lucia	27.5
				Saint Vincent and the Grenadines	20
				Saudi Arabia	26.3
				Serbia	29.4

(*continued on next page*)

Table 1A (*continued*)

Countries by food security situation and wheat share in daily total dietary energy per person (%)					
Serious, alarming, extremely alarming	Wheat share (%)	Moderately food insecure	Wheat share (%)	Food secure	Wheat share (%)
				Seychelles	22.8
				Slovakia	26
				Slovenia	27.1
				Spain	20.2
				Sweden	20.9
				Switzerland	20.6
				Trinidad and Tobago	25.6
				Tunisia	45.3
				Turkey	34.1
				Turkmenistan	51.5
				Ukraine	27.9
				United Arab Emirates	26.1
				Kingdom of Great Britain and N	25.5
				United States of America	15.7
				Uruguay	25.3
				Uzbekistan	41.9
				Group average	23.9

Table 2A
Estimated functions applying the Conditional (recursive) mixed process estimator with multilevel random effects and coefficients explaining the consumption of wheat (yearly/capita/kg), calorie intake from wheat (daily/capita/kcal), and protein intake from wheat (daily/capita/grams). Only 2018 data.

	ln(Wheat consumption (yearly/capita/kg))	ln(Calorie intake (daily/capita/kcal))	ln(Protein intake (daily/capita/grams))
Food security status dummies (base country: hunger situation is normal = 0)			
Dummy for the country where hunger situation is serious/alarming/extremely alarming (yes = 1)	−0.98***	−0.97***	−0.93***
	(0.20)	(0.20)	(0.20)
Dummy for the country where hunger situation is moderate (yes = 1)	−0.74***	−0.72***	−0.73***
	(0.15)	(0.15)	(0.15)
ln(producers' price, US$/ton)	−0.74***	−0.69***	−0.79***
	(0.23)	(0.21)	(0.21)
GDP per capita (000, US$)	−0.00074	−0.00028	0.00078
	(0.00)	(0.00)	(0.00)
GDP growth rate (%)	−0.023	−0.024	−0.023
	(0.02)	(0.02)	(0.02)
% Urban population	0.0051	0.0049	0.0046
	(0.00)	(0.00)	(0.00)
Constant	8.40***	10.2***	7.23***
	(1.37)	(1.27)	(1.25)
Dependent variable	**ln(producers' price of wheat)**		
ln(Domestic production of wheat, tons)	−0.018***	−0.017***	−0.018***
	(0.00)	(0.00)	(0.00)
Export + import of wheat (MMT)	−0.011***	−0.011***	−0.010***
	(0.00)	(0.00)	(0.00)
ln(International wheat price ton/USD)	0.87***	0.87***	0.86***
	(0.08)	(0.08)	(0.08)
Constant	1.13**	1.12**	1.14**
	(0.46)	(0.45)	(0.46)
lnsig_1	−0.39***	−0.40***	−0.38***
	(0.08)	(0.07)	(0.07)
lnsig_2	−1.30***	−1.30***	−1.30***
	(0.11)	(0.11)	(0.11)
atanhrho_12	0.25	0.24	0.27*
	(0.16)	(0.16)	(0.16)
No. of observations	163	163	163
Wald $chi^2(15)$	870.5	868.3	
Prob > chi2	0.00	0.00	0.00
Log pseudolikelihood	−181.5	−180.8	

Values in parentheses are clustered standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

References

Abay, K., Abdelfattah, L., Breisinger, C., Glauber, J., Laborde, D., 2022. The Russia-Ukraine Crisis Poses a Serious Food Security Threat for Egypt. IFPRI Blog : Issue Post. https://www.ifpri.org/blog/russia-ukraine-crisis-poses-serious-food-security-threat-egypt.

Aksoy, M.A., Isik-Dikmelik, A., 2008. Are low food prices pro-poor? Net food buyers and sellers in low-income countries. Journal of Rural Mental Health 32 (2), 46–79. https://doi.org/10.1037/h0095951.

