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Sustainability of the Philippine food system

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Understanding the status of the Philippine food system is vital in identifying pathways to improve sustainable nutrition security in the country. In the present study, we quantitatively examined the sustainability status of the Philippine food system using the Sustainable Nutrition Security (SNS) metrics. The country's food system obtained low scores for resilience, food nutrient adequacy, ecosystem stability, and food safety, while better scores were obtained for sociocultural wellbeing, food affordability and availability, and waste and loss reduction. The Philippine food production and supply face important challenges in diversification, coupled with socioeconomic disparities. Potential convergence points among relevant stakeholders were identified to improve the diversity of the food supply chain and to develop the overall resilience of the Philippine food system.

KEYWORDS
food system, sustainability, resilience, sustainable nutrition security, metrics

1 Introduction

In recent years, there has been a renewed call to address hunger, food security, and nutrition concerns through efforts that are embedded in a food systems approach, which recognizes the importance of context-specific and intersectoral approaches to building transformative pathways toward sustainable nutrition security. Central to these pathways is the conduct of a food system assessment to characterize multiple domains of the food system of a particular geographic entity to direct policy shifts. The Sustainable Nutrition Security (SNS) proposed by Gustafson et al. (2016) is an assessment methodology that quantifies the status and/or performance of food systems using a combination of multiple indicators grouped into seven (7) domains: food nutrient adequacy, ecosystem stability, food affordability and availability, sociocultural wellbeing, food safety, resilience, and food waste and loss reduction (Gustafson et al., 2016). The indicators in this assessment framework were selected through a series of consensus-building activities among global experts on nutrition, economics, food systems, and climate change (Chaudhary et al., 2018) and have been applied in the assessment of national food systems in highly- and less-developed countries (Gustafson et al., 2016; Chaudhary, 2018).

For decades, the Philippines has invested in approaches to address problems of food, nutrition, and hunger. However, most of these policies and programs have been implemented in isolation. For instance, agricultural institutions manage policies and programs to boost food production and distribution, while nutrition concerns are considered the responsibility of health and nutrition stakeholders, and environmental institutions focus on the country's conservation issues. Often, these sectors function in silos via different and uncoordinated strategies. It is important to recognize the importance of the food systems approach to promote collaboration and exchange of information, determine the underlying issues, and identify potential leverage and trade-offs for sustainable nutrition security. A primary and necessary step is the assessment of the country's food system status using a comprehensive assessment framework. However, at present, food system research in the country remains largely limited, and the use of internationally developed food system assessment metrics has not yet been explored. Thus, in the present study, we address this research gap and characterize the status of the Philippine food system at the national scale, utilizing the SNS indicators to identify key areas for improvement, collaboration, and transformation.

2 Materials and methods

In the present study, the SNS metrics are employed to assess the country-level status of the Philippine food system utilizing relevant international and local data (Table 1) and following the methods described in the studies by Gustafson et al. (2016) and Chaudhary et al. (2018). Each of the metrics consists of multiple indicators scaled on a 0 to 100 scale, with desirable higher values (Gustafson et al., 2016).

2.1 Food nutrient adequacy

These metrics include indicators to characterize the availability, diversity, and adequacy of the food supply and dietary intakes of the population. The calculation of scores utilized available country-level food balance sheets and food consumption data.

2.1.1 Shannon diversity of food supply

This indicator quantifies the diversity of the country's food supply. The general formula for Shannon Diversity reported in the study by Gustafson et al. (2016) was employed in calculating this indicator (Eq. 1). To derive the score for this indicator, the 2018 food consumption data from the Department of Science and Technology—Food and Nutrition Research Institute (DOST-FNRI) Expanded National Nutrition Survey (ENNS) (in kcal *per capita* per day)—was utilized.

$$Shannon\ Diversity = -\sum_{i} s_i \ln(s_i) \quad (1)$$

where s_i is the share (by weight) of the i_{th} food item in the food supply.

2.1.2 Non-staple food energy

This indicator estimates the percentage of calories that come from non-staple foods in the food supply (Gustafson et al., 2016; INDDEX Project, 2018). As staple foods vary among countries, it was important to initially identify staple vs. non-staple foods in the Philippines to facilitate the calculation of this indicator. Following the definition of staple foods as foods that are eaten routinely and in quantities that account for a large share of dietary energy intakes (Gustafson et al., 2016), food consumption patterns for the Philippines were examined using the ENNS 2008–2019 data. Accordingly, cereals and cereal products contribute primarily to the average daily food and energy intake of Filipinos across these survey periods. Following this rationale, cereals and cereal products were identified as staple foods in the country, and this includes rice and rice products, corn and corn products, and other cereals.

Using the 2019 FAOSTAT Food Balance Sheet (FBS) for the Philippines, the equation from the International Dietary Data Expansion (INDDEX) project was adopted to calculate the score for this indicator (see Eq. 2).

$$\frac{Food\ supply\ of\ all\ non-staple\ foods\ (kcal\ per\ capita\ /\ day)}{Food\ supply\ for\ all\ foods\ (kcal\ per\ capita\ /\ day)} x100 \quad (2)$$

2.1.3 Modified functional attribute diversity

This indicator measures the diversity in the nutritional components of food items in the country's food supply, and as such, MFAD does not increase with the consumption of food items that are functionally identical (i.e., those that have similar nutritional composition) but does increase with intake of functionally dissimilar food items (Remans et al., 2014; Gustafson et al., 2016). The use of MFAD prevents an increase in the measured dietary diversity without the existence of nutritional diversity (INDDEX Project, 2018).

In the calculation of the value for this indicator, the formula (Eq. 3) proposed by Remans et al. (2014) was employed utilizing the 2018 ENNS food consumption data. Dissimilarity in the nutritional components of food items consumed was quantified using the Euclidean distance formula following the methods employed by Remans et al. (2014). Furthermore, in counting the total number of functional units, food items consumed that were similar in nutritional components (as identified using the Euclidean distance) were not counted as separate food items (Remans et al., 2014).

$$MFAD = \frac{\sum_{i-1}^{n} \sum_{j-1}^{n} d_{ij}}{N} \quad (3)$$

where:
n is the number of food items;
d is the calculated dissimilarity between food items i and j;
N is the number of functional units (i.e., total number of foods considered).

2.1.4 Population share with adequate nutrients

This indicator is an estimate of the proportion of the population in the country with intake levels for nutrients that are above the demographically weighted requirement thresholds for that country. For

TABLE 1 Data sources for the operationalization of the Sustainable Nutrition Security (SNS) metrics and indicators.

