A new method for calculating the food self-sufficiency ratio: Supply-side food self-sufficiency ratio

Author Name: Goro Takahashi

Email address: takaha@vega.aichi-u.ac.jp

Affiliation: Aichi University, Japan

Abstract

Background: The conventional formula for calculating food self-sufficiency cannot cover all the food we eat on a daily basis, and the food self-sufficiency ratio (FSSR) of each country cannot be calculated. The conventional food self-sufficiency ratio (CFSSR) can only calculate the FSSRs of each country for grains. To determine the actual state of food insecurity worldwide as accurately as possible, a method for calculating the FSSR of each country for all the foods we eat on a daily basis is needed. To address this situation, this study proposes the supply-side food self-sufficiency ratio (SSFSSR), which can be used to systematically calculate the self-sufficiency ratio of all foods in all countries/regions.

Results: We compared the results of both calculations under the same conditions and used the same data to determine whether the CFSSR or the SSFSSR is a more suitable method for obtaining basic information and formulating measures of global food security. The results showed that the SSFSSR has advantages and practicality over the CFSSR. The SSFSSR can calculate self-sufficiency ratios for all foods in all countries/regions of the world, and the figures for various statistical tests are better. The food that is the subject of the calculation in the SSFSSR formula is the entire supply from production, distribution, storage, and consumption, excluding duplication in the calculation, and includes primary products required to produce secondary products, such as livestock products and edible oils. The study also highlighted the value of reducing the amount of primary products used to produce secondary products such as livestock and edible oils, thereby lowering the primary product conversion rate (PPCR).

Conclusion: This study used actual data to estimate the SSFSSR for each country/region to demonstrate the applicability of this method and that lowering the PPCR would lead to an increase in the food self-sufficiency ratio. To further refine this methodology, we find that the most important tasks for the future

are to collect more reliable data on calories per weight for a large number of foods, expand the number of types covered by more reliable PPCRs, and analyze those data.

Keywords:
Self-sufficiency, Food security, Least developed countries, Nutritional intake, Food supply, Food production, Food supply chain, Conversion rate

1. Background

Food insecurity is increasing worldwide (1–5). The desire of a country to ensure its food security by increasing its domestic food production or importing food is one that must be made for itself. Regardless of the choice, it is one of the responsibilities of policymakers to know the current state of their country's FSSR. However, in reality, there is no accurate formula for calculating the FSSR for each country. The prerequisite for each country to secure food is that the world’s food production and exports are sufficient. However, unexpected agricultural climate change (6–12), changes and disruptions (13) in the food supply chain (14–18), and conflicts between major agricultural producing countries have caused food insecurity in food-importing countries (19–24). The world’s largest food-importing countries, China and Japan, as well as the United Kingdom, South Korea, Germany, Switzerland, and Taiwan, have begun to calculate their own FSSRs(25–31). However, the calculation of the FSSR of these countries is based only on the simplest formula: current domestic food production/current supply food (current domestic production + current export volume - current import volume ± current inventory volume)(32), and there is no uniformity in the methods used, such as the target foods, unit of measurement, and handling of secondary products, such as livestock products and edible oils. As a result, it is not possible to compare the FSSRs of these countries, and it is even impossible to understand how well the calculated results represent the actual situation. We attempted to reproduce the FSSR data of the seven countries above published by their respective governments, but we were unable to do so. Previous studies of formulas for calculating FSSRs have also been limited by methodological trial and error or inconsistency. Recent studies in this area have evolved to consider the nutritional status of the population in addition to food security (4,33–39). Although various methodologies for measuring FSSRs have been discussed, the current situation remains inconsistent. Recent studies on food security have generally considered per capita dietary energy supply (DES) or dietary energy production (DEP) as indicators of food security, regardless of whether food is self-produced or imported (33,40–42). However, both methods have limitations in validating food insecurity in all countries for which food insecurity is calculated. Therefore, this study extracts and explains the advantages and problems of the conventional FSSR. Our goal is to determine how to solve these problems and how to create a practical formula for calculating the food self-sufficiency ratio. We would like to draw conclusions as to whether the formula proposed in this study has an advantage over the conventional formula by comparing both formulas from various angles. The conventional FSSR framework itself is based on the FAO's definition: "The concept of food self-sufficiency is generally interpreted to mean the extent to which a country is able to meet its food needs with its own resources" (2,20,32). This study also follows this definition. Whether it is a fundamental principle of national control or an expanding concept of food sovereignty in developing countries, the FSSR is an important indicator for assessing the degree of food security in countries (43–45).

Previous studies have used weights as units of measurement, limiting the ability to calculate FSSR for all food types in all countries. That is, while it is possible to quantify production and supply using the weight of a single type of food, comparing the weights of different foods, such as wheat and edible oil or beef and vegetables, is problematic. The alternative approach of calculating calorie self-sufficiency, which considers the daily per capita share of calories consumed within a country, also does not accurately reflect the actual food supply and demand. Using the current market value of all foods as a measure, the price-based FSSR has a functional advantage over weight- or calorie-based ratios because it is a common measure. However, a major drawback is that prices fluctuate over time and between markets.

The calculation formula proposed in this study, the SSFSSR, solves this problem. This study positions calories as an alternative quantitative analytical measure to weight and price. The methods of calorie measurement are generally consistent; thus, calories can be used as a homogeneous measure common to all foods. The SSFSSR uses caloric intake as a quantitative analytical metric and employs the primary product conversion rate (PPCR: primary product input/secondary product output) to convert imported secondary products back into primary products. It is assumed that the PPCR varies by byproduct. According to the FAOSTAT[1], feed input into livestock production, a typical secondary product worldwide in 2021, accounted for 32% of the domestic supply. This "feed" refers to concentrated feed types and excludes feed consumed by the livestock farmer and nonconcentrated feed purchased from the market–by the farmer from neighboring farms[2]. When combined with feed release through off-market channels, the percentage of global consumption could easily exceed 32%[3].

Although feed accounts for such a large proportion of the total, livestock farmers may be able to save on many feeds if livestock production is made more efficient. For this reason, there has never been a

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[1] FAOSTAT, Food Balances(2010-)

[2]FAOSTAT, Definitions and standards - Food Balances (2010-)

[3] (61)

time when a method of calculating the food self-sufficiency ratio that allows countries to calculate it uniformly and more accurately is necessary.

2. Methods and Materials

2.1. Method

The study hypothesis of this study is that the SSFSSR formula is more compatible and effective than the CFSSR formula in determining the actual state of global food self-sufficiency, and the objective of this study is to test this hypothesis. The objective of this study is to test this hypothesis. The study framework for achieving this objective is shown in Fig. 1. The best way to test this hypothesis is to compare the two formulas.