Araujo-Enciso, S.R., Fellmann, T., Santini, F., M'barek, R., 2017. Eurasian grain markets in an uncertain world: a focus on yield variability and harvest failures in Russia, Ukraine and Kazakhstan and their impact on global food security. In: Gomez y Paloma, S., Mary, S., Langrell, S., Ciaian, P. (Eds.), The Eurasian Wheat Belt and Food Security. Springer International Publishing, pp. 247–257. https://doi.org/10.1007/978-3-319-33239-0_15.

Balagtas, J.V., Bhandari, H., Cabrera, E.R., Mohanty, S., Hossain, M., 2014. Did the commodity price spike increase rural poverty ? Evidence from a long-run panel in

long-run panel in Bangladesh. Agric. Econ. 45 (3), 303–312. https://doi.org/10.1111/agec.12066.
Baquedano, F.G., Liefert, W.M., 2014. Market integration and price transmission in consumer markets of developing countries. Food Pol. 44, 103–114. https://doi.org/10.1016/j.foodpol.2013.11.001.
Barrett, C.B., Dorosh, P.A., 1996. Farmers' welfare and changing food prices : nonparametric evidence from rice in Madagascar. Am. J. Agric. Econ. 78 (3), 656–669. https://doi.org/10.2307/1243283.
Baudron, F., Ndoli, A., Habarurema, I., Silva, J.V., 2019. How to increase the productivity and profitability of smallholder rainfed wheat in the Eastern African highlands? Northern Rwanda as a case study. October 2018 Field Crop. Res. 236, 121–131. https://doi.org/10.1016/j.fcr.2019.03.023.
Bechdol, B., Glauber, J., Dozba, T., Welsh, C., 2022. Agriculture and Food Security: Casualties of the War in Ukraine. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/220317_Welsh_Food_Ukraine.pdf?vXxJNXSAEmiyeqBh.hBYer4LRlp_WMlC.
Bentley, A.R., Donovan, J., Sonder, K., Baudron, F., Lewis, J.M., Voss, R., Rutsaert, P., Poole, N., Kamoun, S., Saunders, D.G.O., Hodson, D., Hughes, D.P., Negra, C., Ibba, M.I., Snapp, S., Sida, T.S., Jaleta, M., Tesfaye, K., Becker-Reshef, I., Govaerts, B., 2022. Near- to long-term measures to stabilize global wheat supplies and food security. Nature Food 3 (7), 483–486. https://doi.org/10.1038/s43016-022-00559-y.
Bruinsma, J., 2009. The resource outlook to 2050: by how much do land, water use and crop yields need to increase by 2050?. In: In *Paper Presented at the Export Meeting on How to Feed the World in 2050* https://doi.org/10.1007/978-3-642-41714-6_180309, 24-26, June).
Ceballos, F., Hernandez, M.A., Minor, N., Robles, M., 2016. Transmission of food price volatility from international to domestic markets: evidence from Africa, Latin America and South Asia. In: Kalkuhl, M., Von Braun, J., Torero, M. (Eds.), Food Price Volatility and its Implications for Food Security and Policy. Springer International Publishing AG Switzerland, pp. 303–328.
Chikava, E., 2022. The World Food System Is under Threat. It Doesn't Have to Be that Way. Bill & Melinda Gates Foundation. https://www.gatesfoundation.org/ideas/articles/war-in-ukraine-and-global-food-crisis.
Clapp, J., Cohen, M.J., 2009. The Global Food Crisis: Governance Challenges and Opportunities. Wilfrid Laurier Univ. Press.
Conforti, P., 2004. Price transmission in selected agricultural markets. In: FAO Commodity and Trade Policy Research Working. *Paper* (No. 7; FAO Commodity and Trade Policy Research Working Paper, Issue 7). https://www.fao.org/3/j2730e/j2730e.pdf.
de Hoyos, R.E., Medvedev, D., 2011. Poverty effects of higher food prices: a global perspective. Rev. Dev. Econ. 15 (3), 387–402. https://doi.org/10.1111/j.1467-9361.2011.00615.x.
Deininger, K., Byerlee, D., Lindsay, J., Norton, A., Selod, H., Stickler, M., 2011. Rising Global Interest in Farmland: Can it Yield Sustainable and Equitable Benefits. The International Bank for Reconstruction and Development/The World Bank. https://documents1.worldbank.org/curated/en/998581468184149953/pdf/594630PUB0ID1810Box358282B01PUBLIC1.pdf.
Dixon, J., 2007. The Economics of Wheat: research challenges from field to fork. In: Buck, H.T., Nisi, J.E., Salomón, N. (Eds.), Wheat Production in Stressed Environments, Developments in Plant Breeding, 12. Springer, pp. 9–22. https://doi.org/10.1007/1-4020-5497-1_2.