Metrics	Indicators	Data sources	Year
Food nutrient adequacy	Shannon Diversity of Food Supply	DOST-FNRI ENNS Food Consumption Survey	2018
	Non-staple Food Energy	FAOSTAT Food Balance Sheet	2019
		DOST-FNRI ENNS Food Consumption Survey	2018
	Modified Functional Attribute Diversity (MFAD)	DOST-FNRI ENNS Food Consumption Data 2018	2018
	Population Share with Adequate Nutrients	DOST-FNRI ENNS Food Consumption Survey	2018
	Nutrient Balance Score	DOST-FNRI ENNS Food Consumption Survey	2018
		Philippine Dietary Reference Intakes (PDRI)	2015
	Disqualifying Nutrient Score	DOST-FNRI ENNS Food Consumption Survey	2018
		Philippine Dietary Reference Intakes (PDRI)	2015
Ecosystem stability	Ecosystem Status	Yale Center for Environmental Law and Policy Environmental Performance Index (EPI)	2022
	Per Capita Greenhouse Gas (GHG) Emissions	FAOSTAT Emissions Total	2019
		World Bank Population Estimates	2019
	Per Capita Land Use	FAOSTAT Land Use	2019
		World Bank Population Estimates	2019
	Per Capita Freshwater Consumption	FAO AQUASTAT	2018
		World Bank Population Estimates	2018
	Per Capita Non-renewable Energy Use	World Bank World Development Indicators (WDI)	2018
		World Bank Population Estimates	2018
Affordability and availability	Food Affordability	Economic Intelligence Unit (EIU) Global Food Security Index (GFSI)	2021
	Food Availability	GFSI	2021
	Poverty Index	GFSI	2021
	Income Equality	World Bank Gini Index	2018
Sociocultural wellbeing	Gender Equity	World Economic Forum (WEF) Global Gender Gap Index (GGGI)	2021
	Extent of Child Labor	Philippine Statistics Authority (PSA)	2020
	Respect for Community Rights	World Resources Institute (WRI) Environmental Democracy Index (EDI)	2015
	Animal Health and Welfare	World Animal Protection (WAP) Animal Protection Index (API)	2020
Resilience	ND-GAIN Country Index	University of Notre Dame Notre Dame Global Adaptation Index (ND-GAIN)	2020
	Food Production Diversity	FAOSTAT Food Production	2019
Food safety	Global Burden of Foodborne Illness	Chaudhary, et al.	2018
	Food Safety Score	GFSI	2021
Waste and loss reduction	Food Loss	GFSI	2021
	Food Waste	Food Waste Index Report	2021

the Philippines, data on the percentage of the population that has nutrient intake levels above the Estimated Average Requirements (EAR) across all age groups was readily available in the 2018 ENNS food consumption survey for nutrients including protein, calcium, phosphorous, iron, vitamin A, thiamin, riboflavin, niacin, and vitamin C. Hence, the calculation of the value for this indicator was limited to the average proportion of the population meeting the EAR for these nine (9) nutrients, considering data availability in the country. The value derived was subsequently multiplied by 100 to obtain the percentage of the population share with adequate nutrient intakes.

2.1.5 Nutrient balance score

To calculate the NBS, the Qualifying Index (QI) for protein, calcium, phosphorous, iron, vitamin A, thiamin, riboflavin, niacin, and vitamin C was initially calculated by adopting the formula for QI from Chaudhary et al. (2018) (Eq. 4). QI represents the ratio of a particular nutrient's amount in a 2000-kcal of a given food/meal relative to the Dietary Reference Intakes (DRI) for those nutrients (Chaudhary et al., 2018). The calculated QI in this study is limited to the nutrients mentioned due to the unavailability of country-level data for other nutrients. Afterward, the calculated QI was employed to obtain the NBS (Eq. 4). After calculating the QI values, the NBS is calculated—an indicator of the capacity of the diet to meet the daily dietary requirements for the qualifying nutrients (Fern et al., 2015).

$$QI_{q,k} = \frac{2000}{E_k} \cdot \frac{a_{q,k}}{DRI_q} \tag{4}$$

Where E_k is the total daily caloric intake for the country k in kcal *per capita* per day, $a_{q,k}$ is the daily intake amount of a qualifying food nutrient in the country, and $DRIq$ is the recommended intake level for the qualifying nutrients (see Eq. 5).

$$NBS_k = 100.\left(\frac{\sum_{q=1}^{9} \Sigma QI_{q,k}}{N_q}\right) \tag{5}$$

Where $QI_{q,k}$ is the calculated QI value and $_q$ is the number of nutrients considered.

2.1.6 Disqualifying nutrient score

For this indicator to be calculated, it was necessary to initially derive the disqualifying index (DI) (Eq. 6) for each of the identified public health-sensitive nutrients. The DI is defined as the ratio of the amounts of these nutrients in a 2000-kcal diet and the maximum reference value (MRV) for these nutrients of concern (Chaudhary et al., 2018).

$$DI_{d,k} = \left(\frac{2000}{E_k} \cdot \frac{a_{d,k}}{MRV_d}\right) \tag{6}$$

Where E_k is the total daily caloric intake for the country k in kcal *per capita* per day, $a_{d,k}$ is the total daily intake level for each of the identified public health-sensitive nutrients d in the country k, and MRV_d values are obtained from the PDRI 2015 [Department of Science and Technology-Food and Nutrition Research Institute (DOST-FNRI), 2017].

Public health-sensitive nutrients that were considered in the present study are sugar, sodium, saturated fat, and cholesterol. We obtained these data from the 2018 ENNS Food Consumption Survey and the MRV for each of these nutrients from the PDRI 2015 [Department of Science and Technology-Food and Nutrition Research Institute (DOST-FNRI), 2017] to calculate the DI values. A single DI value was obtained by calculating the average DI values for the four (4) nutrients, and the DNS was calculated using the equation below (see Eq. 7):

$$DNS = 100.\left[\left(1 - \frac{\sum_{d=1}^{4} DI_{d,k}}{N_d}\right)\right] \tag{7}$$

2.2 Ecosystem stability

This metric considers the sustainability status of the natural resource base to support food systems. It includes an indicator that quantifies the country-level status of ecosystems and a group of indicators that take into account eco-efficiency (Gustafson et al., 2016). Higher scores are indicative of lower *per capita* environmental impacts of food system activities (Gustafson et al., 2016). The general equation employed for calculating the scores for the ecosystem stability indicators was adopted from Gustafson et al. (2016).

$$Per\ capita\ ecosystem\ indicator = 100\ x\ \exp\left[\ln(0.5)x\left(\frac{F_i}{F_{50}}\right)\right] \tag{8}$$

Where F_i is the factor (e.g., GHG emissions or land use or freshwater withdrawal) for the i_{th} country.

