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# Global food stability and its socio-economic determinants towards sustainable development goal 2 (Zero Hunger)

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## Abstract

Food security is guaranteed only when unexpected shocks, e.g., epidemics, economic crises, and extreme climates can be well responded to the stable food supply. Food stability, which is not exclusive of the status that we have enough food stock to satisfy a population's food demand to avoid people from hunger for a certain period until the regular food supply recovers, has never been quantified. Here, we propose a new metric, the ratio of stock to demand, to quantify how domestic food consumption need of a population can be satisfied by the domestic food stock. This study collects the data available for 117 economies from 1991 to 2018 to analyze the grain stock-demand ratio (GSDR) and its determinants of the world. In terms of GSDR, global food stability has increased. In particular, the increased stability found expression in Asia and Africa. The increased stability was mainly driven by the growth of grain stock-production ratio (GSPR) and grain cropping yield (GCY) most significantly from 2000 to 2010 and the decrease of average labor input in unit agricultural land (ALI) majorly from 1991 to 2000. Meanwhile, GSDR was pulled down significantly by the sharp fall of grain crop land (% of total agricultural land) (GCL) from the year 1991 to 2000 and continuous decrease of employment in agriculture (% of total employment) (EIA) particularly from 2000 to 2018. Based on the results, policy suggestions are proposed towards sustainable development goal 2 (Zero Hunger).

**KEYWORDS**
food security, food stability, sustainable development goal 2, socio-economic determinants

## 1 | INTRODUCTION

The UNBC (1987) defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." The Millennium Summit (2000) led to the elaboration of eight MDGs to reduce extreme poverty by 2015. The United Nations (2015) Sustainable Development Summit subsequently adopted the 2030 Agenda for Sustainable Development, with 17 SDGs at its core. SDGs have been researched in many dimensions, e.g., carbon emission reduction (Erdoğan et al., 2021; Ma et al., 2022), air pollutants (Chen et al., 2022; Zhao et al., 2021), and health systems (Asi & Williams, 2018; Shuai et al., 2022). Food security has played a fundamental role in supporting the global SDGs, particularly SDG-2 (Zero Hunger) (Erdogan, 2022). The FAO (2003) defined food security as a status that "people always have physical, social, and economic access to sufficient, safe, and nutritious food that satisfies their food preferences and dietary needs for an active and healthy life". To be food secure, four dimensions should be well guaranteed: the availability of sufficient quantities of food of appropriate quality supplied through domestic production or imports (Availability); access by individuals to adequate resources for acquiring appropriate foods for a nutritious diet (Access); utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met (Utilization); a stable status that a population, household or individual must have access to adequate food at all times (Stability) (FAO, 2006).

  

However, recent evidences show that many people in the world are still suffering from hunger and food crisis (FAO et al., 2021). FAO et al. (2021) assessed the state of food security for 2020, showing hunger still affects 21.0 percent of the population in Africa, 9.0 percent in Asia and 9.1 percent in Latin America and the Caribbean. In the meantime, FAO et al. (2021) highlighted the challenges that between 720 and 811 million people in the world faced hunger in 2020, which is between 118 and 161 million more people than that in 2019. Understanding the global food stability patterns and spatiotemporal variations is crucial for mitigating food insecurity. Currently, a plethora of research has studied the food security statuses and determinants. The existing studies on food security status and determinants can be categorized to two types. One is the food security of farming and rural individuals and households (e.g., Bolarinwa et al., 2020; Ingutia & Sumelius, 2022; Omotesho et al., 2016), which considers how their food amount, access, nutrition, and stable supply are affected by their characteristics and environment. The other is the food security statuses and their influencing factors in terms of regions, involving a certain country (e.g., Ahmed et al., 2017; Bashir et al., 2012; Bolarinwa et al., 2020), particular part of a country, or community (e.g., Akukwe, 2020; Anand et al., 2019; Obayelu, 2012). Accordingly, the studies on regional food security mainly consider how it was affected by the climate change, social economic development, and geographical features. Food security research from a global perspective could be found mainly in a qualitative way. For example, Poudel and Gopinath (2021) conducted comparative analysis among the indicator systems developed by different organizations, i.e., FAO, UNDP, IFPRI and USDA through file analysis; Bashir and Schilizzi (2013) compared food security statuses between Africa and Asia through literature review; and reviews also involved climatic factors (Schmidhuber & Tubiello, 2007; Wheeler & von Braun, 2013), supply-side, demand-side and market-side determinants (Grote, 2014) on global food security. Those studies were often conducted through literature review and file analyses, which are pure qualitative research, meaning a lack of quantitative analyses.

The aim of this study is to quantify how global food security has been influenced by various socio-economic factors. The stock-demand ratio, here indicating the ratio of the food stocked amount to the food demanded amount for a population, can be used as a proxy for quantifying food stability. This study selected grain, which is energy-giving raw materials to avoid people from hunger, to analyze the global food stability status and its socio-economic determinants with the available data. The innovation of the study may lie in the use of quantitative approaches to discover global food stability statuses and the establishment of a new metric to measure global grain food stability, i.e., national GSDR. The results of the study provide policy makers of national government and international organizations with a fuller picture of the global food stability, its socio-economic determinants, and targeted policy suggestions towards accelerating the progress directly on the SDG-2.

## 2 | LITERATURE REVIEW

The SDGs established by United Nations have emphasized the urgent need to tackle food insecurity in achieving human rights by the year 2030. Most relatedly to food security is the second (SDG-2: Zero Hunger), i.e., 'end hunger, achieve food security, improved nutrition, and promote sustainable agriculture'. The studies on food security can be summarized to three categories, i.e., at household level, at the regional or national level, and at global level, previous studies were conducted among different targeted populations, research methods, and representative crops though. This section reviews studies on food security and its determinants at the three levels, and then explains why grain is selected as the representative food type for guaranteeing global food stability.

### 2.1 | Household food security and its determinants

Studies have been conducted mainly through social surveying and literature review, which identified a variety of food security determinants at the individual or household level. For example, Bezu (2018) conducted household-level survey and discovered that drought, population pressure, backward agriculture, land degradation, poor infrastructure facility and low level of off-farm/non-farm activities had jeopardized the food security of nearly 33 million Ethiopian people. Rasheed et al. (2022) selected Pakistan households as the research objects and showed their food security statuses were significantly improved by education level, livestock breeding, foreign remittances, and family head gender; whilst poverty showed a negative and significant impact on food security. Reincke et al. (2018) conducted household survey and semi-structured interview and identified the food security determinants in the context of cassava, a staple food in Tanzania to avoid people from hunger, including markets, food processing, social perception, and knowledge level. Household food security has been studied in the context of the Sub-Saharan Africa (Drammeh et al., 2019), Bangladesh (Kundu et al., 2021), and Ethiopia (Abebaw & Betru, 2019), which commonly identified poverty, income, education, household size, employment status, age, gender of household head and food price as the determinants, although food security in rural and urban households are influenced to different degrees by those socioeconomic factors (Frimpong & Asuming-Brempong, 2013).