Dixon, J., Braun, H.-J., Kosina, P., Crouch, J., 2009. *Wheat Facts and Futures 2009*. International Maize and Wheat Improvement Center (CIMMYT). https://repository.cimmyt.org/handle/10883/1265.
Douglas, R., 2022. Ukraine war poses growing threat to global food security. Sci Dev Net: Bringing Sci. Dev. Togeth. through News & Anal. https://www.scidev.net/global/news/ukraine-war-poses-growing-threat-to-global-food-security/, 2022. (Accessed 24 March 2022).
D'Souza, A., Jolliffe, D., 2012. Rising food prices and coping strategies: household-level evidence from Afghanistan. J. Dev. Stud. 48 (2), 282–299. https://doi.org/10.1080/00220388.2011.635422.
Erenstein, O., Chamberlin, J., Sonder, K., 2021. Estimating the global number and distribution of maize and wheat farms. Global Food Secur. 30 (May), 100558 https://doi.org/10.1016/j.gfs.2021.100558.
Erenstein, O., Jaleta, M., Mottaleb, K.A., Sonder, K., Donovan, J., Braun, H.-J., 2022. Wheat improvement: food security in a changing climate. In: Reynolds, M.P., Braun, H.-J. (Eds.), Wheat Improvement: Food Security in a Changing Climate. Springer International Publishing. https://doi.org/10.1007/978-3-030-90673-3.
FAO, 2011. *Price Volatility and Food Security: A Report by the High Level Panel of Experts on Food Security and Nutrition* (Issue July). https://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE-price-volatility-and-food-security-report-July-2011.pdf.
FAO, 2022. Impact of the Ukraine-Russia Conflict on Global Food Security and Related Matters under the Mandate of the Food and Agriculture Organization of the United Nations *(FAO)* (Issue 8 April 2022). https://reliefweb.int/sites/reliefweb.int/files/resources/EN_125.pdf.
FAO, I.F.A.D., UNICEF, W.F.P., WHO, 2020. The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets. In: The State of Food Security and Nutrition in the World 2020. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ca9692en/ca9692en.pdf.
FAOSTAT, 2022a. *FAOSTAT, Crops*. Food and Agriculture Organization of the United Nations, Database on Crops. https://www.fao.org/faostat/en/#data.
FAOSTAT, 2022b. *New Food Balances*. Food Agric. Organ. United Nations, Online Database on Food Balance. http://www.fao.org/faostat/en/#data/FBS.
FAOSTAT, 2022c. *Producer prices- Annual*. Faostat; Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/faostat/en/#data/PP.
Fischer, G., Shah, M., 2010. *Farmland Investments and Food Security: Report prepared under World Bank IIASA Contract - Lessons for the Large-Scale Acquisition of Land from a Global Analysis of Agricultural Land Use* (No. 64445; Part 2: Statistical Annex: Farmland Investments and Food Security, Issue August). https://documents1.worldbank.org/curated/en/884731468221080363/pdf/644450WP00publ00Security0BOX361537B.pdf.
October 1 Gettleman, J., Manik, J.A., Raj, S., 2019. India Isn't Letting a Single Onion Leave the Country. The New York Times. https://www.nytimes.com/2019/10/01/world/asia/india-modi-onion-prices.html.
Glauber, J., Laborde, D., 2022a. How Will Russia's Invasion of Ukraine Affect Global Food Security? IFPRI Blog : Issue Post. https://www.ifpri.org/blog/how-will-russias-invasion-ukraine-affect-global-food-security.
Glauber, J., Laborde, D., 2022b. How Will Russia's Invasion of Ukraine Affect Global Food Security?.
Government of India, 2007. Ban/restriction on export of non-basmati rice - clarification regarding. Agric. Proc. Food Prod. Exp. Dev. Author. Directorate General of Foreign Trade, Ministry of Commerce & Industry https://apeda.gov.in/apedawebsite/Latest_Notification/Non-Basmati.html, 2007. (Accessed 27 September 2019).
Greb, F., Jamora, N., Mengel, C., von Cramon-Taubadel, S., Wurriehausen, N., 2012. Price transmission from international to domestic markets. In: Rural Policies Thematic Group of ARD (RPTG), Development and Research Group's Agriculture and Rural Development (DECAR), and Poverty Reduction and Equity Unit (PRMPR). https://doi.org/10.1596/24054.