F_{50} is the median (50th percentile) of the full range of values for a particular factor across all countries, measured during a particular reference year.

2.2.1 Ecosystem status

The Environmental Performance Index (EPI) was developed by the Yale University Center for Environmental Law and Policy and the Columbia University Center for International Earth Science Information Network. This metric quantifies the country's performance on sustainability using 32 performance indicators across 11 issue categories and 2 policy objectives. The indicators considered in the EPI serve as a gauge of a country's proximity to established environmental policy targets (Wendling et al., 2020). The 2020 EPI ranks 180 countries based on their performance in addressing environmental challenges. The EPI score is scaled from 0 to 100, and the Philippine EPI score is directly adopted for use in the present study.

2.2.2 *Per capita* greenhouse gas emissions

This indicator is defined as the *per capita* annual food system GHG emissions (kgCO_2e per person per year) (Gustafson et al., 2016). To obtain *per capita* GHG emissions, the equation proposed by Gustafson et al. (2016) was adopted (Eq. 8) to derive the *per capita* GHG emissions on a 0 to 100 scale.

In the calculation of the value for this indicator in the present study, datasets from the (i) 2019 FAOSTAT Domain Emissions Total and (ii) 2019 World Bank Population Estimates were used. In particular, data on GHG emissions for agricultural land were considered, and it was divided by the estimated population in the Philippines obtained from the World Bank.

2.2.3 *Per capita* land use

Gustafson et al. (2016) define this indicator as *per capita* food system land use (per person per year) regardless of where land use occurs and what kind it is. The calculation of this indicator also employed Eq. 8, with land use as the factor under consideration. In the calculation of the value for this indicator, data on agricultural land use from the (i) 2019 FAOSTAT Domain Land Use and (ii) 2019 World Bank Population Estimates were utilized.

2.2.4 *Per capita* freshwater consumption

This indicator is defined as the *per capita* annual food system net freshwater withdrawals (m^3 freshwater per person per year), regardless of where those water withdrawals were made (Gustafson et al., 2016). By this definition, "net withdrawals" are equated to water that has been utilized by the food system and is no longer available for other purposes and users (Gustafson et al., 2016). For the present study, data on agricultural water withdrawal (including irrigation, livestock, and aquaculture) in AQUASTAT were considered. AQUASTAT presents data on water withdrawal in 10^9m^3/year, and this was converted to m^3/year and subsequently divided by the 2018 Philippine population estimates to derive the *per capita* water withdrawal as suggested by Gustafson et al. (2016) (Eq. 8).

2.2.5 *Per capita* non-renewable energy use

Proponents of the SNS metrics define this indicator as *per capita* annual food system non-renewable energy use (MJ per person per year) (Gustafson et al., 2016). To calculate the country score for this indicator in the present study, data on (i) 2018 Renewable Energy Consumption (% of Total Final Energy Consumption from the World Bank Development Indicators (WDI) data bank) and (ii) 2018 World Bank Population estimates were obtained. Owing to the lack of sector-specific data, the values for % renewable energy consumption of the country obtained from the WDI Data Bank were assumed to be the same for the % renewable energy use in the food system. A similar presumption was made in the calculations by Chaudhary et al. (2018). To calculate the % non-renewable energy use, the % renewable energy consumption obtained was subtracted from 100.

2.3 Affordability and availability

The Global Food Security Index (GFSI) was developed by the Economist Impact and supported by the Corteva Agriscience to assess food security by considering its different dimensions, i.e., food affordability, food availability, quality, and safety, and natural resources and resilience [The Economic Intelligence Unit (EIU), 2021]. The GFSI is developed by taking a food systems perspective and is based on a dynamic quantitative and qualitative benchmarking model of 58 indicators that measure the drivers of food security both in developed and developing countries [The Economic Intelligence Unit (EIU), 2021]. The three (3) indicators in this metric (food affordability, food availability, and poverty index) are included in the GFSI 2021 analysis/report across 113 countries, including the Philippines. Each indicator in the 2021 GFSI consists of sub-indicators—sub-indicator weights determine the relative contribution of each sub-indicator to its parent indicator (e.g., Food Affordability indicator), and indicator weights subsequently determine its relative contribution to the overall food security environment of the country of interest (The Economic Intelligence Unit (EIU), 2021).

Similar to the approach employed by Gustafson et al. (2016) and Chaudhary et al. (2018), the Philippine scores for these three (3) indicators were directly imported from the GFSI 2021 country-level score for use in this study.

2.3.1 Food affordability

The 2021 GFSI Food Affordability score consists of sub-indicators, each of which was assigned weights relative to their individual contribution to the parent indicator. Its calculation is scaled between 0 and 100 as the weighted average scores of the underlying sub-indicators [The Economic Intelligence Unit (EIU), 2021]. The Philippine score was directly adopted for use in the present study.

2.3.2 Food availability

The GFSI Food Availability score is expressed on a scale of 0 to 100, and the score for the Philippines for this indicator is directly adopted in this study.

2.3.3 Poverty index

The 2021 GFSI defines this indicator as a measure of the prevalence of poverty and calculated as the proportion of the population in a country under the global poverty line [i.e., living on less than US$3.20/day at 2011 Purchasing Power Parity (PPP)] [The Economic Intelligence Unit (EIU), 2021]. The 2021 GFSI reports the Poverty Index in percentage (%), and similar to the two (2) previous indicators in this metric, the score for the Philippines is directly imported.

2.3.4 Income equality

The World Bank estimates the extent to which the distribution of income among individuals or households within a country deviates from a perfectly equal distribution through the GINI Index—such that a Gini Index of 0 indicates perfect (income) equality, while an index of 100 implies perfect (income) inequality (World Bank Data Bank, n.d.). The country-level GINI Index is reported in the World Bank Poverty and Inequality Platform on a 0 to 100 scale, and the Philippine GINI Index is directly adopted for use in this study using the 2018 data as the most recent published year.

2.4 Sociocultural wellbeing

This metric reflects the status of food system-related societal factors and is derived by averaging the scores of four (4) underlying indicators that are societal in nature and with quantifiable data available at the country level (Gustafson et al., 2016).