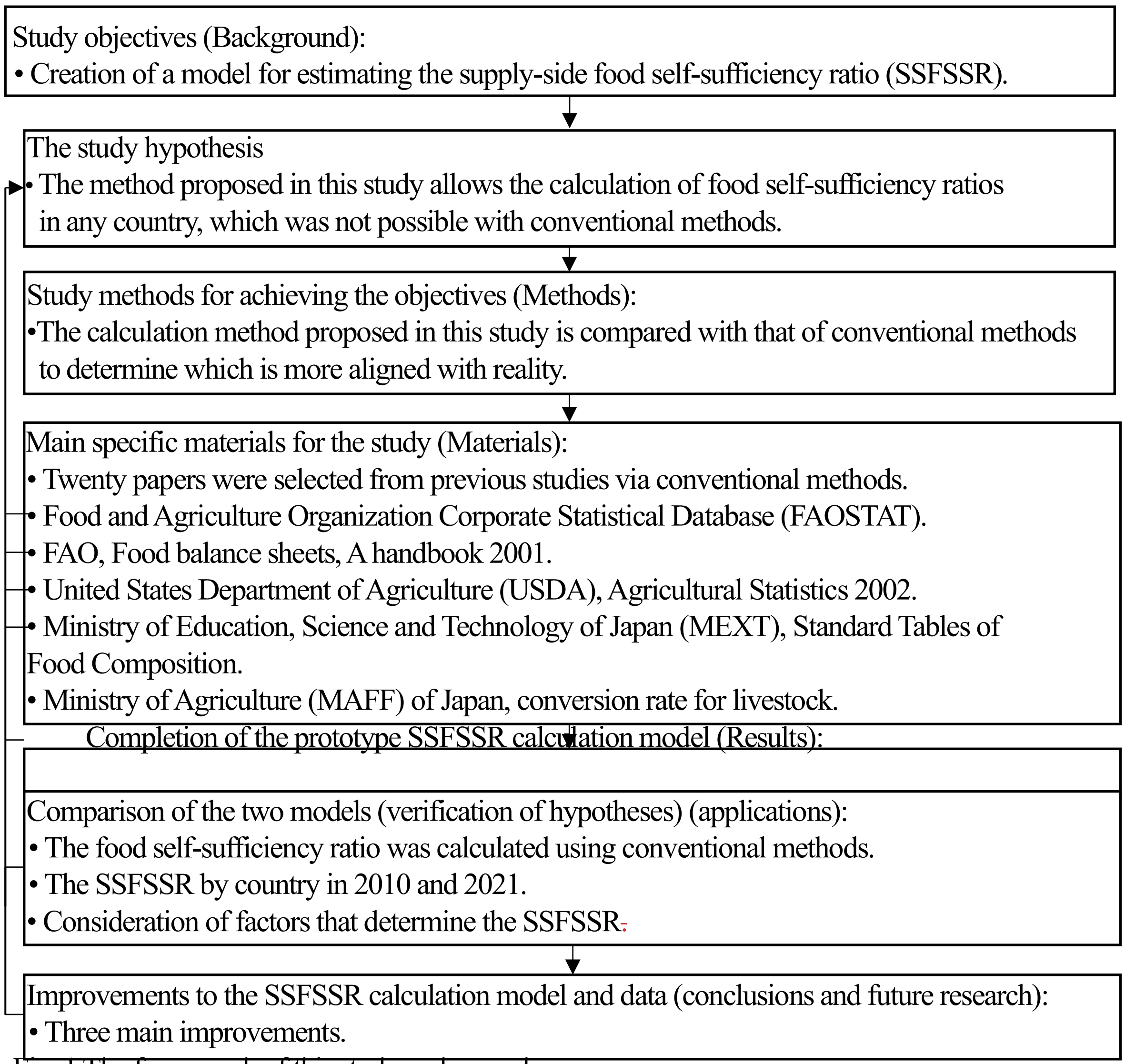

Fig. 1 The framework of this study and procedure.

Source: Created by the author.

2.1.1 The CFSSR

The general formula for calculating the CFSSR is as follows:

$$\left(\sum_{i=1}^{n} Di\right) \times 100 / \sum_{i=1}^{n} Si \qquad (1)$$

where i is the calculation type, such as domestic wheat, rice, corn, soybeans, or millet, and the unit of measurement is weight. D indicates that this sum is the total production of domestic products i through

n. S indicates that this sum is the total supply of types i through n. The same formula applies to beef, pork, broilers, mutton, and other livestock products.

In this formula, grain and livestock products cannot be added together. This is because grains and livestock products are different types of agricultural products. Calculations by the CFSSR are usually performed for a specific country/region, and no reliable formula has been presented to calculate the CFSSR for any country in the world. The formula does not allow for an integrated calculation of the food self-sufficiency ratio, which includes all food consumed in the daily diet, regardless of country/region. The traditional food self-sufficiency formula allows for the aggregation of cereals, vegetables, fruits, meat, dairy products, eggs, edible oils, sugar products, fish and seafood, and salt as units of calculation.

In some cases, such as Japan and Taiwan, a certain portion of self-sufficiency is calculated using calories, but there are several problems. The specific method assumes that the amount of food eaten by each citizen per day is 100%, after which the percentage of domestically produced food is calculated. This method ignores inefficiencies and losses that occur during the conversion or processing of primary products into secondary products from the time food is produced (harvested) to the time it is consumed by humans, as well as damage and losses that occur during transportation and storage. For example, this method of calculating the FSSR for 2,500 kcal consumed orally per day ignores the 3,000 kcal that may have been expended in producing or processing 2,500 kcal of food prior to consumption; in other words, this method is insufficient, as it calculates only the FSSR for a portion of the total food supply. The reason for this is that the food used in the calculation is not distinguished between primary and secondary products. Another conventional method for calculating FSSR is to calculate food by weight, but this method lacks a scientific basis. In addition, each CFSSR has the disadvantage that the calculations are not reproducible and the calculation results cannot be verified.

2.1.2 SSFSSR

The formula for calculating the SSFSSR in this study is as follows:

$$\frac{\sum_{i=1}^{k}(dwi \times Ci)}{\sum_{i=1}^{m}(wi \times Ci) + \sum_{i=1}^{n}(wi \times Ppcri \times Ci)} \times 100 \qquad (2)$$

$\sum_{i=1}^{k}(dwi \times Ci)$: Total domestic production of 45 primary products.
where k is the number of 45 domestic products, i is the kth product among the 45–products, dwi is the domestic production weight of the kth product (kg), and Ci is the caloric content per kg of the kth product.

$\sum_{i=1}^{m}(wi \times Ci)$: Total supply of 45 primary products.
where m is the number of 45 primary products, i is the mth product among the 45 products, wi is the supply amount (kg) of the mth product among the 45 products, and Ci is the caloric content per kg of the mth product.