### 2.2 | Regional or national food security and its determinants

At regional or national level, the determinants of food security tend to be macro than those at the individual and household level in the literature. The determinants at the regional or national level were identified in a plethora of previous research. For example, Lv et al. (2022) reorganized the social, economic, agricultural, climatic factors of food security in China, which varied substantially with the regional scale: the added value of tertiary industry plays important role at the prefecture level, and gross agricultural output value dominates the provincial and national levels. Tiwari and Joshi (2012) analyzed the natural and socio-economic factors influencing food security in the Himalayas combining the socio-economic surveys, satellite data and other information and found that depletion of natural resources and changing precipitation pattern were the inhibiting determinants. Pakravan-Charvadeh et al. (2020) studied the determinants of food security in Iran and found government policy and income distribution played important roles. Enilolobo et al. (2022) found environmental issues, e.g., acidic rain and emission of poisonous gases, were key factors affecting food security in the context of Nigeria. Galiev and Ahrens (2021) identified the determinants of the increase in food self-sufficiency in Russia over the past decade, and the labor productivity, crop yield productivity of livestock and poultry, total factor productivity were considered highly related with the national food production efficiency thus influencing the national food security. Previous studies also show the persistent and severe starvation, which is a substantial indicator for food security, in normal circumstances, could be mainly attributed to the holocaust, vulnerable social systems, environmental threats, global warming, and pesticides, decreased wages, and interrupted distribution networks (e.g., Sarkar et al., 2021).

### 2.3 | Potential factors influencing global food security

At global level, a large number of studies were conducted through qualitative approaches. Through literature review, Premanandh (2011) identified the determinants of global food security, which included population growth, land degradation, water scarcity and climate change and advocated the adoption of science-based technological innovations to address the food insecurity issues; and Fones et al. (2020) found the climate change boosted emerging pathogens, particularly fungi and oomycetes may cause the crop devastation thus threatening global food security. Through comparative analysis, Bashir and Schilizzi (2013) identified the differences of the statuses and particular determinants between a continent and another, and a few studies compare those among a few countries, including in Brazil, China, Japan, India, Malaysia, Mexico, and Nigeria (Dev & Zhong, 2015; Koizumi, 2013; Sharma & Gulati, 2015). Particularly, a few studies found China and India are different in their approaches to achieve food security (Sharma & Gulati, 2015), the impact of trade and stock management on national food security (Dev & Zhong, 2015), and national food security policies (Yu et al., 2015). During the pandemic, recent study showed the limiting food supply and access may persist longer as a combined effect of economic slowdown and increase in poverty owing to the COVID-19 on global food security (Udmale et al., 2020). Overall, the literature shows the current jigsaws (i.e., countries) of global food security are still in fragmented pieces, calling for more investigation to form a full picture. To sum up, quantitative analysis joining the fragmented factors is needed to discover the socio-economic driving mechanisms of global food security. Therefore, this study includes nearly as many countries as possible based on the data availability to quantitatively analyze the status and driving mechanisms of global food security so as to reflect a fuller picture.

### 2.4 | Grain stock and global food security

Food security, which was characterized with four dimensions: availability, access, utilization and stability (FAO, 2006). Using public food grain stocks to enhance food security had been a commonly used instrument in government responses to food crisis and food price spikes (World Bank, 2012). Grain, as the basis of providing calories, plays a crucial role in ensuring food security. Grains are well suited to be stored for long periods in silos since dry grains are more durable than meat, vegetables and staple foods, such as starchy fruits and tubers (Wessel, 1984). Also, grain is widely used in the food industry, for example, in the production of bakery products, groats, pasta, and also as the fodder of livestock (Ksenofontov et al., 2019). There are a large number of studies showing grain is closely related to food security. Storage of grain is also advocated as a security strategy for many countries and regions, such as Kazakhstan, China, Kenya, Middle East, North Africa, and Asia (Bruins & Bu, 2006; Tireuov et al., 2018; Wright & Cafiero, 2011; Zachary et al., 2015). For example, Rice serves as the basis of staple food for over half of the world population, particularly those in developing countries, so increasing rice yield is substantial for addressing food shortage, ensuring food security, and reducing poverty (Bandumula, 2018; Kumar & Kalita, 2017). Grain stock of a country has been regarded particularly important, thus lowering the risk of losing access to grains has played a pivotal role for global and national food security (Kumar & Kalita, 2017). While quantifying national food stability in the light of the SDG-2, this study proposed a new metric, i.e., GSDR, which indicates a country's ability to dissolve risk of losing access to food once sudden shocks (e.g., an economic or climatic crisis) or cyclical events (e.g., seasonal food insecurity) occur.

## 3 | METHODS AND DATA

This study aims to identify the statuses and determinants of food stability at the global level, focusing on the national grain food stability. The aim could be achieved mainly through two research steps. The first step is to identify the change of global food security over recent a few decades by measuring the GSA and GSDR (i.e., the proxies of food stability) of countries available of relevant data, and then classify the countries into different food-stability levels according to their annual GSDRs, which explicitly explains how much the local grain stock can satisfy the local grain demand in cases of sudden shocks, such as an economic crisis, climatic disasters, and cyclical food insecurity. The second step is to identify the determinants of the change of GSDR of each country during each decade, where the LMDI is used to factorize the changes in GSDRs through decomposition. Data are collected based on the need of the measurement and decomposition of the GSA, GSDR, and factors involved.

### 3.1 | Measuring food stability

In measuring food stability for a certain country, this study adopts the grain stock per capita and grain stock-demand ratio as the proxies. The GSA of country ($GSA_i$) can be measured with Equation (1); and GSDR for country i ($GSDR_i$) can be measured with Equation (2).

$$GSA_i = \frac{\sum_{j=1}^{j=n} GS_{ij}}{P_i} \tag{1}$$

$$GSDR_i = \frac{\sum_{j=1}^{j=n} GS_{ij}}{\sum_{j=1}^{j=n} D_{ij}} \tag{2}$$

Where $GS_{ij}$ is the annual ending stock of grain crop $j$ in country $i$, and $P_i$ is the population of country $i$, $D_{ij}$ is the annual consumption of grain crop $j$ in country $i$, which indicate the demand of grain crop $j$ in country $i$.