2.4.1 Gender equity

The Global Gender Gap Index (GGGI) was developed by the World Economic Forum (WEF) in 2006 to measure global progress toward gender parity by considering four (4) main components (sub-indices): economic participation and opportunity, educational attainment, health and survival, and political empowerment [World Economic Forum (WEF), 2021]. The GGGI score can be interpreted as the distance to gender parity in a particular country (i.e., the percentage of the gender gap that has been closed) [World Economic Forum (WEF), 2021]. The 2021 GGGI reports gender gap scores of 156 countries on a scale of 0 to 1 [World Economic Forum (WEF), 2021], and to convert this into the SNS metric scale of 0 to 100, the country score is multiplied by 100 (Gustafson et al., 2016).

2.4.2 Extent of child labor

For this indicator, we followed the definition of "child labor" established by the International Labor Organization-International Programme on the Elimination of Child Labor's (ILO-IPEC) definition of child labor as "work situations that deprives children of their childhood, their potential and their dignity, and that is harmful to physical and mental development; work that is physically, socially or morally dangerous and harmful to children, and/or interferes with their schooling" [International Labor Organization-International Programme on the Elimination of Child Labor (ILO-IPEC) (n.d.)]. In the Philippines, chill labor refers to work situations where children aged 5–17 years are engaged for long working hours, as specifically identified in the Department of Labor and Employment (DOLE) Administrative Order No. 149 [Philippine Statistics Authority (PSA), 2021].

Gustafson et al. (2016) define the indicator Extent of Child Labor as the percentage of children aged 5–17 years, in a country that are employed in the food system. Hence, in the present analysis, data on the percentage of child laborers employed in the agriculture industry were obtained from the Philippine Statistics Authority (PSA).

2.4.3 Respect for community rights

Environmental democracy is a concept that promotes meaningful public participation in concerns that involve land and natural resources by reinforcing the citizens' rights to adequate and equitable access to information on environmental quality and problems, to participate meaningfully in decision-making, and to seek enforcement of environmental laws or compensation for harm (Worker and De Silva, 2015). The World Resources Institute (WRI) and the Access Initiative developed the Environmental Democracy Index (EDI) as a measure of the extent and degree to which national laws promote environmental democracy rights in 70 countries (Worker and De Silva, 2015). The EDI consists of 75 legal indicators that are concerned with the development and implementation of legislation (laws, constitutions, regulations, and other legally binding, enforceable rules at the national level) and 24 practice indicators that are concerned with the assessment of evidence of implementation of environmental democracy in practice (Worker and De Silva, 2015). The EDI scores are reported on a scale of 0 to 2.39, and the present study adopted the approach by Gustafson et al. (2016) to convert the Philippine EDI score to the 0 to 100 scale by multiplying it by a factor of 40.

2.4.4 Animal health and welfare

The Animal Protection Index (API) developed by the World Animal Protection assesses animal welfare policy and legislation across 50 countries. The API scoring scheme is provided into letter grades, i.e., from rank "A" (being the highest) to rank "G" (being the lowest). Gustafson et al. (2016) converted these letter grades into a numeric scale of 0 to 100 by designating corresponding scores, and this is adopted for use in the present study to convert the Philippine letter API letter score into a numeric score.

2.5 Resilience

This metric takes into consideration the use of the Notre Dame Global Adaptation Initiative (ND-GAIN) and Food Production Diversity as indicators. The ND-GAIN serves as a quantified measure of a country's overall resilience, while Food Production Diversity serves as an additional measure of resilience, i.e., more diverse food production contributes to a country's resilience by lessening the impacts of catastrophic occurrences due to the loss of a single crop (Gustafson et al., 2016).

2.5.1 ND-GAIN country index

The ND-GAIN was developed by the University of Notre Dame to quantify a country's vulnerability to climate disruptions and to assess its readiness to leverage private and public sector investments for adaptive actions (Chen et al., 2015). The ND-GAIN consists of more than 74 variables forming 45 core indicators quantifying two main dimensions, i.e., vulnerability and readiness (Chen et al., 2015). Accordingly, vulnerability is the propensity of human societies to be negatively impacted by climate hazards, while readiness is an assessment of a country's readiness to make effective use of investments for adaptation actions (Chen et al., 2015). ND-GAIN assesses the vulnerability of a country by evaluating the sectors of food, water, health, ecosystem services, human habitat, and infrastructure (Chen et al., 2015). Higher ND-GAIN scores indicate a better state of resilience and are thus desirable. The overall ND-GAIN country score is reported on a 0–100 scale, and the 2019 Philippine ND-GAIN score is directly imported for use in the present study.

2.5.2 Food production diversity

Utilizing the Philippine food production dataset linked with the food supply energy dataset from FAOSTAT, the score for this indicator is calculated using Eq. 1.

2.6 Food safety

This metric consists of two (2) indicators: the Global Burden of Foodborne Illnesses (GBFI) reported by the World Health Organization (WHO) and the Food Safety score reported by the GFSI (Gustafson et al., 2016).

2.6.1 Foodborne diseases burden

The country's score for this indicator was directly adopted from the study by Chaudhary et al. (2018) and Table 1. The authors utilized data from the WHO Estimates of the Global Burden of Foodborne Diseases Report (World Health Organization (WHO), 2015), which reports comprehensive region-level data on mortality, morbidity, and daily adjusted life years (DALYs) that are associated with major foodborne diseases (i.e., enteric diseases, parasitic diseases, and chemicals and toxins). Country-level data are not provided in the report but are considered to provide the best current estimates of foodborne disease burden (Gustafson et al., 2016).

2.6.2 Food safety score

The GFSI reports food safety as part of the quality and safety indicators. The food safety score is reported on a 0 to 100 scale, and the Philippine score in 2021 was directly adopted for use in the present study.

2.7 Waste and loss reduction

Food loss and waste are defined by the FAO as the decrease in the quantity (or quality) of food (FAO, 2014) and comprise two (2) dimensions, i.e., loss and waste. Food loss pertains to human-edible commodities that either directly or indirectly exit the supply chain during production, storage, transportation, processing, and up to but excluding the point of retail (FAO, 2018). Food waste, on the other hand, refers to the removal (of food commodities) from the food supply chain that occurs from the point of retail to the stage of final consumption (FAO, 2018). Gustafson et al. (2016) reported a single score for this indicator as the average proportion of food lost and wasted at the country level. Similarly, a single score was reported for this indicator in the analysis of Chaudhary et al. (2018). In the present study, however, separate scores are reported for food loss and waste. This approach is essentially intended to acknowledge that while these two (2) elements are related, they focus on different aspects of the value chain and relate to different policy concerns (National Academies of Sciences, Engineering, and Medicine, 2019). Furthermore, food loss and food waste impact food systems differently across countries, i.e., while food loss is a relatively more important concern in lower-income countries, food waste is of greater consideration in higher-income countries (Gustafson et al., 2016).