$\sum_{i=1}^{n}(wi \times Ppcri \times Ci)$: Total supply of 20 secondary products converted to primary products.
where n is the number of secondary products, i is the nth product out of the 20 products, wi is the nth product out of the 20 products supplied (kg), Ppcri is the PPCR of the nth product, and Ci is the caloric content per kg of the nth product.

2.1.3 SSFSSR food unit of measurement

The SSFSSR positions calories as an alternative quantitative analytical measure to the weight of food. The methods of calorie measurement are generally consistent; thus, calories can be used as a homogeneous measure common to all foods. The principle that the caloric content is 4 kcal/gram of protein, 9 kcal/gram of fat, and 4 kcal/gram of carbohydrates is widely accepted in both academia and industry (46,47). This rule can be used to calculate the caloric content of all foods, after which the caloric content can increase or decrease on the basis of weight. Many foods have different compositions and amounts of protein, fat, and carbohydrates; therefore, even if they have the same weight, their caloric content will differ. This property of calories makes them a suitable common measure for comparing different foods. The role of calories in foods is thus similar to the role of price in goods. However, prices fluctuate over time and from region to region, whereas calories have no such fluctuations, making them an absolute measure that can be used similarly to a value measure.

2.1.4 Meaning of supply-side food

The structure of the SSFSSR thus created is described in Fig. 2. The SSFSSR calculates the FSSR by considering food from the point at which it enters the supply chain after harvest until it is consumed. It thus incorporates the stages of postharvest, storage, and import. Most food in these stages is in the form of primary products, some of which are processed into secondary products, such as livestock products, edible oils, sugar products, and juices, which undergo compositional changes. The SSFSSR automatically accounts for the quantitative loss of food due to spoilage, waste, rodent damage, and attrition during processing after harvest (14,15,48–50). The conventional FSSR methods exclude the calories of primary products used as intermediate inputs, such as livestock feed and raw materials for edible oils, as well as losses, spoilage, waste, rodent damage, and attrition during processing from the postharvest stage until human consumption.

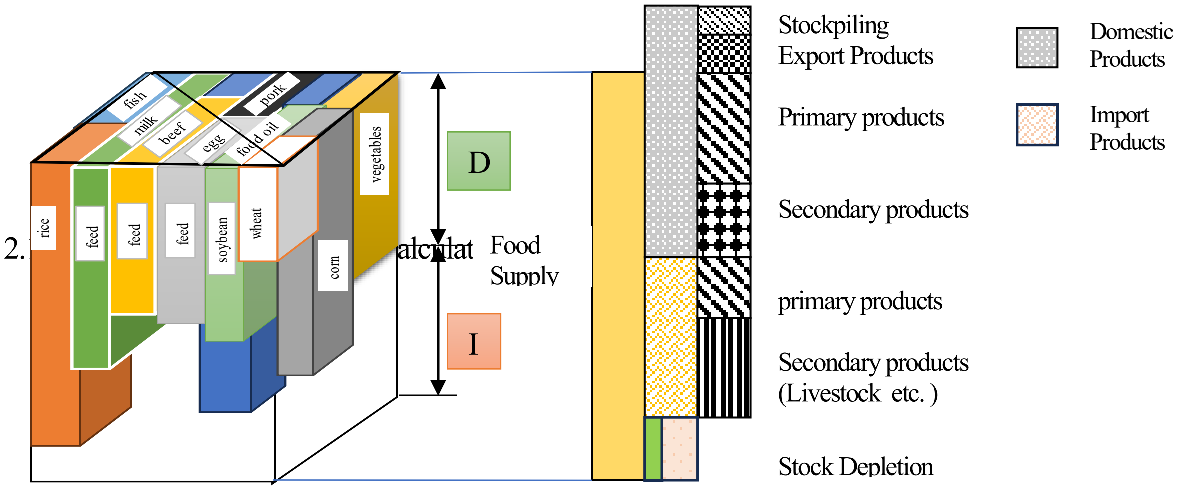

Fig. 2 Framework for the SSFSSR.
Source: Created by the author.
D: Domestically produced primary products in the food supply. I: Imported products in the food supply. The formula for I= Imported primary products + Products converted to primary products was calculated using PPCR for all types of imported secondary products ($\sum_{i=1}^{n} ppcri \times xi$). n: Number of imported secondary product types, ppcri: PPCR for imported secondary products i, xi: Import volume of secondary products i). D and I each include food losses such as spoilage, deterioration, and losses during the processing process from harvesting and importing food to processing and delivery to households. When calculating an SSFSSR that includes secondary products, adding a secondary product to a domestic agricultural product will result in a doubled count. In the case of imported secondary products, the FSSR cannot be accurately calculated unless the secondary products are converted to primary products, which are the raw materials. As shown on the left side of Fig. 2, the concept of calculating the SSFSSR is based on quantitatively converting imported secondary products into primary products.

In this study, the calculation of the SSFSSR was focused on 65 food types (Table 1), encompassing both primary and secondary products. The primary products included 45 types, such as grains, legumes, roots, vegetables, fruits, raw materials for edible oils, raw materials for sugar, and seafood. There were 20 secondary products, including livestock products, dairy products, edible oils, and sugar products. These 20 secondary products are produced from 45 primary products as raw materials. Excluding these 65 types are juices, seasonings, food additives, spices, alcoholic beverages, coffee, and tea. The calories per kg for secondary products are not based on the calories per kg of the type itself (e.g., pork) but on the calories of the primary products used to produce one kg of the secondary products. Producing one kg of beef requires more than 10 kg of feed (which means that the PPCR is 10), so the input calories needed to produce one kg of fillet steak amount to 3,560 kcal (per kg)× 10 kg = 35,600 kcal.

Table 1 List of food products(65 types)

	Products		Products		Products
1	Barley and products	23	Groundnuts	45	Aquatic Animals, Others
2	Maize and products	24	Apples and products	*46*	*Bovine Meat*
3	Millet and products	25	Bananas	*47*	*Pigmeat*
4	Oats	26	Grapefruit and products	*48*	*Poultry Meat*
5	Rice and products	27	Grapes and products (except Wine)	*49*	*Meat Other*
6	Rye and products	28	Oranges, Mandarines	*50*	*Eggs*
7	Sorghum and products	29	Pineapples and products	*51*	*Milk-Excluding Butter*
8	Wheat and products	30	Sugarcane	*52*	*Butter, Ghee*
9	Cereals, Other	31	Sugar beet	*53*	*Maize Germ Oil*
10	Tomatoes and products	32	Sunflower seed	*54*	*Soyabean Oil*
11	Sweet potatoes	33	Sesame seed	*55*	*Groundnut Oil*
12	Onions	34	Rape and Mustard seed	*56*	*Sunflower seed Oil*
13	Potatoes and products	35	Oil Palm	*57*	*Sesameseed Oil*
14	Yams	36	Palm kernels	*58*	*Rape and Mustard Oil*
15	Roots, Other	37	Olives (including preserved)	*59*	*Palm Oil*
16	Cassava and products	38	Oilcrops, Other	*60*	*Palmkernel Oil*
17	Vegetables, other	39	Cotton seed	*61*	*Olive Oil*
18	Soyabeans	40	Coconuts-Incl Copra	*62*	*Oilcrops Oil, Other*
19	Beans	41	Aquatic Plants	*63*	*Cottonseed Oil*
20	Pulses, Other and products	42	Pelagic Fish	*64*	*Coconut Oil*
21	Peas	43	Freshwater Fish	*65*	*Sugar (Raw Equivalent)*
22	Nuts and products	44	Demersal Fish		

Primary products: No.1-45, *Secondary products: No.46-65.*

Source: Food balances (2010-). Products are selected by the Author.