Green, R., Cornelsen, L., Dangour, A.D., Turner, R., Shankar, B., Mazzocchi, M., Smith, R. D., 2013. The effect of rising food prices on food consumption: systematic review with meta-regression. BMJ 346, 1–9. https://doi.org/10.1136/bmj.f3703.
Headey, D., Hirvonen, K., 2022. A food crisis was brewing even before the Ukraine war - but taking these three steps could help the most vulnerable. IFPRI. Blog : Issue Post. https://www.ifpri.org/blog/food-crisis-was-brewing-even-ukraine-war—taking-these-three-steps-could-help-most-vulnerable. (Accessed 29 March 2022).
Hertel, T.W., Winters, L.A., 2006. In: Hertel, T.W., Winters, L.A. (Eds.), Poverty & the WTO: Impacts of the Doha Development Agenda, Issue 1). Palgrave Macmillan and the World Bank. https://doi.org/10.1093/erae/jbn008.
Ianchovichina, E.I., Loening, J.L., Wood, C.A., 2014. How vulnerable are arab countries to global food price shocks? J. Dev. Stud. 50 (9), 1302–1319. https://doi.org/10.1080/00220388.2014.928698.
IPCC, 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In: Shukla, P.R., Skea, J., Buendia, E. C., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Pereira, J.P., Vyas, P., Huntley, E., et al. (Eds.), Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Intergovernmental Panel on Climate Change, Geneva, pp. 131–247. https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf. (Accessed 24 September 2022).
Ivanic, M., Martin, W., 2008. Implications of higher global food prices for poverty in low-income countries. Agric. Econ. 39 (Suppl. 1), 405–416. https://doi.org/10.1111/j.1574-0862.2008.00347.x.
Ivanic, M., Martin, W., Zaman, H., 2012. Estimating the short-run poverty impacts of the 2010-11 surge in food prices. World Dev. 40 (11), 2302–2317. https://doi.org/10.1016/j.worlddev.2012.03.024.
Kliger, R., 2008. Cairo Grappling with Bread Crisis (2008, March 17). *The Jerusalem Post*. http://www.jpost.com/Middle-East/Cairo-Grappling-with-Bread-Crisis.
Kron, J., 2011. Protests in Uganda over Rising Prices Grow Violent. April 21). The New York Times. April 21, 2011. https://www.nytimes.com/2011/04/22/world/africa/22uganda.html.
Lokshin, M., Ravallion, M., 2004. Gainers and losers from trade reform in Morocco. In: In the Policy Research Working Paper Series (No. 3368, 3368. WPS. http://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-3368.
Mason, N.M., Jayne, T.S., Shiferaw, B., 2015. Africa's rising demand for wheat : trends, drivers, and policy implications. Dev. Pol. Rev. 33 (5), 581–613.
Mazzocchi, M., Shankar, B., Traill, W.B., 2012. *The development of Global Diets since ICN 1992: Influences of Agri-Food Sector Trends and Policies* (No. 34. FAO Commodity and Trade Policy Research Working Paper). https://www.fao.org/3/ap625e/ap625e.pdf.
Menon, S., 2022. India Wheat Export Ban : Why it Matters to the World. BBC News. https://www.bbc.com/news/world-asia-india-61590756.
Minot, N., 2010. Transmission of world food price changes to African markets and its effect on household welfare. In: In Paper Prepared for "Food Price Variability: Causes, Consequences, and Policy Options" on 25-26 January 2010 in Maputo, Mozambique (Issue January 2010). https://ebrary.ifpri.org/digital/collection/p15738coll5/id/738.
Minot, N., Goletti, F., 2000. Rice Market Liberalization and Poverty in Viet Nam. https://web.worldbank.org/archive/website00519/WEB/PDF/MINOT200.PDF.
Mottaleb, K.A., Rahut, D.B., Kruseman, G., Erenstein, O., 2018a. Wheat production and consumption dynamics in an asian rice economy: the Bangladesh case. Eur. J. Dev. Res. 30 (2), 252–275. https://doi.org/10.1057/s41287-017-0096-1.
Mottaleb, K.A., Rahut, D.B., Kruseman, G., Erenstein, O., 2018b. Evolving food consumption patterns of rural and urban households in developing countries. Br. Food J. 120 (2), 392–408. https://doi.org/10.1108/BFJ-12-2016-0620.
Mottaleb, K.A., Sonder, K., Ridaura, L.S., Frija, A., 2021. Wheat Consumption Dynamics in Selected Countries in Asia and Africa: Implications for Wheat Supply by 2030 and 2050. No. 2; Integrated Development Program Discussion Paper). https://repository.