2.7.1 Food loss

The 2021 GFSI reports food loss as a measure of food lost at post-harvest and pre-consumer and defines this indicator as the ratio of the domestic supply (i.e., including domestic production, net imports, and stock changes) for crops, livestock, and fish commodities (Global Food Security Index, 2021). Data from the FAO were primarily utilized to calculate the 2021 GFSI score for this indicator (Global Food Security Index, 2021). The food loss score in the 2021 GFSI is expressed on a 0 to 100 scale, with higher scores indicating better status. The Philippine score for food loss is directly imported from the 2021 GFSI.

2.7.2 Food waste

In 2021, the United Nations Environment Programme (UNEP) published the first UNEP Food Waste Index Report, which provides comprehensive country-level estimates of food waste from households, retail establishments, and the food service industry (United Nations Environment Programme (UNEP), 2021). This index measures food waste at the retail and consumer level, but although there are available estimates/datapoints for food service and retail, there is a large scarcity of data in these sectors (United Nations Environment Programme (UNEP), 2021). Nonetheless, the report provides substantial information on household food waste across 215 countries in regions included in the study (Northern Africa, Sub-Saharan Africa, Latin and the Caribbean, Northern America, Central Asia, Eastern Asia, South-eastern Asia, Southern Asia, Western Asia, Eastern Europe, Northern Europe, Southern Europe, Western Europe, Australia and New Zealand, Melanesia, Micronesia, and Polynesia) (United Nations Environment Programme (UNEP), 2021). The best available household food waste data were collected for each of these countries, adjusted to account for biases and improve comparability, and subsequently grouped into confidence ratings (United Nations Environment Programme (UNEP), 2021). Household food waste estimates from collected data are given high and medium confidence ratings, while estimates that were extrapolated based on the average food waste observed in a particular country's region and income grouping were classified either with low or very low confidence ratings (United Nations Environment Programme (UNEP), 2021).

To calculate the country's score for this indicator, *per capita* annual household food waste was calculated by employing Eq. 8 and using the data on household food waste estimates (in kg/capita/year) from the 2021 Food Waste Index Report. The calculated score is scaled from 0 to 100.

3 Results

In the present study, we examine the sustainability status of the Philippine food system at the national scale using quantitative multi-indicator assessment metrics proposed by Gustafson et al. (2016). The metrics consider seven (7) dimensions of a sustainable food system: (i) food nutrient adequacy; (ii) ecosystem stability; (iii) food affordability and availability; (iv) sociocultural wellbeing; (v) resilience; (vi) food safety; and (vii) waste and loss reduction (Gustafson et al., 2016).

Our findings indicate that across the seven (7) metrics, the Philippine food system obtained the lowest average score for resilience (score = 23.5). The calculated scores for food nutrient adequacy (score = 48.2), ecosystem stability (score = 50.5), and food safety (score = 54.8) were low relative to other low- and low-middle-income countries (LMICs) (Chaudhary et al., 2018). On the other hand, the country's food system obtained scores on sociocultural wellbeing (score = 65.3), food affordability and availability (score = 63.1), and waste and loss reduction (score = 65.8), which were comparable to the scores of Latin American and South Asian countries (Chaudhary et al., 2018) (Figure 1).

3.1 Food nutrient adequacy

The country's average score for this metric (48.2) is below the reported global median score of 61 and close to the minimum score of 46 obtained by lower-middle-income economies such as Cambodia and Bangladesh (Chaudhary et al., 2018). As to the individual indicators, we noted that the non-staple food energy score is quite high for the Philippines (Table 2), indicating the high availability of non-staple food items in the country's food supply. It must be noted, however, that the score for this indicator does not necessarily reflect the actual consumption of the population. This notion is evident in

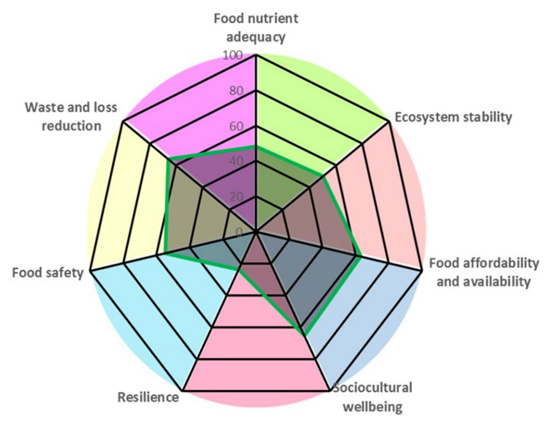

FIGURE 1
Average metric scores for the Philippine food system. The areas of the polygon represent the relative national status of food system sustainability (with higher scores indicating better status).

TABLE 2 Calculated scores for the Sustainable Nutrition Security (SNS) metrics: Philippines.

Metrics/Indicators	Score
Food nutrient adequacy	48.2
Shannon Diversity of the Food Supply	22.5
Non-staple Food Energy	80.4
Modified Functional Attribute Diversity (MFAD)	5.7
Population Share with Adequate Nutrients	31.5
Nutrient Balance Score (NBS)	82.8
Disqualifying Nutrient Score (DNS)	66.2
Ecosystem Stability	50.5
Ecosystem Status (EPI)	28.9
Per Capita Greenhouse Gas Emissions	46.9
Per Capita Land Use	80.4
Per Capita Freshwater Consumption	1.9
Per Capita Non-renewable Energy Use	94.5
Food Affordability and Availability	63.1
Affordability	74.3
Availability	53.9
Poverty Index	81.7
Income Equality	42.3
Sociocultural Wellbeing	65.3
Gender Equity	78.4
Extent of Child Labor	63.6
Respect for Community Rights	54.0
Animal Health and Welfare	65.0
Resilience	23.5
ND-GAIN Country Index	43.9
Food Production Diversity	3.3
Food Safety	54.8
Global Burden of Foodborne Illness (GBFI)	20.0
Food Safety Score	89.5
Waste and Loss Reduction	65.8
Food Loss	84.6
Food Waste	47.0

Scores are scaled from 0 to 100, with higher values desirable; scores for each of the seven (7) metrics (shaded in light blue) were derived by averaging the scores for the indicators.

the low scores obtained for the indicators Shannon Diversity of the Food Supply and Modified Functional Attribute Diversity (MFAD) (Table 2), which suggests that the food items consumed by the population have less diversity and are relatively similar in their nutritional composition.