2.1.6 Primary product conversion rate (PPCR)

An essential variable in the SSFSSR calculation formula is PPCR (see formula (2)).– However, at this stage, no study has published PPCR values for all secondary products. Therefore, in the present study, we adopted provisional PPCRs for 20 types of products (Table 2), including livestock products, edible oils, and sugar products. This study used PCR to convert the total amount of secondary products, including edible oils, sugars, and other products, into the amount of primary products. The definition of PPCR includes the feed conversion rate (FCR) for livestock products, as shown in several previous studies (51–57). The PPCR, which is the kg of primary products to be input per kg of secondary products to be output, is defined in exactly the same way as the FCR. In that sense, the PCCR builds on the findings of FCR studies and overcomes the theory of FCR. To our knowledge, no previous studies have asserted the necessity of a conversion rate for all secondary products, not just livestock products. The PPCR method varies for each type of secondary product and is influenced by the technology used to produce the final secondary product from the primary product, as well as the quality and variety of the primary product. These factors vary significantly by country/region, farmer, and company that manufactures secondary products.

Table 2 PPCR of secondary products (mutable)

Product	PPCR
Beef	11.0
Pork	6.0
Poultry	4.0
Meat, other	4.0
Eggs	2.0
Milk - excluding butter	1.0
Butter, ghee	1.0
Maize-germ oil	2.2
Soybean oil	5.5
Groundnut oil	2.5
Sunflower seed oil	5.0
Sesame seed oil	2.1
Rape and mustard oil	2.8
Palm oil	2.0
Palm kernel oil	2.0
Olive oil	4.0
Oil from other oil crops	3.4

Cottonseed oil	6.1
Coconut oil	1.4
Sugar (raw equivalent)	8.0

Source: USDA, Ministry of AFF of Japan,
https://www.doinggroup.com/index.php?u=show-1986.html
(Viewed on Nov.10, 2023), Interview by the author.

2.2. Materials

2.2.1 Materials for creating the CFSSR formula

The fundamental data sources used for the calculation of the CFSSR and SSFSSR include the Global Food and Agriculture Statistics of FAOSTAT (2,21,32,58–67). The basic data used to compare the two formulas are from the same FAOSTAT, which extracts the annual production and supply in weight units. The CFSSR is unable to calculate livestock products. The reason for this is that the self-sufficiency ratio for livestock products cannot be regarded as purely domestic if imported feed is used, even if the livestock products themselves are domestically produced.

The reference material used to construct the CFSSR formula (1) itself is a list that consolidates 20 previous studies (Table 3: This table is available at the end of this document). The prototype of the CFSSR has been officially defined by the FAO(32). Formula (1) of the CFSSR is a summary of the greatest common divisor of the studies (8,19,68–74) that calculate the FSSR using weight as the unit of measurement of food. For the purposes of this formula, the nine grains included were wheat and products, maize and products, rice and products, barley and products, rye and products, oats, millet and products. These nine grain crops represent the majority of the grain crops grown in the world. The formulas listed in the same table (Table 3: This table is available at the end of this document) include study results that look beyond the CFSSR, such as the use of calories as a unit of measurement (75,76), and noteworthy studies that use the primary product conversion rate (PPCR) as a variable for calculating food self-sufficiency (54,57,77,78). However, a formula for calculating the food self-sufficiency ratio itself has not been established.

2.2.2 Materials for creating the SSFSSR formula

The SSFSSR is a formula for calculating food self-sufficiency that was devised in this study out of the need to overcome the problems with the CFSSR. In this sense, the CFSSR itself is one of the materials for the study of the SSFSSR. To develop a prototype SSFRSR, information needs to be obtained on the list of primary and secondary products to be calculated, the calorie content per kg of all primary products, the multiplication factor of the primary product required to produce one unit of secondary product, and the primary product conversion rate (PPCR). For the calorie content per kg of all primary products, see Table 4, and for the PPCRs of all secondary products, see Table 2. To compare the CFSSR and SSFSSR, it is necessary to show the actual calculation of the FSSR. The following materials were used for this purpose.

The materials used exclusively for the SSFSSR include International Monetary Fund (IMF) data (79); statistics from Japan's Ministry of Agriculture, Forestry and Fisheries (26); interviews with relevant officials; data from the United States Department of Agriculture (80); FAO's "Food Balance Sheets, A Handbook, 2001" (58); and Japan's food composition database (81), which are indispensable for this study because they offer primary nutritional composition tables for key foods, caloric data, and especially fundamental measurements in the calculation of the SSFSSR.

Table 4 Calories contained in primary products (kcal/kg).

Product	kcal/kg	Product	kcal/kg
Barley and barley products	3460	Apples and apple products	480

Maize and maize products	3560	Bananas	600
Millet and millet products	3400	Grapefruit and grapefruit products	160
Oats	3850	Grapes and grape products (excl wine)	530
Rice and rice products	3600	Oranges and mandarins	640
Rye and rye products	3190	Pineapples and pineapple products	260
Sorghum and sorghum products	3430	Sunflower seed	3080
Soybeans	3350	Sugarcane	500
Wheat and wheat products	3340	Sugar beet	500
Cereals, other	3400	Sesame seed	5730
Tomatoes and tomato products	670	Rape and mustard seed	4940
Sweet potatoes	920	Oil palm	1580
Onions	310	Palm kernels	5140
Yams	1010	Olives (including preserved)	1750
Roots, other	910	Oil crops, other	3870
Vegetables, other	220	Cottonseed	2530
Potatoes and potato products	670	Coconuts - incl copra	1840
Cassava and cassava products	1090	Pelagic fish	860
Pulses, other and their products	3400	Freshwater fish	690
Peas	3460	Demersal fish	420
Nuts and nut products	2620	Aquatic animals, others	1360
Ground nuts	5670	Aquatic plants	540
Beans	3410		

Source: FAO, Food Balance Sheet. A Handbook 2001, MEXT of Japan, n.d.