### 3.2 | Identifying determinants with LMDI

The previous studies investigating the factors influencing food security employed mainly two approaches: regression models (e.g., Lv et al., 2022; Reincke et al., 2018) and LMDI (e.g., Chen & Lu, 2018; Liu et al., 2013). The modeling goodness is largely affected by the explanatory variables and models input in the regression, which is not able to attribute all the change of food security to the explanatory variables, so that the residues, which shows the unexplained part of the change, exist. However, the LMDI, first proposed by Ang et al. (1998) to factorize changes in environmental indicators through decomposition, has been frequently used in previous studies on various areas, such as carbon emissions (Dong et al., 2019; Chen et al., 2020; Yan et al., 2022; Xiang et al., 2022; Zhang et al., 2022), energy consumption (Chen et al., 2021; Chen et al., 2020; Chen et al., 2022), and air pollution (Zhang et al., 2022). In food security, for example, it was used to identify the factors influencing the food security of Bangladesh, India and Myanmar (Chen & Lu, 2018) and grain production of a Chinese region at county level (Liu et al., 2013). Compared with various regression methods, LMDI is used to completely attribute the change of a dependent variable to all the selected explanatory variables with no residuals, which makes a part of the change remains unexplainable (Ang et al., 1998). Therefore, this study takes the advantages of LMDI to identify the determinants of GSDR.

According to the recent data availability, this study decomposes a country's GSDR change over three periods, i.e., 1991 to 2000, 2000 to 2010, and 2010 to 2018, respectively to the effects of the country's GSPR, GCY, GCL, $ALI^{-1}$, EIA, national employment rate (ER) and 1/(grain demand per capita) ($AD^{-1}$) of each country. The decomposition of any GSDR can be described with an identical relation, i.e., Equation (3).

$$\begin{aligned} GSDR &= \frac{GS}{GP} \times \frac{GP}{GCA} \times \frac{GCA}{AL} \times \frac{AL}{AE} \times \frac{AE}{E} \times \frac{E}{P} \times \frac{P}{D} \\ &= GSPR \times GCY \times GCL \times ALI^{-1} \times EIA \times ER \times AD^{-1} \end{aligned} \tag{3}$$

where GS is the national grain stock amount, GP is the national grain production amount, GCA is the national grain crop area, AL is the national agricultural land, AE is the agricultural employment, and E is the national total employment. According to the identical relation of LMDI method, GSDR can result from grain stock-production ratio ($GSPR = \frac{GS}{GP}$), grain crop yield ($GCY = \frac{GP}{GCA}$), grain crop land ($GCL = \frac{GCA}{AL}$), 1/(average labor input in agricultural land) ($ALI^{-1} = \frac{AL}{AE}$), employment in agriculture ($EIA = \frac{AE}{E}$), employment rate ($ER = \frac{E}{P}$), and 1/(grain demand per capita) ($AD^{-1} = \frac{P}{D}$). Therefore, the change of GSDR, i.e., $\Delta GSDR$ can be decomposed into the effects of these factors, i.e., GSDR changes caused by GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, i.e., c$\Delta GSDR_{GSPR}$, $\Delta GSDR_{GCY}$, $\Delta GSDR_{GCL}$, $\Delta GSDR_{ALI^{-1}}$, $\Delta GSDR_{EIA}$, $\Delta GSDR_{ER}$, and $\Delta GSDR_{AD^{-1}}$, which are described with equation (3).

$$\begin{aligned} \Delta GSDR &= GSDR^T - GSDR^0 \\ &= \Delta GSDR_{GSPR} + \Delta GSDR_{GCY} + \Delta GSDR_{GCL} + \Delta GSDR_{ALI^{-1}} \\ &\quad + \Delta GSDR_{EIA} + \Delta GSDR_{ER} + \Delta GSDR_{AD^{-1}} \end{aligned} \tag{4}$$

The effects of GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$ on the change of GSDR can be calculated with Equations (5)–(11), respectively. $GSDR^T$ and $GSDR^0$ indicate the GSDR for the target year and the base year, respectively.

The effect of GSPR:

$$\Delta GSDR_{GSPR} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{GSPR^T}{GSPR^0}\right) \tag{5}$$

The effect of GCY:

$$\Delta GSDR_{GCY} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{GCY^T}{GCY^0}\right) \tag{6}$$

The effect of GCL:

$$\Delta GSDR_{GCL} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{GCL^T}{GCL^0}\right) \tag{7}$$

The effect of $ALI^{-1}$:

$$\Delta GSDR_{ALI^{-1}} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{ALI^0}{ALI^T}\right) \tag{8}$$

The effect of EIA:

$$\Delta GSDR_{EIA} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{EIA^T}{EIA^0}\right) \tag{9}$$

The effect of ER:

$$\Delta GSDR_{ER} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{ER^T}{ER^0}\right) \quad (10)$$

and

The effect of $AD^{-1}$:

$$\Delta GSDR_{AD^{-1}} = \frac{GSDR^T - GSDR^0}{lnGSDR^T - lnGSDR^0} \times ln\left(\frac{AD^0}{AD^T}\right) \quad (11)$$

where the $GSPR^T$ and $GSPR^0$, $GCY^T$ and $GCY^0$, $GCL^T$ and $GCL^0$, $ALI^T$ and $ALI^0$, $EIA^T$ and $EIA^0$, $ER^T$ and $ER^0$, and $AD^T$ and $AD^0$ represent the GSPR, GCY, GCL, ALI, EIA, ER and AD for the target year and the base year, respectively.

### 3.3 | Data

This study collected data for GS, P, D, GP, GCA, AL, AE, and E in 1991, 2000, 2010, and 2018 from the databases of World Bank (2022) and USDA (2022), which are the original data for measuring food stability and identifying the determinants in the LMDI models. The year 2018 is selected as the ending year to guarantee as many countries as possible to be involved in the measurement and analysis. With the original data prepared, GSA and GSDR can be measured. Then, the data for the seven factors, i.e., GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, are ready for the decomposition analysis to fit LMDI models for the three periods, i.e., 1991 to 2000, 2000 to 2010, and 2010 to 2018. The years from 1991 to 2018 are selected because the data for the period is available to the largest extend, while that from 2019 to 2022 are insufficient for fitting the LMDI models. Further, the countries are selected based on the following criteria.

1. The countries should be available of data for the 4 years, i.e., 1991, 2000, 2010, and 2018, which are the time nodes for the LMDI models of the three periods.
2. The countries should have original data for the basic indicators, i.e., GS, P, D, GP, GCA, AL, AE, and E, which are used to generate the GSDR, GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER, and $AD^{-1}$ of both the target and base years.
3. The countries without complete data for basic indicators in any of the 4 years should be removed.

Eventually, this study remained 117 countries/economies which satisfy the requirements that all of them are available of complete original data.