cimmyt.org/bitstream/handle/10883/21871/64912.pdf?sequence=1&isAllowed=y.
Mundlak, Y., Larson, D.F., 1992. On the transmission of world agricultural prices. World Bank Econ. Rev. 6 (3), 399–422. https://doi.org/10.1093/wber/6.3.399.
Nagarajan, S., 2005. Can India produce enough wheat even by 2020. Curr. Sci. 89 (9), 1467–1471. https://www.jstor.org/stable/24110907.
Preckel, P.V., Hertel, T.W., 2007. *Poverty Analysis Using an International Cross-Country Demand System* (No. 4285. Policy Research Working Paper, Issue July). https://openknowledge.worldbank.org/bitstream/handle/10986/7476/wps4285.pdf?sequence=1&isAllowed=y.
Quiroz, J., Soto, R., 1995. International price signals in agricultural prices: do governments care?. In: Documento de investigacion, 88 Documento de Investigación. Issue 562. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:International+Price+Signals+in+Agricultural+Prices+:+Do+Governments+Care+?#0.
Rattner, N., Barnett, A., 2022. March 19). *Russia-Ukraine War Adds Pressure to Already High Food Prices. Threatening Food Security for Millions*. 22. https://www.wsj.com/articles/russia-ukraine-war-adds-pressure-to-already-high-food-prices-threatening-food-security-for-millions-11647691202.
Ravallion, M., 1990. Rural welfare effects of food price changes under induced wage responses: theory and evidence for Bangladesh. Oxf. Econ. Pap. 42 (2), 574–585. https://doi.org/10.1093/oxfordjournals.oep.a041964.
Roodman, D., 2011. Fitting fully observed recursive mixed-process models with cmp. STATA J.: Prom. Commun. Statist. Stata 11 (2), 159–206. https://doi.org/10.1177/1536867X1101100202.
Roser, M., 2019. The short history of global living conditions and why it matters that we know it. Our World In Data. https://ourworldindata.org/a-history-of-global-living-conditions-in-5-charts?linkId=62571595. (Accessed 7 November 2019).
Sabaghi, D., 2022. How the Ukraine war impacts food security in MENA. Polit. Today. March 21, 2022. https://politicstoday.org/ukraine-war-food-security-mena/.
Seale, J., Regmi, A., Bernstein, J., 1904. Electronic Report from the Economic Research Service International Evidence on Food Consumption Patterns, 43.
Shewry, P.R., 2009. Wheat. J. Exp. Bot. 60 (6), 1537–1553. https://doi.org/10.1093/jxb/erp058.
Shiferaw, B., Smale, M., Braun, H., Duveiller, E., Reynolds, M., Muricho, G., 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Secur. 5 (3), 291–317. https://doi.org/10.1007/s12571-013-0263-y.
Silva, J.V., Reidsma, P., Baudron, F., Jaleta, M., Tesfaye, K., van Ittersum, M.K., 2021. Wheat yield gaps across smallholder farming systems in Ethiopia. Agron. Sustain. Dev. 41 (1), 12. https://doi.org/10.1007/s13593-020-00654-z.
Smaller, C., 2022. Overcoming the threats to global food systems from Russia's invasion of Ukraine. In: IFPRI Blog : Guest Post. https://www.ifpri.org/blog/overcoming-threats-russias-invasion-ukraine-poses-global-food-systems.
Sneyd, L.Q., Legwegoh, A., Fraser, E.D.G., 2013. Food riots: media perspectives on the causes of food protest in Africa. Food Secur. 5 (4), 485–497. https://doi.org/10.1007/s12571-013-0272-x.