The calories of wheat flour, rice flour, corn flour, etc.,, are almost the same as those of the original wheat, rice, and corn, etc.

3. Comparison of the results

3.1 CFSSR 2021

The average CFSSR for countries around the world in 2021 was 66.4%, with 108 countries/regions below the average accounting for 59.0% of the total. The median is 54.6%, which is 11.8% above the average. The standard deviation is also large at 68.1%, indicating that the disparity in FSSRs among countries/regions using this formula is abnormally large. The coefficient of variation for the data is high at 102.6%, suggesting that there are problems with the reliability of the data. The countries/regions with the highest CFSSR are Australia at 388.8% and Ukraine at 367.5%, while eight other countries/regions have a CFSSR of more than 200%: Bulgaria at 284.6%, Argentina at 277.1%, Latvia at 261.4%, Lithuania at 252.1%, Guyana at 229.2%, Moldova at 221.6%, Estonia at 216.1%, and Romania at 204.8%. Thirty-nine countries/regions, or 21.3% of the total 183 countries/regions, had a CFSSR of more than 100% (Table 5: This table is available at the end of this document). The countries/regions with the lowest CFSSR are Antigua Barbuda, Bahrain, Cabo Verde, Dominica, French Polynesia, Djibouti, Kiribati, Grenada, Maldives, Nauru, Micronesia, Saint Kitts and Nevis, Saint Lucia, Seychelles, Trinidad Tobago, Burkina Faso, and Samoa, with 17 with 0%. Food is heavily influenced by agricultural geography and natural conditions, but if only grains are considered, the FSSR has an extreme distribution, as shown here. Forty-four countries/regions had a CFSSR of 10% or less, accounting for 24.0% of the total.

3.2 SSFSSR 2021

3.2.1 Specific calculation process for each country's SSFSSR

The method for calculating the SSFSSR for each country in this study divides all the food supplied into primary and secondary products (see Additional file 1). This method is new in that it covers all the food produced, processed, stored, and transported by humans. This method has the advantage of overcoming the problems associated with CFSSR calculations and can accurately measure a country's food shortages and export capabilities.

The largest dataset containing the data needed for this calculation is FAOSTAT. Here, we selected the country/region to be calculated from FAOSTAT; the necessary types, such as production volume, import volume, and supply volume, measured by weight from “elements”; and the necessary food types from “items” (wheat and agricultural products, corn and agricultural products, etc.); and then selected the relevant year. The foods to be selected were the 45 primary and 20 secondary products listed in Table 1. The foods selected for supply volume were the 45 primary products, the foods selected for production volume were also the 45 primary products, and the foods selected for import volume were the 20 secondary products. The imported volume of secondary products is converted into primary products and subsequently added to the supply volume of primary products. If a secondary product is added to the supply volume, the primary product used to produce it will also be included. Similarly, secondary products are not included in the domestic production volume because secondary products are processed products that use primary products as the main raw material, and adding secondary products to the domestic production volume results in a doubling of the supply volume.

For each food type allocated by weight to production, imports, and supply, the weight is converted to a caloric intake measure via the food composition in terms of the retail weight (“as purchased”) in 100 × g for international use”(58). For example, the production and supply of 10 kg of primary products such as wheat and its products is equal to 100 × 334 kcal = 33,400 kcal because the caloric value of wheat and its products is 334 kcal per 100 g. All 45 primary products are quantified as calories in this way. In contrast, imported secondary products are converted to primary products as measured by caloric intake via PCR. The calculation method converts the volume of imported secondary products to calories in the same manner as in the previous example and then multiplies the result via the PPCR. For example, the caloric conversion value of 10 kg of beef, a secondary product, is 228.3 kcal per 100 g (average); thus, the caloric conversion value is 22,830 kcal (228.3 kcal × 100 g). Furthermore, this caloric conversion value of 22,830 kcal was multiplied by 11, which is the PPCR for beef in Table 2. In total, 10 kg of beef would be worth 22,830 kcal multiplied by 11, which would be 251,130 kcal. Since

10 kg of imported beef has already been supplied domestically, it is converted into a primary product, such as feed grain, which is then added to the supply and becomes part of the total supply as feed grain. As described above, to calculate a country's SSFSSR for a certain period, production, imports, and supply are compiled for 45 primary and 20 secondary products and converted into calories, a common quantitative measure. Finally, the production is divided by the total supply to obtain the SSFSSR.

3.2.2 The SSFSSR for 183 countries/regions (2021)

According to the SSFSSR, the average for each country in 2021 was 58.9%, which was 7.5% lower than the average CFSSR. The highest country/region is Australia at 245.3%, and the lowest is Bahrain at 0.2%. Australia's CFSSR is 388.8%, which is 143.5% lower than that calculated via the SSFSSR. The reason why 0% of countries/regions that exist in the CFSSR do not exist in the SSFSSR is that the formula covers 65 food types in various sectors and is unlikely to miss the reality of countries/regions that are marginally self-sufficient in food. There were 93 countries/regions with values less than the average, accounting for 50.8% of the 183 countries/regions. The standard deviation of the SSFSSR was 43.3%, which means that there is less variation between countries/regions than that of the CFSSR. Even when the SSFSSR formula is used, the disparities between countries/regions remain large. The world comprises 26 countries/regions (14.2%) with an SSFSSR of 100% or more and 157 countries/regions (85.8%) with an SSFSSR of less than 100%. However, not all countries/regions with an SSFSSR of 100% or more have enough home-grown food that they can afford to export (73). It cannot be ignored that some countries/regions with an SSFSSR of 100% or more, despite economic hardship, are not only unable to import the shortfall in domestic consumption but also export food to earn foreign currency, resulting in a calculated SSFSSR of 100% or more. Of the 183 countries/regions for which the SSFSSR was calculated, 22 have a per capita GDP of less than $1,000, including the Central African Republic, Burundi, Afghanistan, and Mozambique. Of these, 18 had an SSFSSR of 70% or more, 11 had an SSFSSR of 80% or more, and one had an SSFSSR of 100%. Among countries with a per capita GDP of less than $1,000, only four have an SSFSSR below 50%: Afghanistan, Georgia, Liberia, and Yemen. Although these four countries are economically poor, they are mathematically able to import more than 50% of their domestic food needs (Table 6).