## 4 | RESULTS AND DISCUSSIONS

### 4.1 | Evolution of global GSA

To reflect the global situations of the GSA, the median of the GSA of the involved countries are shown in Figure 1, indicating the number that the most population of countries' values draw near. Figure 1a is the full density curve of the GSA of the 117 economies, while Figure 1b only shows the distribution of countries falling in the 0–100 interval for clearer presentation. Figure 1b shows the change of GSA from 1991 to 2000 was not significant as most countries draw near 15 Kg/capita in the year 1991 and 14 Kg/capita in the year 2000. Particularly, from the density curves for 1991 and 2000, the percentage of countries in GSA lower than 30 Kg/capita decreased in the decade but that in GSA higher than 30 Kg/capita increased, which indicates the decade widened the gaps of GSA levels of the global countries. For the decade from 2000 to 2010, the improvement of the median GSA was very significant, changing from 14 Kg/capita to 24 Kg/capita, which means the world's GSA had largely improved. For the decade from 2010 to 2018, the median GSA improved from 24 Kg/capita to 30 Kg/capita, which means the GSA of most countries also increased in the decade. To sum up, the recent two decades, from 2001 to 2018, had witnessed a surge of GSA, which could increasingly or longer meet people's grain food demand.

### 4.2 | Evolution of global GSDRs

FAO identified 14% as the warning line and 18% as the baseline for indicating food security from the perspective of the food stock-demand ratio. In the light of the two lines, this study groups the GSDR to six intervals, which we name (60%–200%) as sufficient stock interval, (30%–60%) as adequate stock interval, (18%–30%) as base stock interval, (14%–18%) as warning stock interval, (5%–14%) as insecure stock interval, and (0%–5%) as dangerous stock interval. The number of countries whose GSDRs fall in the six intervals are presented in Table 1. It could be seen that the number of countries in the dangerous interval experienced continuous declination, from 49 countries in the dangerous stock interval in 1991 to nearly half level in 2018 (i.e., 26 countries). For insecure interval, the number of countries kept stable in the first two decades but surged in 2018, which means 2000 was the securest year considering the smallest number of countries fell in the insecure and dangerous intervals in the year. The year 2010 had the largest number of countries falling in the warning interval but the situation turned better in 2018; also, 2018 had the largest number of countries which reached the base level and above, which indicates 2018 basically witnessed the peak of basic food stability in terms of GSDR. For adequate and sufficient intervals of GSDR, the year 2010 experienced the most countries in the two upper levels of food security. The period from 2000 to 2010 witnessed the advancement particularly in Russian Federation and countries in Africa and Southeast Asia, significantly shown from the difference between the b and c facets in Figure 2. Overall, 2018 was the best year for countries to reach a baseline of food stability, while 2010 was the best year for countries reaching sufficient and adequate intervals.

The GSDRs of the 117 economies for the 4 years are plotted in Figure 2 with four global maps, respectively. Generally, the global food security in terms of GSDR is better in the 2010 s than 1990 s and 2010 s. The recent three decades also witnessed that Asia and

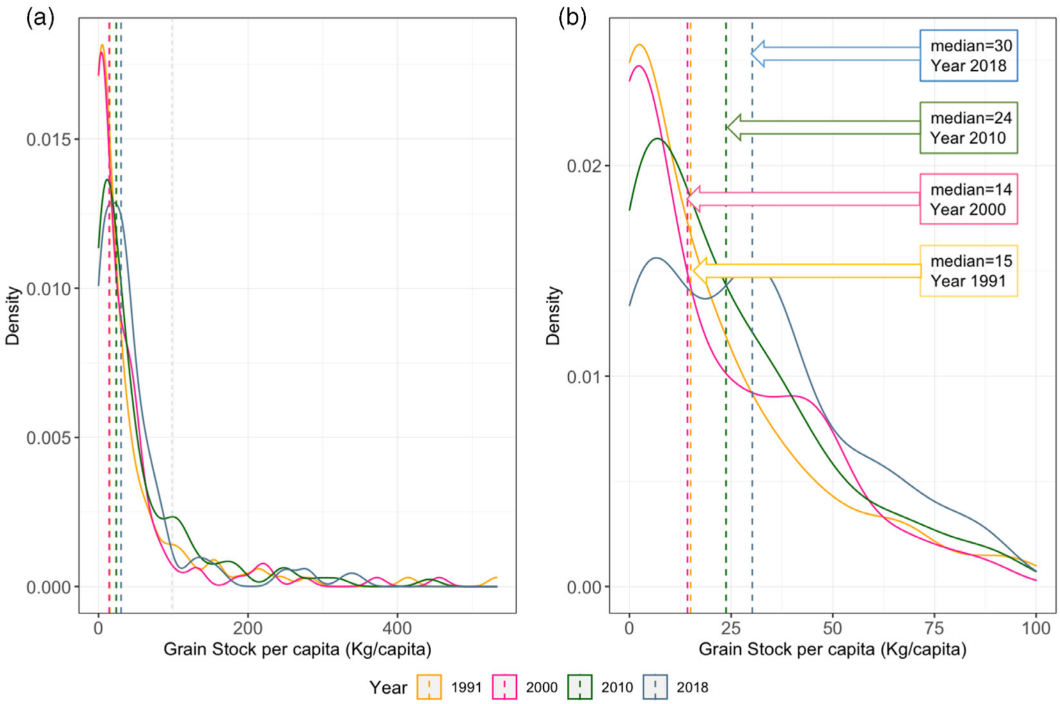


**FIGURE 1** The density curve of GSA in 1991, 2000, 2010 and 2018 for the 117 economies

**TABLE 1** Number of countries in six food stock intervals

| Year | Sufficient (60%–200%) | Adequate (30%–60%) | Base (18%–30%) | Warning (14%–18%) | Insecure (5%–14%) | Dangerous (0%–5%) |
|---|---|---|---|---|---|---|
| 1991 | 4 | 5 | 13 | 14 | 31 | 49 |
| 2000 | 4 | 5 | 17 | 6 | 36 | 48 |
| 2010 | 3 | 16 | 12 | 16 | 34 | 35 |
| 2018 | 3 | 4 | 26 | 11 | 46 | 26 |

Africa having become securer and securer in terms of GSDR, Southeast Asia and Africa are mostly below the warning line though; South American countries during the period generally have relative stable GSDRs, which are mostly below warning line except for Argentina; for North America, Canada has also been in a relatively adequate level of food security, USA experienced warning, base, and adequate stock intervals, and Mexico had been continuously below base line; for Europe, European Union has been experienced adequate stock interval in 1991 and turned to base stock interval since 2000. On one hand, there are a few countries obviously in relatively good food security status. For example, China can be obviously recognized as the most food security large-area country as 3 years are in sufficient stock interval, i.e. (60%–200%), and 1 year in the adequate stock interval, i.e. (30%–60%); Australia is also the large-area country of large GSDRs, i.e., the years 1991 and 2018 in the adequate stock interval and the years 2000 and 2010 in sufficient stock interval; Saudi Arabia lasted three decades' adequate food stock status; India experienced insecure stock interval but has fallen in the adequate stock interval from 2000 to 2018. On the other hand, there are also a few countries having insecure and dangerous grain stock performances. For example, Russian Federation experienced unstable gain stock, from warning, insecure, and adequate intervals to insecure status again; Mongolia is also obviously in the danger interval; and a large number of countries in Africa, e.g., Nigeria, Congo, and Libya are in insecure and dangerous intervals.