The Nutrient Balance Score (NBS) is an indicator of the capacity of the diet to meet the daily dietary requirements for the nutrients of interest (Fern et al., 2015) and the calculated NBS for the Philippines indicates that a 2000-kcal diet can meet ~80% of the required intake levels for the nutrients considered in the analysis (protein, calcium, phosphorous, iron, vitamin A, thiamin, riboflavin, niacin, and vitamin C). However, the calculated score for the indicator Population Share with Adequate Nutrients implies that only a small proportion of the country's population had intake levels that were above the Estimated Average Requirement (EAR) for these nutrients (Table 2). Similar to lower-middle-income economies such as Angola, Bangladesh, Ghana, and Lesotho (Chaudhary et al., 2018), the calculated Disqualifying Nutrient Score (DNS) for the Philippines in the present study indicates that daily intakes for public health-sensitive nutrients (sugar, sodium, saturated fat, and cholesterol) are within the Maximum Reference Values (MRVs) for these nutrients.

3.2 Ecosystem stability

The Environmental Performance Index (EPI) scores and rankings indicate the countries' performance in addressing sustainability issues related to ecosystem vitality, climate change, and environmental health (Wolf et al., 2022). In 2022, the Philippines ranked 158th among 180 countries (Wolf et al., 2022), with a relatively low score (Table 2), indicating the need for the country to invest more in policies and initiatives that protect the environment and conserve biodiversity and natural resources.

The extent of the food system's environmental footprint is indicated by the scores for diet-related indicators. For the Philippines, the calculated scores for *per capita* GHG emissions and freshwater consumption are relatively low, while the country scored better for *per capita* land use and non-renewable energy use (Table 2). Rice remains the Philippines' major food staple, and rice cultivation is considered among the top sources of agricultural emissions in the country (United Nations Development Programme (UNDP) n.d.) and among the food items identified to be major contributors to diet-related freshwater consumption at the global level (Chaudhary et al., 2018). Meanwhile, *per capita* land use scores are reportedly lower in countries with more pasture lands used primarily for animal food production (Chaudhary et al., 2018), and for the Philippines, the contribution of meat in the Filipino diet is relatively small (DOST-FNRI, 2022), which may explain in part the country's low land footprint. In terms of energy use, low-income countries such as the Philippines primarily utilize energy for cooking (Gustafson et al., 2016; International Renewable Energy Agency (IRENA) and FAO, 2021) and consume less non-renewable energy for food production, processing, and transport.

3.3 Food affordability and availability

Global-level analysis reported that country scores for this metric ranged between 30 for low-income countries and > 80 for high-income countries (Chaudhary et al., 2018). The same analysis indicated that this metric has a high positive correlation with national Gross Domestic Product (GDP) levels (Chaudhary et al., 2018). For the Philippines, the calculated score is 63.1 (Table 2), which is in the mid-range of country-level scores. The GFSI views the first indicator—affordability—as the capacity of the country's population to pay the cost of food under a broad array of environmental conditions (i.e., both under normal circumstances and at times of food-related shocks) (The Economic Intelligence Unit (EIU), 2015). On the other hand, availability considers the factors that influence the country's food supply and the ease of access to food (The Economic Intelligence Unit (EIU), 2015). Following the GFSI score cutoff categories, the Philippine score for affordability is considered "good," but the score for availability is considered "moderate". Sufficiency of supply and agricultural infrastructure are considered "weak" aspects of the country's food availability [The Economic Intelligence Unit (EIU), 2021], thus the lower score for this indicator.

The poverty index is defined as the proportion of the country's population living above the poverty line (Chaudhary et al., 2018) established at US$3.20/day [The Economic Intelligence Unit (EIU), 2021]. The score for the Philippines (Table 2) for this indicator is considered "Very Good" by GFSI cutoffs. For the last indicator in this metric, the Philippines' Gini index is 42.3, which implies disparities in distribution in the country.

3.4 Sociocultural wellbeing

The reported global scores for this metric range between <40 (for low-income countries in the Sub-Saharan African region) and ~ 90 (for high-income countries in the Western Europe region) (Chaudhary et al., 2018), and the calculated score for the Philippines (61.2) is in the mid-range. The Philippines obtained a Global Gender Gap Index (GGGI) score of 78.4% [World Economic Forum (WEF), 2021], which means that the remaining gender gap to close in the country stands at 21.6%. Among the four (4) dimensions of this index, the country obtained the lowest score (hence, the largest gender gap) for political empowerment (36.2%) [World Economic Forum (WEF), 2021]. For the indicator Extent of Child Labor, we opted to adopt the percentage of child laborers in the agriculture sector from the Philippine Statistics Authority (PSA)—a figure that is notably high (Table 2). The PSA reports that among the seventeen (17) regions in the country, Northern Mindanao had the largest share of the country's child laborers in 2020 [Philippine Statistics Authority (PSA), 2021].

The Philippines obtained a score of 54.0 (Table 2) for the indicator Respect for Community Rights. This score was derived from the country's Environmental Democracy Index (EDI) score (multiplied by 40), as reported by the World Resources Institute (WRI) (2015). Country-level EDI score is the average score for the three pillars: (i) access to information; (ii) public participation; and (iii) access to justice (Worker and De Silva, 2015). By disaggregating the country's EDI score by pillars, it can be deduced that the Philippines scored well on the access to justice pillar (pillar score = 1.71) and access to information (pillar score = 1.53) but not quite well on the public participation pillar (pillar score = 0.81) (Environmental Democracy Index (EDI) n.d). In terms of Animal Health and Welfare, the Philippines obtained an API score of D (equivalent to a numerical score of 65.0) (Table 2). As a whole, the country's Animal Protection Index (API) score indicates that while there are legislations and designated agencies in the country that protect animal welfare, these are generally weak, not aligned, insufficiently enforced, and outdated [Animal Protection Index (API), 2020].

3.5 Resilience

The Philippines' obtained a low average score for the two (2) complementary indicators in this metric. The country's score for the first indicator (ND-GAIN) indicates high vulnerability to climate change but with low readiness levels, thereby increasing investments and innovation to improve resilience [University of Notre Dame Global Adaptation Index (ND-GAIN), 2020]. The food production diversity score is also quite low (Table 2), implying that the country needs to produce more diverse food commodities to improve the resilience of the food system.