Table 6 SSFSSR for Low GDP per Capita Countries ($1000 or Less)

	GDP/P($)	SSFSSR(%)
Burkina Faso	893	84.5
Burundi	221	89.4
Central African	461	89.1
Chad	686	89.1
DRC	577	97.2
Ethiopia	925	83.6
Guinea	795	76.7
Guinea-Bissau	759	73.1
Madagascar	503	77.9
Malawi	634	103.0
Mozambique	492	71.4
Niger	591	76.5
PRK	645	85.9
Rwanda	821	70.5
Sierra Leone	505	94.8
Sudan	750	72.5
Togo	964	81.6
Uganda	883	80.2
Afghanistan＊	364	48.9
Georgia＊	772	28.2
Liberia＊	676	43.5
Yemen＊	604	7.2

Source: Created by the author.

* Countries with low GDP per capita and low SSFSSR.

3.3 Comparison of the CFSSR and SSFSSR calculation results

3.3.1 Statistical indicators

The calculation results for the CFSSR and SSFSSR are shown in Table 5. There was a statistically significant difference between the two datasets (p value=0.0048), so it is meaningful to compare them. The CFSSR is high in countries/regions with high grain production and 0% or very low in countries/regions with no or little grain production. Countries/regions with a foreign exchange reserves per capita (FSLR) of 100% or more have a CFSSR of 39 and an SSFSSR of 26, and from the perspective of food security, the CFSSR provides a sense of security. However, this only applies to grains, and it will be of only partial security to people who live on other types of food. There are countries/regions where the CFSSR significantly exceeds the SSFSSR, but this does not meet the self-sufficiency requirements for food as a whole. For example, in Austria, the CFSSR accounts for 79.8%, but the SSFSSR accounts for 42.8%, meaning that the SSFSSR is approximately half the CFSSR. Since the country is a major producer of wheat, barley, and corn, it is natural that the CFSSR, which is a formula for calculating the self-sufficiency ratio that only covers grains, would be high. On the other hand, the country is also a major producer of livestock products such as dairy, beef, and pork, which also act as factors in pushing up the FSSR; however, consumption is also high, and feed is imported, so the FSSR should generally be lowered. Nevertheless, Austria's FSSR, as measured by the CFSSR, is at a high level. A similar pattern can be seen in other regions, such as Croatia, the Czech Republic, Denmark, Finland, Germany, Italy, Luxembourg, Mongolia, New Zealand, Slovakia, Slovenia, Suriname, Sweden and Egypt, whose CFSSRs are well above 100%.

We compare the SFSSR and SSFSSR in greater depth from the perspective of which is more suitable as a method of calculating each country's FSSR. The two data distributions are relatively similar, but when we perform a Shapiro–Wilk test(82,83) on the self-sufficiency ratios of both countries, the p values are both very small, less than 10^{-8}, and they both share the common feature of not following a normal distribution. The SSFSSR is 17.32×10^{-8}, while the CFSSR is 1.99×10^{-13}, which is even smaller and significantly deviates from the normal distribution, making it more susceptible to statistical outliers and more likely for the average value to deviate from reality. The CFSSR, which is the FSSR limited to the single food sector of grains, can be strongly influenced by each country's natural, socioeconomic and agricultural production conditions, as well as by abnormal weather and changes in specific weather conditions; moreover, it cannot be denied that it may be detached from overall food trends. When the results calculated for the CFSSR and SSFSSR were statistically analyzed, the difference between the average and median for the SSFSSR was smaller than that for the CBFSSR, and the overall data were symmetrical. The standard deviation is smaller for the SSFSSR, and the variation in the data is smaller. The coefficient of variation of the data is smaller and more stable for the SSFSSR. For these reasons, we believe that the SSFSSR is more reliable than the CFSSR for calculating FSSR (Table 7).

Table 7 Comparison of the SFSSR and SSFSSR calculation results

	Mean (%)	Median(%)	S/D(%)	C/V(%)	Shapiro–Wilk test
CFSSR	66.4	54.6	68.1	102.6	1.99×10^{-13}
SSFSSR	58.9	55.9	43.3	73.9	7.32×10^{-8}

Source: Table 5.

S/D: standard deviation, C/V: coefficient of variation.

3.3.2 Reducing PPCR Increases the SSFSSR

The PPCR in the SSFSSR calculation formula has a special function. The factor determining PPCR is the processing efficiency of the secondary product production process. In theory, a lower PPCR indicates that raw materials (primary products) can be saved or that more secondary products can be produced with fewer primary products. If the PPCR could be reduced, the SSFSSR would increase, which could be achieved without increasing absolute commodity production. The validity of these findings is shown by the formula for calculating the SSFSSR, and its effect is explained in Fig. 3. The SSFSSR is inversely proportional to the decrease in the PPCR. The results of our SSFSSR calculations reveal that increasing food production on domestic farmland is not the only method used to improve the SSFSSR. This point, which has been overlooked by conventional calculation methods and their underlying ideologies, is a finding of this study. Lowering the PPCR of a particular country or specific food type increases the SSFSSR of that country or food type.

Two studies that attributed the degree of beef PPCR to the composition and formulation of feed demonstrated that the range of PPCR can decrease from 13.1% to 74.4% (53,84). Another study quantified residual feed intake (RFI)[4] and dry matter intake (DMI)[5] to match the individual characteristics of fattening cattle and reported that individualized management can reduce daily feed intake by 13%(85). In the case of pork, the quality of breeding management, which accounts for breed and individual characteristics, can reduce PPCR from 2.23±0.07 to 2.65±0.07 (56). Additionally,

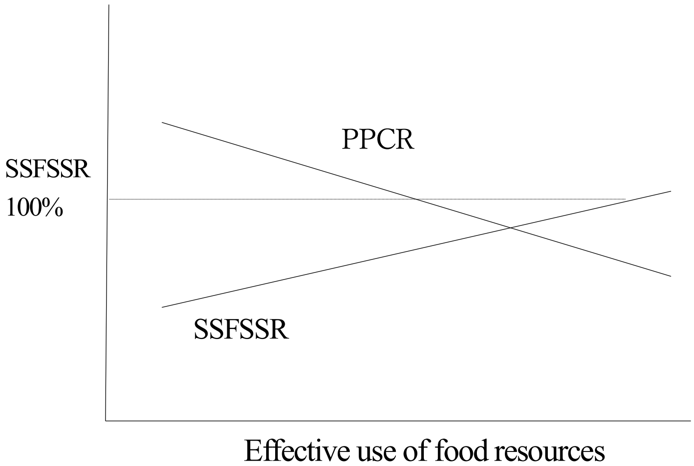

Fig. 3 Effect of lowering PPCR in SSFSSR
source: Created by the author.

Nutritional management, loss prevention, feed digestion promotion, individualized weight management (86), structural improvements in breeding pig houses, seasonal management, and sex management of pigs resulted in an average PPCR of 2.71±0.14, with a minimum of 2.44 and a maximum of 3.20, indicating a reduction of 31.1% (51). For broilers, one study compared the effects of reducing feed

[4] RFI = Actual feed intake − Predicted feed intake.