## 4.3 | Determinants of food security for each economy

The countries in insecure and dangerous intervals need particular attention and food security improvement, and those in secure statuses also provide experiences for the GSDR improvement. This study decomposed the factors of the GSDR improvement and declination for deepening the understanding of the determinants of global food security for the three decades. The results are shown in Figures 3–5 for 1991 to 2000, 2000 to 2010, and 2010 to 2018, respectively. The shaded countries, e.g., Angola, Belarus, Benin, and Chile, have no

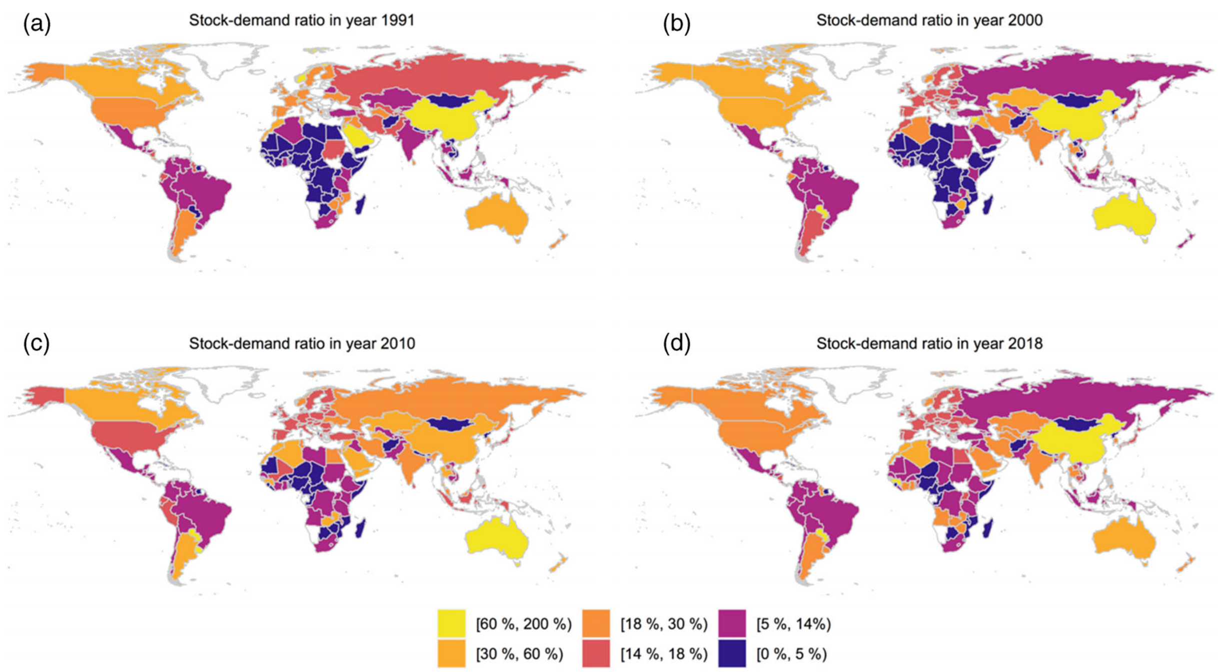


**FIGURE 2** Maps of grain stock-demand ratio in 1991, 2000, 2010 and 2018 for the 117 economies

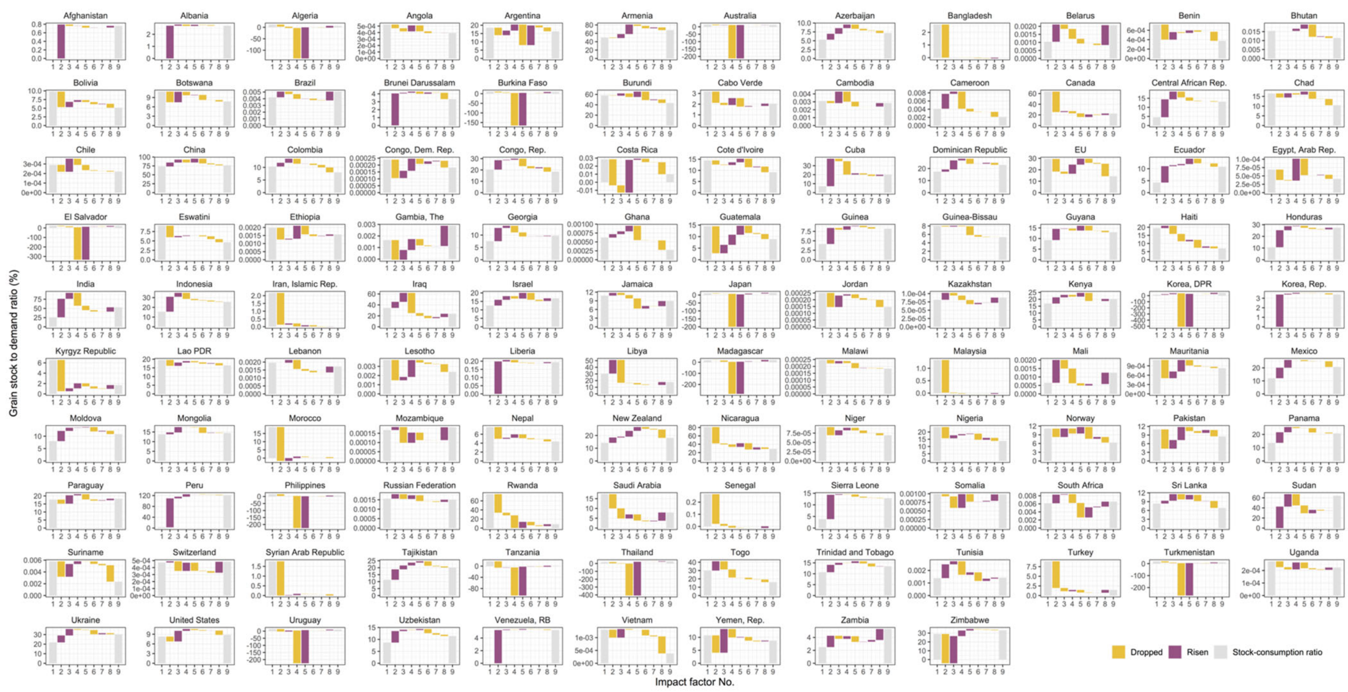


**FIGURE 3** GSDRs and factor-driven changes of the 117 economies from the year 1991 to 2000. (*Source*: No. 1 denotes the GSDR value in 1991, No.s 2, 3, 4, 5, 6, 7, 8 denote the effect of GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, respectively, and No. 9 denotes GSDR in 2000)

changes in the GSDRs and factors from the base year to the target year, so the GSDR was not changed or decomposable. In Figures 3–5, every facet is the LMDI decomposition for a certain country; the x-axis of each facet indicates the Impact factor No., where the GSDR for the base year, effects of the seven factors, i.e., GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, and GSDR for the target year are numbered as No.s 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively; and the y-axis of each facet is the dropped, risen and net GSDRs.