The Associated Press, 2022. Ukraine Bans Exports of Wheat, Oats and Other Food Staples. March 9), 9–11. https://abcnews.go.com/International/wireStory/ukraine-bans-exports-wheat-oats-food-staples-83337319.
Ulimwengu, J.M., 2009. How Does Food Price Increase Affect Ugandan Households ? *Food Policy*. July. http://www.ifpri.org/publication/how-does-food-price-increase-affect-ugandan-households.
UNCTAD, 2008. The least developed countries report 2008: growh, poverty and the tems of development partnership. In: United Nations Conference on Trade and Development. United Nations Publication. https://unctad.org/system/files/official-document/ldc2008_en.pdf.
United Nations, 2022a. Goal 2 : Zero Hunger COVID-19 Response. Sustainble Development Goals. https://www.un.org/sustainabledevelopment/hunger/.
United Nations, 2022b. UN Comtrade: Internaitonal Trade Statistics. Department of Economics and Social Affairs, Statistics Division, Trade Statistics, United Nations. https://comtrade.un.org/data.
USDA, 2022. USDA Foreign Agricultural Service. United States Department of Agriculture (USDA), Foreign Agricultural Service (FAS). https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery.
von Grebmer, K., Bernstein, J., Delgado, C., Smith, D., Wiemers, M., Schiffer, T., Hanano, A., Towey, O., Chéilleachair, R.N., Foley, C., Gitter, S., Ekstrom, K., Fritschel, H., 2021. *Global hunger Index: Hunger and Food Systems in Conflict Settings* (Issue October), 2021. https://www.globalhungerindex.org/pdf/en/2021.pdf.
WBGU, 2020. Flagship Report: Rethinking Land in the Anthropocene: from Separation to Integration. German Advisory Council on Global Change (WBGU). https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/hg2020/pdf/WBGU_HG2020_en.pdf.
World Bank, 2018. Poverty and Shared Prosperity 2018: Piecing Together the Poverty and Puzzle. World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/30418/9781464813306.pdf.
World Bank, 2021. *DataBank: Population estimates and Projections*. Population Estimates and Projections Resource Type: Query Tool. https://databank.worldbank.org/reports.aspx?source=Health Nutrition and Population Statistics: Population estimates and projections.
World Bank, 2022. *World Development Indicators: Data Bank*. Data Bank, World Development Indicators. https://databank.worldbank.org/source/world-development-indicators#.
World Bank Group, 2022. April 2022. Commodity Markets Outlook: the Impact of the War in Ukraine on Commodity Markets, 1. Issue January). https://openknowledge.worldbank.org/bitstream/handle/10986/37223/CMO-April-2022.pdf.
Zaki, S.A., Chaaban, J., Nasreddine, L., Chalak, A., 2006. The impact of food price increases on nutrient intake in Lebanon. Agric. Food Econ. 9 (7), 921–927. https://doi.org/10.1017/PHN2005921.
Zerbe, N., 2009. Setting the global dinner table. Exploring the limits of the marketization of food security. In: The Global Food Crisis. Governance Challenges and Opportunities. The Centre for International Governance Innovation {&} Wilfrid Laurier University Press, Waterloo.