[5] DMI=Total feed intake×(1−Moisture content).

intake by 5%, 10%, 15%, and 20%, concluding that a 15% reduction resulted in the best survival and growth rates for chicks, with a reduced PPCR of 2.15±0.02 (87,88). Similarly, in poultry egg production, a study demonstrated that adding protein nutrients to feed could reduce PPCR by 5% (89,90). In addition to feed nutrient adjustment, the administration of albumin and globulin, which affect milk yield and quality, respectively, to dairy cattle resulted in a decrease in PPCR of 2.32±0.1, a 32.8% reduction compared with the worst-case scenario (91,92). For seafood, improvements in rearing environments and feed tailored to the characteristics of seafood species have been shown to reduce PPCR (52). Similarly, for edible oils and sugar, improvements in processing technology and the use of high-quality raw materials reduce PPCR by conserving primary products (93–95).

A reduction in the PPCR rate is applied to all domestically produced secondary products. If the reduction ratio is R, the amount of primary product after savings can be calculated as Ppcr× (1-R). As a result, the food supply corresponding to the denominator decreases, and the SSFSSR increases. Therefore, formula (1) can be modified as follows:

$$\frac{\sum_{i=1}^{k} w_i \cdot C_i}{(\sum_{i=1}^{m} w_i \cdot C_i)+\sum_{i=1}^{n} w_i \cdot Ppcr_i \cdot (1-R) \cdot C_i} \times 100 \qquad (2)$$

4. Discussion

Relationship to previous studies:

This study shares the concerns of previous studies regarding the expansion of food crises and the importance of understanding FSSRs. This study also discusses the spread of nutrition-oriented methodologies such as DESs[6] from the conventional weight-based approach. In particular, studies on FCR have spread; that is, FSSR methodologies that consider the input of primary products into

[6] Per capita dietary energy supply.

secondary products have expanded. On the basis of these findings of previous studies, this study proposes that it is appropriate to adopt the calories contained in all foods in a measurable state as a unit of measurement for FCR and further proposes PPCR as a development of FCR studies. As a result, we have derived the theory that FSSRs increase if PPCR decreases, that is, if the efficiency of the technology for producing secondary food products is improved. By developing the results of previous studies into this new methodology, it has been possible to address issues that could not be solved via previous methods. In other words, it is possible to use these variables in the formula for calculating the overall FSSR, which includes grains, beans, fruits and vegetables, livestock products, edible oils, sugar products, and seafood that people eat on a daily basis; the results show that these variables can be used to calculate the FSSRs of countries around the world. Previously, the only methods available for calculating FSSRs for each country in the world were limited to grains.

Limitations of this methodology:

The proposed formula, the SSFSSR, has several limitations. In this study, no unit of measurement other than calories was used. For example, protein, fat, carbohydrates, etc., could be used as units of measurement, but in this study, no unit of measurement other than calories was found to have measurable quantities for all foods. This study should have considered more deeply whether there are any factors other than calories that are more appropriate as a unit of measurement for calculating the food self-sufficiency ratio, but this study did not do so. In addition to calories, other elements can be assumed, such as protein, fat, and carbohydrates. There are foods that do not contain these elements, and there is room for research into whether this is possible.

The PPCR, one of the coefficients in the SSFSSR calculation formula, is affected by each country's technological levels for food production, distribution, storage, and processing. The proposed SSFSSR calculation formula does not take this into account, so the fact that the PPCR remains at an average level is one of the limitations of this study that cannot be overlooked.

Practical issues with this methodology:

To apply the SSFSSR formula in practice, systematic foods such as grains, soybeans, livestock products, edible oils, fruits and vegetables, and seafood are included in the calculation. There are 65 items, 45 of which are primary and 20 of which are secondary products. Although the number of food types was greater than the number used in the CFSSR and the FSSRs published by the seven governments mentioned above, various canned foods, packed and sterilized foods, frozen processed foods, and seasonings were excluded. In addition, not all livestock products, beans, fruits, or vegetables are included in the calculation.

The caloric intake per kg of food used to calculate the SSESSR in this study was taken from the Food Balance Survey (FAO)(61), and it is necessary to consider the possibility that the accuracy of the SSESSR may have decreased. The FAO has not updated its new data. The same product is divided into many varieties, and it is not realistic to use all of them as the subject of the calculation; however, ideally, the entire product should be used as the subject of the calculation.

Future study topics and ideal study directions

- Expand the list of types with data on calories per kg and collect those data. Currently, datasets that comprehensively organize data on calories per kg of food eaten on a daily basis by humans include FAO Food balance sheets(61), the USDA Energy Value of Foods(47), the China Food Composition(96), and Japan Standard Tables of Food Composition(97). Our goal was to extract the most common food types in international diets and obtain the average value of calories per kg from each country's dataset.
- Create a calculation formula that incorporates food waste. To do this, we need to develop a method to grasp food waste within the home and a method to distinguish between imported and domestically produced food waste.

- Future studies on the SSFSSR should include a detailed examination of the factors that determine PPCR, which is a critical component of the SSFSSR. Secondary products are derived from primary products that weigh several times more than the primary products. In addition, secondary products are produced via complex processing techniques. Proper postharvest handling, storage, and logistics of primary products are also factors that can reduce PPCR. The entire food supply chain also contains essential information for developing specific measures to improve food supply efficiency and reduce losses and waste (15).

One of the problems common to all formulas for calculating the food self-sufficiency ratio is that they do not incorporate factors that reflect the nutritional intake status of the nation's citizens(98). It is not necessarily the case that people in a country with a 100% food self-sufficiency ratio are well nourished, whereas people in a country with a food self-sufficiency ratio of 30% are very poorly nourished. An element for future improvements to the SSFSSR includes incorporating this factor into the formula.

5. Conclusion

This study hypothesized that the SSFSSR is a more appropriate method for measuring the food self-sufficiency ratio of countries/regions around the world than conventional formulas are for calculating the food self-sufficiency ratio and verifying this hypothesis. For verification, the two formulas for calculating the food self-sufficiency ratio share the same data required for calculation; a comparison was made of the foods and the range of countries/regions covered by the calculation, and statistical tests were also performed on the results of each calculation. As a result, it was possible to calculate the food self-sufficiency ratios of 183 countries for which the necessary data were available for 65 types of foods, and it was concluded that the SSFSSR, which passed valid statistical tests, is the most appropriate formula.

The formula of this study, which incorporates PPCR (Table 2), clarified that a decrease in PPCR is directly linked to an increase in the FSSR. This study is the first positive evaluation of the role of the PPCR among similar studies. A decrease in the SSFSSR indicates that production is not keeping up with consumption, but the impact of stagnant PPCR and lower production and processing efficiency of secondary products is undeniable. However, improving these data to increase their accuracy is also a topic of future study. Specifically, we hope that the dataset of calories per kg of food will be updated and internationally standardized and that country-specific PPCEs will be internationally standardized to reflect differences in food processing technology. This study determined that it is best to set calories per kg of food as the unit of measurement; however, one of the future study topics is to explore other units of measurement that play roles equivalent to calories.