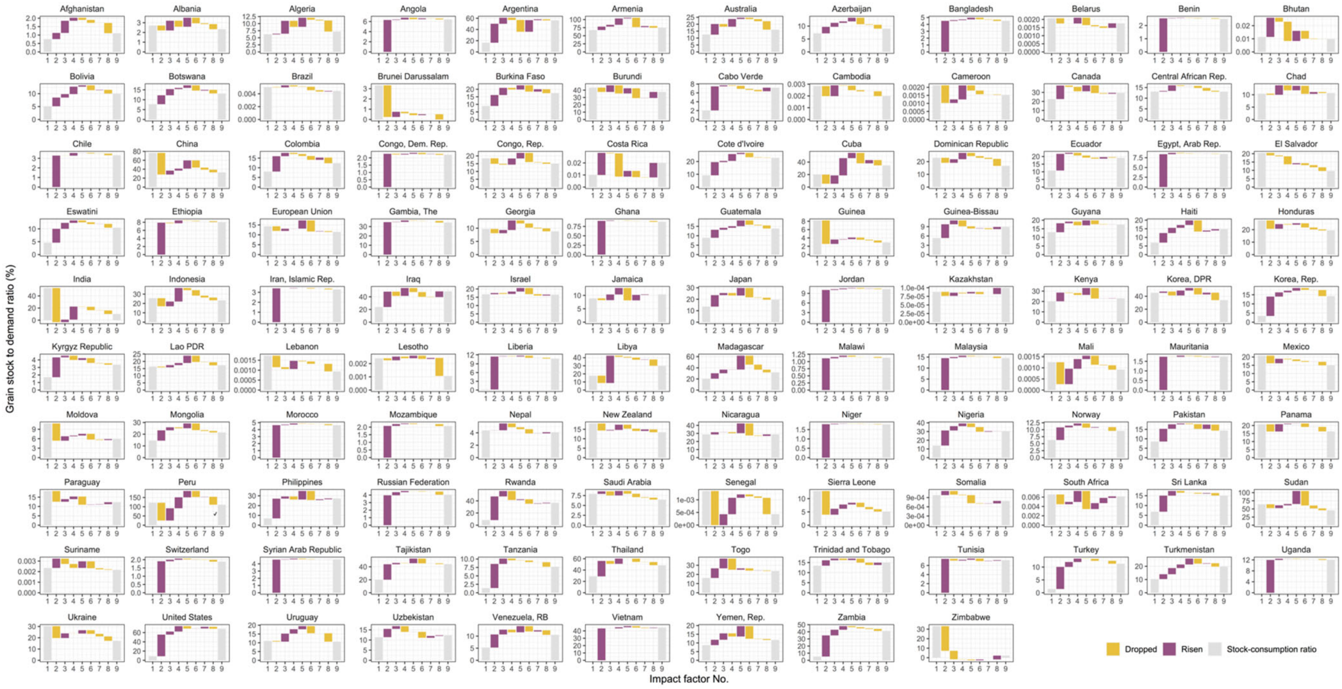


**FIGURE 4** GSDRs and factor-driven changes of the 117 economies from the year 2000 to 2010. (*Source*: No. 1 denotes the GSDR value in 2000, No.s 2, 3, 4, 5, 6, 7, 8 denote the effect of GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, respectively, and No. 9 denotes GSDR in 2010)

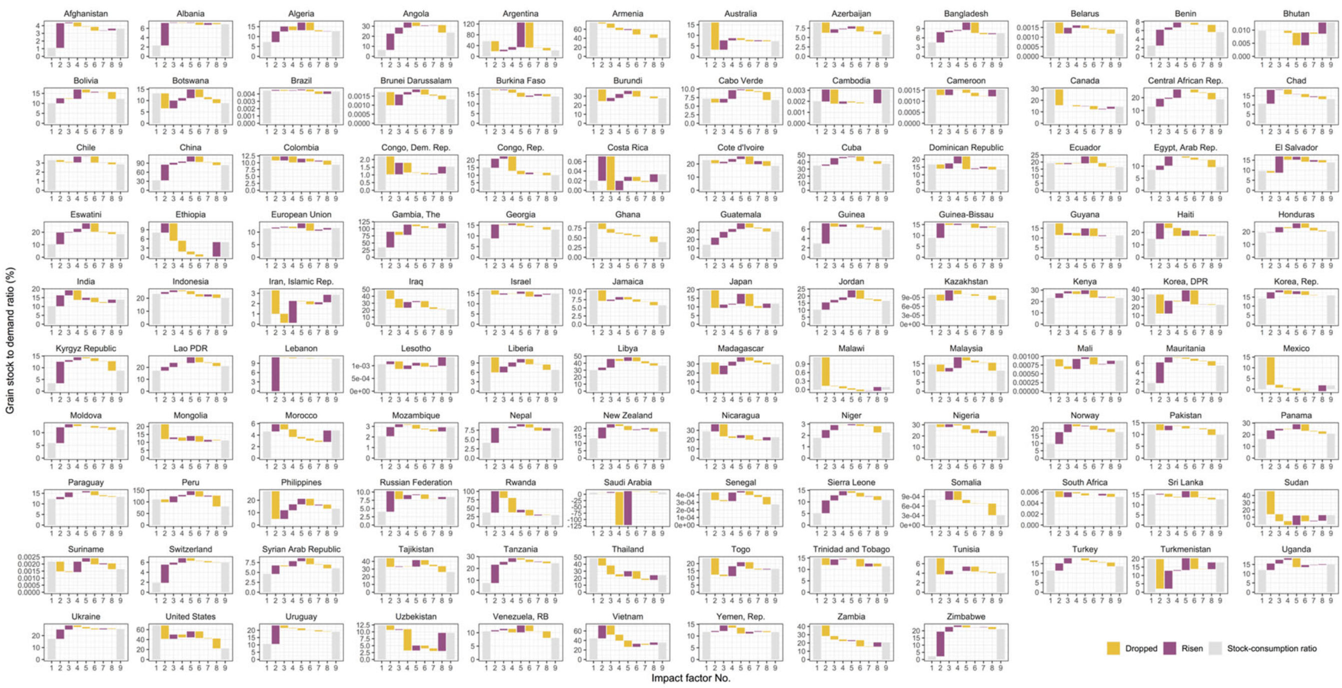


**FIGURE 5** GSDRs and factor-driven changes of the 117 economies from the year 2010 to 2018. (*Source*: No. 1 denotes the GSDR value in 2010, No.s 2, 3, 4, 5, 6, 7, 8 denote the effect of GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$, respectively, and No. 9 denotes GSDR in 2018)