3.6 Food safety

This metric has been shown to be strongly correlated with GDP, and high-income countries obtained very high scores (~90) while low-income countries have correspondingly low scores (~20) (Chaudhary et al., 2018). The calculated metric score for the Philippines is in the mid-range of these reported global scores. For the indicator Global Burden of Foodborne Illnesses (GBFI), the Philippines scores relatively low (Table 2), which is similar to the scores of countries in the Sub-Saharan Africa and South Asia regions (see Chaudhary et al., 2018) due to lower incomes, tropical climate, and the relative lack of medical facilities and resources. On the other hand, the Philippines scored better on the second indicator Food Safety Score, which reflects the country's 'Very Good' status in terms of the efficacy of food safety mechanisms (e.g., food safety standards, legislations, guidelines, laboratory capacity, etc.) in place, access to drinking water, and access to electricity to facilitate proper food storage (The Economic Intelligence Unit (EIU), 2021).

3.7 Waste and loss reduction

For the indicator Food Loss, the Philippines' score (Table 2) is considered "Very Good" by GFSI cutoffs [The Economic Intelligence Unit (EIU), 2021], suggesting a small ratio of post-harvest and pre-consumer losses to the total domestic food supply. The score on the indicator Food Waste (calculated in terms of the estimated *per capita* annual household food waste), however, is lower (=47) than the other low- or lower-middle-income countries (LMICs) such as Mongolia, India, Sri Lanka, and Indonesia (Chaudhary et al., 2018).

4 Discussion

The present study examines the status of the Philippine national food system utilizing a set of metrics that consists of economic, environmental, social, and nutritional indicators. Overall, our findings show that the country's food system has low performance scores in terms of resilience, food nutrient adequacy, ecosystem stability, and food safety. On the other hand, scores are relatively better on sociocultural wellbeing, food affordability and availability, and waste and loss reduction. Aside from the average metric scores, the observed scores for individual indicators highlight valuable insights. Foremost is the observation that the country's food production has limited diversity, which impacts the nutritional diversity of the food supply, the nutritional quality of diets, and the resilience of the food system itself. The present study also highlights encouraging observations on the status of gender equality in the country, albeit mired in socioeconomic disparities.

Diversification is a vital strategy for improving productivity and farm income. It aims to maximize the use of resources such as land, water, and other resources by growing different crops (Espino and Atienza, n.d.). By diversifying, the opportunity to increase agricultural revenues is increased (Pellegrini and Tasciotti, 2014), while the risk for uncertainty and loss is lessened, thereby providing economic viability, particularly when high-value crops are integrated. In addition to its economic advantages, diversification is also recognized as an important pathway to improving the nutritional functional diversity of the food supply and dietary diversity (Pellegrini and Tasciotti, 2014; Dwivedi et al., 2017). Dietary diversity is typically defined (and measured) as the number of different foods (or food groups) consumed over a given reference period and is often used as a proxy indicator of nutritional quality. Intuitively, diversifying agricultural production increases the diversity of the food supply and the likelihood of the population consuming a more varied diet. Recently, diversification has also emerged as a conduit for improving the resilience of food systems (Tamburini et al., 2020; Hertel et al., 2021). Agricultural diversification increases crop species diversity, thereby improving functional biodiversity and the delivery of ecosystem services, e.g., reduction of pests and diseases, enhancement of soil fertility and nutrient cycling, boosting pollination, and improvement in water regulation (Pellegrini and Tasciotti, 2014; Tamburini et al., 2020). In the light of these findings, diversification is undoubtedly imperative. In the Philippines, however, the lack of diversification in agricultural production has been a persistent challenge. The importance of diversification has been recognized since the inception of the High Value Development Act of 1995, yet the Philippines has continued to focus primarily on the production of traditional crops such as rice, corn, coconut, and sugarcane (Briones, 2013; Briones et al., 2017). Analyses indicate that palay and corn have among the lowest productivity returns, while high-earning crops such as mango, pineapple, coffee, and vegetables have greater profitability (Briones, 2013). Despite these, resource allocation is still disproportionately favoring traditional crops, and there has been too little movement toward more diversified food production in the country. The failure to diversify has been constantly pointed out as a significant factor that constrains agricultural development in the Philippines (Briones et al., 2017; World Bank, 2020).

What possibly hinders the country from diversifying its food production? One of the highly discussed potential constraints is the perception of food security being heavily and irrationally skewed to achieving food self-sufficiency (Briones, 2009; Clarete, 2015), particularly for rice. The pursuit of achieving rice self-sufficiency emanated from the food crisis in 2007 and 2008 to protect the population from the risks of food insecurity (Clarete, 2015). From then on, rice marketing and trade have been among the priorities of government intervention and resource allocation, hence depriving more worthy initiatives such as agricultural diversification (Briones, 2009). Implementation problems in policies and programs are also a perennial constraint to achieving meaningful diversification outcomes. The Philippines has a long list of relevant policies and programs, including the High Value Development Act of 1995, the Comprehensive Agrarian Reform Law of 1998, the Ginintuang Masaganang Ani—High Value Commercial Crops (GMA-HVC) Program, and the Diversified Farm Income and Market Development Project. These initiatives are conceived with the best intention of improving agricultural development, food security, and nutrition in the country. However, the gap between the planned goals and the actual results of these initiatives is wide. Often, the implementation gap in developing countries is due to the lack of sectoral coherence and continuity in policies, inadequate resources, and corruption (Makinde, 2005).