## 4.4 | Determinants of food security by phase

To analyze the determinants at the global level, the effects and absolute effects of all the 117 economies are added up and shown in Table 2. The three phases had a few common or coherent patterns. First, the effects of GSPR, GCY, and $ALI^{-1}$ on GSDR sustained the increasing tendency from 1991 to 2018 according to Table 2, which can all be regarded as the driving determinants if the whole period is

**TABLE 2** Total and absolute effects (%) of the seven factors by three phases

| Phase | Effect | $\Delta GSDR_{GSPR}$ | $\Delta GSDR_{GCY}$ | $\Delta GSDR_{GCL}$ | $\Delta GSDR_{ALI^{-1}}$ | $\Delta GSDR_{EIA}$ | $\Delta GSDR_{ER}$ | $\Delta GSDR_{AD^{-1}}$ |
|---|---|---|---|---|---|---|---|---|
| 1991–2000 | Total | 68.48 | 133.87 | −3276.51 | 3157.88 | −112.13 | −18.36 | 45.27 |
| | Absolute | 846.93 | 355.92 | 3440.89 | 3353.49 | 187.28 | 56.31 | 225.21 |
| 2000–2010 | Total | 337.46 | 285.10 | 173.98 | 189.18 | −371.37 | −12.53 | −166.39 |
| | Absolute | 1040.75 | 352.81 | 346.45 | 325.59 | 420.49 | 77.61 | 232.41 |
| 2010–2018 | Total | 112.92 | 99.05 | −130.17 | 374.40 | −415.81 | −7.24 | −140.83 |
| | Absolute | 859.91 | 366.00 | 427.27 | 513.11 | 439.49 | 65.11 | 292.65 |

considered; second, GSPR in each phase experienced spiral rising instead of stable increment according to the third column of Table 2; third, the effect of EIA experienced continuous and accelerated drop according to the seventh column of Table 2; fourth, three decades witnessed a sustained but slight ER-driven drop of GSDR. However, it can be also seen from Table 2, the determinants for the three phases are different, which reflects on the determinants for a large group of economies in each phase. For the three phases, from a global perspective, the main drivers appear to be the increase of GSPR and decrease of ALI, and the main inhibitors are the decrease of GCL and EIA.

From 1991 to 2000, the GCL and $ALI^{-1}$ can be regarded as the determinants as the two factors to the largest extent influenced the change of the GSDR of the 117 countries according to their absolute effects; GCL is the largest inhibitor and $ALI^{-1}$ is the main driver, meaning the decrease of ALI drove the increase of GSDR, which indicate the global GSDR change occurred during the period was mainly associated with the large decrease of the percentage of agricultural land for grain crops and labor input in unit agricultural land. As shown in Figure 3, the tradeoff between the inhibiting effect of GCL and driving effect of the decrease of ALI exists in many countries, particularly Algeria, Australia, Burkina Faso, El Salvador, Egypt, Arab Rep., Japan, Korea (DPR), Madagascar, Philippines, Tanzania, Thailand, Turkmenistan, and Uruguay. These countries experienced both shrinkage of agricultural land for grain crops and decrease of labor input in unit agricultural land almost canceled the effect of each other in the decade.

From 2000 to 2010, Table 2 shows GSPR fluctuated widely but still the main driver and EIA as the main inhibitor according to their total and absolute effects, which implies the economies improved their annual grain stocks and shrink the percentage of employment in the agricultural sector. Although GSPR increased to a large extent indicated by the total effect, the great difference between the total and absolute effects indicates the 117 countries experienced imbalance in GSPR, i.e., a part of them had dramatically risen GSPR, at the same time, some countries had a sharp drop during not only this decade but also the other two decades. From Figure 4, the driving effect of GSPR is reflected significantly on a large number of countries, particularly Angola, Argentina, Bangladesh, Benin, Bhutan, Cabo Verde, Chile, Colombia, Congo (Dem. Rep.), Egypt, Arab Rep., Ethiopia, Gambia (The), Ghana, Iran, Islamic Rep., Jordan, Korea (Rep.), Kyrgyz Republic, Liberia, Malawi, Malaysia, Mauritania, Morocco, Mozambique, Niger, Nigeria, Norway, Russian Federation, Rwanda, Sri Lanka, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Tunisia, Turkey, Uganda, United States, Vietnam, and Zambia. The inhibiting effect of EIA is expressed particularly in Armenia, Congo (Rep.), Cuba, European Union, Haiti, Israel, Japan, Kenya, Madagascar, Nicaragua, Yemen (Rep.), and Sudan. The inhibiting effect of EIA is shown less significant than those of GSPR for individual economies.

From 2010 to 2018, the GSPR fluctuated widely but was not the largest driver if all the economies considered, EIA was the largest inhibitor, $ALI^{-1}$ showed to be the largest driver, i.e., the decrease of ALI was a main driver; the data implies the gain stock was unstable, the percentage of employment in the global agricultural sector continued shrinking, and labor input in unit agricultural land largely decreased again. Figure 5 shows GSPR, though not the determinant at the global level, is the main driver for part of the countries, including Afghanistan, Albania, Benin, China, India, Kyrgyz Republic, Lebanon, Mauritania, Moldova, New Zealand, Panama, Russian Federation, Rwanda, Switzerland, Tanzania, Ukraine, Uruguay, Vietnam, and Zimbabwe and also the main inhibitor for another part of the countries, including Australia, Congo (Dem. Rep.), Iran (Islamic Rep.), Japan, Korea (DPR), Malawi, Mexico, Mongolia, Philippines, Sudan, Sudan, Tunisia, Turkmenistan, and United States. The decrease of EIA inhibited and increase of ALI boosted the GSDR, which showed on many countries, including Algeria, Argentina, Bangladesh, Botswana, China, Ecuador, Eswatini, European Union, Guyana, Honduras, Japan, Jordan, Korea (DPR), Lao PDR, Panama, Philippines, Sri Lanka, Sudan, Thailand, Turkmenistan, and Venezuela (RB).

## 5 | POLICY IMPLICATIONS

During the three decades, the improvement of GSDR, which matters food security of each country could be attributed to the seven factors, particularly the major driving determinants for each decade, i.e., the increase of GSPR and decrease of ALI. The above results can imply how the determinants improved the global food stability and what we can do to seek for further improvement.

### 5.1 | How did the world improve its food stability?

GSPR is a major driving determinant for GSDR, particularly in the period of 2000 to 2010. Theoretically, GSPR is the ratio of grain

**TABLE 3** Total grain production of the 117 economies

| Year | 1991 | 2000 | 2010 | 2018 |
|---|---|---|---|---|
| Grain production (1000 MT) | 1,590,671 | 1,825,531 | 2,188,951 | 2,579,063 |

stock to grain production. Table 3 shows the total grain production for the 117 economies, which indicates an increasing tendency as calculated. Therefore, the grain production increased more significantly than grain stock during the three decades, leading to the major driving effect of GSPR on GSDR. The periodical result indicates the stock amount largely increased in a large number of countries during the period of 2000 to 2010 given the GP increased stably in the three decades. According to Equation (12), increasing GI and decreasing GE for the low GSDR countries were the approach to carry the 117 countries to a higher level of GSDR. After the grain stock amount is equipped, the storage actions need more attentions from managerial and technological perspectives considering its unpredictable and often unsustainably high budget costs. For example, high fiscal costs on grain storage actions in Africa and Asia are crowding out needed public investment in agricultural productivity and rural infrastructure (World Bank, 2012) although grain storage actions could respond to the food crisis and price spikes.

$$GS = GP + GI - D - GE \tag{12}$$

The combined effects of the decrease of ALI and EIA implied that mechanization pushed forward the GP, particularly in the first phase, i.e., 1991 to 2000, which then made great advancement of GSDR according to Equation (13). On one hand, the labor input in a unit agricultural land reduced sharply in the 1990 s, which drove the increment of global GSDR and enhanced food security of that decade as shown in Table 2. The decade witnessed a dramatic drop in agricultural employment but higher agricultural production, thus higher amount of grain stocks (Roser, 2013). Considering the sustained drop of EIA, it can be explained that the agricultural labor input in the employment structure has decreased. World Bank data shows the world EIA (%) decreased from 44% to 40% during the decade. Particularly, China's EIA decreased from 60% to 50% according to in India, during 1983–1994, EIA was increasing at the rate of 1.51% per annum as against total employment growth of 2.04%, indicating the growth rate of employment dramatically decreased in agriculture during 1994–2000 (Pradhan, 2007). On the other hand, farm mechanization played its role to alleviate human drudgery and enhance agricultural productivity at the same time; and its impact on agricultural production and productivity had been well recognized during the post-green revolution period in India (Verma, 2006). Similarly, Qiu et al. (2022) attributed the highly close correlation between China's higher rate of adoption of agricultural mechanization services and the related higher productivity of medium farms from 2008 to 2016 to the large-scale agricultural production with machinery instead of most manpower investment in grain production.

$$GSDR = \frac{GS}{D} = \frac{GP + GI - GE}{D} - 1 \tag{13}$$

## 5.2 | What can we further do to improve global food stability?

For addressing the obstacles Facing the dilemma of expensive grain storage actions and needs of grain stock, it is suggested that the low-stock countries could adopt the cost-effective techniques. Usually, an adequate grain storage technique should be able to sustain storage function for at least 5 years and be low-cost and managed scientifically (Olorunfemi & Kayode, 2021). For example, Kimenju and de-Groote (2010) recommended that using a metal silo instead of polypropylene bags could annually save up to USD 100 per ton of grains, which could be considered in the low-stock countries to squeeze the grain storage cost. Agricultural mechanization has many advantages, such as timely crop establishment, harvest, and inter-cultural operations, which together improve the agricultural production. Paudel et al. (2019) proposed to promote higher levels of agricultural mechanization as the primary policy response to solve the labor shortage and out-migration problem in the mid-hills of Nepal owing to the capacity of machinery. Therefore, it is a feasible strategy for the economies to promote agricultural mechanization to reduce manpower input in agricultural land, such that, the grain stocks can be improved along with the grain production. Also, for guaranteeing the national food stability, the countries should hold the bottom line of their own GCL to make sure the enough agricultural land secured for grain production.

Notably, the world needs breaking through the grain cropping technologies in 2020 s to seek for grain food stability, as the driving effect of GCY slowed down in the 2010 s compared with that in 2000 s and 1990 s. Further, Wang et al. (2020) pointed out all major producing countries would still face notable warming-induced yield reduction, which needs scientists to develop climate-smart agriculture. To increase crop yield, technologies and efficient management strategies are suggested to be adopted. Technologically, Chen, Chen, He, et al. (2020) proved that nuclear-encoded synthesis of the D1 subunit of photosystem II could increase photosynthetic efficiency thus boost crop yield; Li et al. (2021) on soils of differing fertility could increase grain yields in intercropped systems by 22% based on four long-term (10–16 years) experiments; and Dawar et al. (2021) pointed out specialized plant membrane transporters can be used to enhance yields of staple crops. Managerially, Chen et al. (2014) proposed a set of integrated soil–crop system management practices, which could increase rice, wheat and maize yields from 7.2, 7.2 and 10.5 Mg/ha to 8.5, 8.9 and 14.2 Mg/ha, respectively, without any increased nitrogen fertilizer input; Wang et al. (2017) proved that double-season rice yield could be improved with the combined effects of increased plant density and optimized nutrient management; and Erdoğan et al. (2021) recommended the resource-rich countries to adopt efficient management strategies when using the arable land and freshwater to improve food yield.

## 6 | CONCLUSIONS

This study investigated the global food security evolution and determinants from the perspective of the stability of the domestic food supply. The evolution was understood through analyzing the grain stocks per capita of 117 economies and how the national grain stocks could satisfy their domestic need using the data available from 1991 to 2018. The determinants were identified through decomposing the change of GSDR of each economy to the effects of seven factors, i.e., GSPR, GCY, GCL, $ALI^{-1}$, EIA, ER and $AD^{-1}$. The result shows that global food security was improved in the 2010 s based on 1990 s and 2010 s, particularly, Asia and Africa significantly turned increasingly securer, American countries, EU and Oceania generally remained stable, but Southeast Asia and Africa are mostly below the warning line though. The global food security in terms of and how the national grain stocks could satisfy their domestic need from 1991 to 2018 was determined by GSPR, GCY, GCL, $ALI^{-1}$ and EIA, which reflects the patterns underlying the evolution of human society, such as improved food crisis consciousness, improved grain cropping skills, extended agricultural mechanization, and changed employment structure. Policy implications were suggested in the purpose of revealing the major driving mechanisms of global food stability and seeking for further improvement, which mainly include developing low-cost grain facilities to generalize the adoption for grain storage, adopting innovative grain cropping technologies and management strategies to seek for further improvement of yield, and taking advantage of the agricultural mechanization to make the agricultural production more labor effective and land effective.

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### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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