Gender equality has been considered vital to achieving food and nutrition security [Asian Development Bank (ADB), 2013]. Women have a significant role in various activities within the food system, particularly in food production, food acquisition and preparation, and household food distribution [Asian Development Bank (ADB), 2013]. The Philippines is doing well in promoting gender equity—ranking 17th among 156 countries in the overall GGGI score, with high scores in terms of economic participation and opportunity, educational attainment, and health and survival [World Economic Forum (WEF), 2021], despite dropping several steps farther below its initial GGGI ranking in 2006 (6th of the 58 countries) (Hausmann et al., 2006). The country has been able to close gender gaps in literacy rate, enrolment in secondary and tertiary education, healthy life expectancy, and participation in senior, professional, and technical employment roles, although Filipino women have not yet fully closed gender gaps in terms of political empowerment [World Economic Forum (WEF), 2021]. Progress on gender equity may be considered offshoots from governance efforts such as the crafting of the Magna Carta for Women. However, although the country's gender equity status seems reasonably well based on the GGGI aggregated ranking and scores, it is worthwhile to note that gender socioeconomic disparities are still persistent in the country. The reported Maternal Mortality Ratio (MMR) in the country was 114 maternal deaths per 100,000 live births in 2015 (Dacuycuy, 2018), which is still considerably below the Sustainable Development Goal (SDG) target of 70/1000,00 MMR (WHO, n.d.). Gender gaps in the agriculture sector are also existent: (i) female workers contribute to only 26% of employment in agriculture; (ii) male agricultural daily real wage rate is higher by PhP15.00 than that of the female's; and (iii) unpaid female's work in agriculture is estimated at 35% vs. 12% unpaid work for male workers (PSA, 2016).

Income inequality and child labor are also among the fundamental socioeconomic challenges in the Philippine food system. Although the country's GFSI score on the poverty index is relatively high, indicator scores for child labor and income inequality imply a different perspective. Almost half (47.4%) of the estimated 870,000 working children in 2020 are working in the food system (i.e., the agriculture sector) [Philippine Statistics Authority (PSA), 2021]. An in-depth analysis of the child labor situation in the country indicates that the cause of the problem comprises a range of interconnected reasons, e.g., lack of education of the family head, lack of job opportunities for the adult members of the family, and lack of family income—all of which are a manifestation of widespread poverty in the country (United Nations Children's Fund (UNICEF) and PSA, 2015). Moreover, disparities in income distribution in the country are still high, which means that the "divide" between wealth classes (poor, middle, and rich) remains huge. Williamson (2017) indicated that the pervasiveness of income inequality in the country may be attributed to the dynastic power of families through generations, i.e., their business dominance and the monopolies they create, as well as their political influence. Other factors contributing to income inequality in the country are as follows: (i) education, i.e., wage inequality between the skilled and unskilled; and (ii) emigration, i.e., overseas workers and emigrants earn better than the workers left behind, skilled or unskilled (Williamson, 2017).

Our observations in the foregoing highlight the importance of employing assessment utilizing a food system perspective and a country-specific approach. A food system lens provides a better understanding of the interconnectedness of indicators within and between food system indicators. Context-specific analysis, on the other hand, frames the interpretation of assessment observations within relevant institutional settings, governance structures, geographical and cultural patterns, etc. Case in point, metric and indicator scores for gender equity and poverty index indicate 'good' status when taken individually and at face value. However, this status may not hold when interpreted together with the scores on child labor and income equality and in the context of the country's economic conditions. Similarly, the significance of improving food production diversity was underscored when its interconnectedness with the diversity of the food supply and diets and with the resilience of food systems are considered.

The present study demonstrates the significance of integrated strategies to improve the diversity in the food supply chain and develop the overall resilience of the Philippine food system. To do this, the country must move away from the traditional organizational silos. Stakeholders need to converge horizontally and vertically to identify potential leverage points that would promote diversification. Shifting from supply-driven to demand-driven agriculture has been identified as a mechanism to improve diversification (World Bank, 2020), and the convergence of relevant stakeholders is valuable to realize this. Modalities of government support may be adjusted to increase resource allocation for the promotion of diversification not only in food production but in the entire food system. Several agencies, such as the Department of Agriculture (DA), the Department of Environment and Natural Resources (DENR), the National Economic and Development Authority (NEDA), the Department of Science and Technology (DOST), and the Department of Trade and Industry (DTI), may develop a multi-stakeholder framework for promoting science-based, sustainable, high-potential agricultural value chains in the country at the national scale which may be adopted at the local level. Technological and infrastructural innovations must also be integrated into the framework. With the implementation of the Mandanas-Garcia ruling, the Department of Interior and Local Government (DILG) and the Department of Budget and Management (DBM) may partake in these initiatives by strengthening the planning and implementation capacities of Local Government Units' (LGUs) development plans to reinforce local food systems, while Civil Society Organizations (CSOs), Non-government Organizations (NGOs), and People's Organizations are integral in implementation monitoring.

In the Philippines, food systems research is relatively young, hence the large paucity of data. Although the SNS metrics have been applied at a global-level assessment of food systems, including the Philippines (Chaudhary et al., 2018), discussion of country-specific findings from this study is limited. As to the authors' knowledge, the present study is the first study in the country that provides context-specific analysis of SNS metric scores, thereby providing vital inputs to the identification of areas for transformation of the Philippine food system to improve its resilience. We acknowledge the potential limitations in the indicators in the SNS metrics we relied on for this study. For one, the values we applied to calculate the scores were from several data sources (both international and local) with inherent uncertainties and limitations. For example, we directly imported scores for various indicators from international data sources following the methods for the application of the SNS metrics; and we did not assess the aptness of each of these indicators (and their sub-indicators) in the Philippine setting. Nonetheless, we integrated the use of local data (e.g., dietary data from the ENNS) whenever possible to improve the relevance of findings in the context of the country's food system. Furthermore, while the SNS metrics are recognized as a valuable tool in the characterization of the country's food system status at the national scale, the type (and level) of data necessary for the operationalization of indicators may limit its utility at smaller geographic scales. Foremost, the Philippines is an archipelagic country with agroecological conditions that are varied and with a system of governance and resource management that is highly devolutionized, providing a varying context of food system status and/or performance. Thus, in addition to the agroecological environment, the local socio-political landscape also exerts an important impact on policies, programs, and investments that define the food systems. Hence, the status of the country's food system at the national scale may not be necessarily applicable across the different regions of the country, and the development of a food system assessment tool contextualized in the Philippine setting would be valuable to facilitate socially and ecologically fit and culturally acceptable recommendations for food system transformations.

5 Conclusion

Understanding the food system status using a holistic approach is vital to identify ways to improve sustainable nutrition security. The present study examines the status of the Philippine food system at the national scale in a quantitative manner using a multi-indicator set of metrics. Findings indicate that the country's food system is characterized by low diversity and resilience and is deeply intertwined with socioeconomic challenges. The analysis demonstrated in the present study underscores the importance of context-specific food system assessment for the identification of convergence mechanisms among stakeholders to improve the diversity in the food supply chain and develop the overall resilience of the Philippine food system.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MG-G: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft. AF: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. NT: Conceptualization, Supervision, Writing – review & editing. CA: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. PG: Conceptualization, Supervision, Writing – review & editing. CD: Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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