This formula allows any country to calculate its own SSFSSR, and the results can be reproduced by anyone. This formula can provide each country with an effective method for closely reexamining the actual state of its own food production and imports. In the future, we would like to provide a formula for calculating the FSSR at a higher level while resolving the multiple issues mentioned above.

Using the SSFSSR formula employed in this study, we calculated food self-sufficiency ratios for 65 different foods for each country in 2021. The results show that only 26 countries/regions, or 14.2% of 183 countries/regions, have a food self-sufficiency ratio of more than 100%, whereas 157 countries/regions, which account for the majority, have a ratio of less than 100%. Ukraine, the United States, Canada, Australia, France, Russia, Brazil, and Argentina are well above 100%, but many developed countries, such as the United Kingdom, Germany, Italy, Japan, and South Korea, are below 50%, China, one of the world's largest population powers, is below 80%, and another population power, India, is slightly over 100%. Twenty-four countries, or 13.1% of the total, have ratios less than 10%. There are 157 countries worldwide that share a surplus of food produced by a small number of countries. However, there is no proof that the shortfall is sufficiently distributed to each country/region.

Increasingly severe agricultural weather extremes, pandemic-damaged food supply chains, escalating conflicts among food superpowers, and a world population that will continue to grow for several years, as well as increasing demand for food, are all factors that exacerbate this growing food insecurity.

The formula for calculating the SSFSSR proposed in this study is not particularly complicated. The purpose of proposing the SSFSSR is for each country to be able to use this formula to calculate its own food self-sufficiency ratio easily for a period of interest. To achieve this, it would be good to have an application that would immediately output a country's food self-sufficiency ratio by inputting the necessary data. Once we have a solution to the above problems, we would like to work on developing such an application.

Governments and international organizations must invest in infrastructure to reduce postharvest food storage and transportation losses, establish cold chains to prevent spoilage and provide education in logistics techniques and training in food management. In addition, policies supporting technological innovation aimed at improving PPCRs through sustainable agricultural practices and food processing efficiency are essential. We suggest that countries/regions that are concerned with the food security of their citizens first learn about the current status of their SSFSSR through comparisons with neighboring countries. Policies to alleviate food insecurity will be effective only if they are based on the current status of the SSFSSR.

List of abbreviations

DEP: Dietary energy production

DES: Dietary energy supply

DMI: Dry matter intake: amount of feed intake $\times \{1 - (\text{moisture content of feed})/100\}$kg

FAO: Food and Agriculture Organization of the United Nations

FAOSTAT: Food and Agriculture Organization Corporate Statistical Database

FCR: Feed conversion rate

FER: Foreign exchange reserves per capita

FSSR: Food self-sufficiency ratio

GDP: Gross domestic product

IMF: International Monetary Fund

MEXT: The Ministry of Education, Culture, Sports, Science and Technology of Japan

PPCR: Primary product conversion rate

RFI: Residual feed intake (an indicator of feed efficiency)

SSFSSR: Supply-side self-sufficiency ratio

USDA: United States Department of Agriculture

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Authors' contributions

The author solely conducted the study and preparation of this manuscript. Specifically, the author was responsible for the following tasks:

- Conceptualize and design the study.
- Data collection and acquisition.
- Data analysis and interpretation.
- Drafting and revising the manuscript.
- Approval of the final version of the manuscript for publication.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The author declares that he has no competing interests.

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Table 3 Formulas for calculating food self-sufficiency rates in previous studies and author comments					
References	Formula	Definitions	Range of items	Data source	Author comments
(68)	*P×100/P+I+E*	FSSR in year t. P: total production of feed grains and meats. I and E: import and export, P + I − E: the consumption in a region or country.	Corn, soybean, pork, beef, mutton, poultry.	China National Bureau of Statistics, United States Department of Agriculture, Food and Agriculture Organization of the United Nations(FAO), Food and Agriculture Organization Corporate Statistical Database (FAOSTAT),China Animal Husbandry and Veterinary Yearbook.	The methodology for calculating food self-sufficiency (FSSR) in this study primarily analyzes two types of cereals and livestock products. The indicator used to assess FSSR is weight. This study adopts a methodological approach that avoids the inappropriateness of aggregating the weights of different items, by calculating thr FSSR for each item separately. This disaggregated approach is useful for informing the formulation of agricultural policies tailored to individual items.
(8)	*P×100/P+I+E*	P: Production, I: Imports, E: Exports.	Rice, maize, wheat, Vegetables, meat, eggs, dairy products.	FAOSTAT.	This study utilizes the basic form of the FSSR calculation formula to compute FSSR for various items such as rice, corn, wheat, meat, and eggs, based on the weight of each item as a scale. This method allows the FSSR for each item to be treated individually. However, it does not enable the assessment of the FSSR for the entire target region or country.
(69)	*Production ×100/(Production − Export +Import)*	No description.	Beef.	Program Statement of the Government of the Slovak Republic, Research Institute of	This is a case study that investigates the calculation formula and its application of beef self-sufficiency in Slovakia. A key feature of this study is that it explains the

	Suggestion of Ministry of Regional Development of the Slovak Republic Food: Potential self－sufficiency: *Potential self-sufficiency ×100/(Production － Export+Import)*			Agricultural and Food Economics, The European Commission Data.	concept of "potential self-sufficiency." Generally, food self-sufficiency is significant in addressing the real issues of food supply and demand. Potential self-sufficiency indicates the potential of domestic production, so we cannot entirely dismiss it. However, the challenge lies in how to ensure its rigorous measurement.
(99)	(excerpt) *Livestock: (PR＋M)×100/(CR＋CM)* *Crop:* *Pc×100/(Ccpop＋Cc 1st)* Livestock: *(PR＋PM)×100/(CR＋CM)* *Primary crop:* *(Ps×100)/(Cc pop ＋Cc emb)*	Livestock: Refers to ruminant milk, meat, eggs, pork, and poultry meat. PR: Milk and meat from cattle, sheep and goats (production). PM: Eggs, pork, poultry meat (production). CR: Milk and meat from cattle, sheep and goats (consumption). CM: Eggs, pork, poultry meat (consumption). Pc: Harvested grass (production). Cc, pop: Crops used for food and other uses (incl. seed and losses) (consumption). Ps: Pc+ used straw (production). Cc, 1st: Crops used for feed. Primary crop: Refers to crops harvested with crops used for food, other uses, and feed crops required to produce consumed livestock products. Cc, emb: Feed crops required for production of consumed livestock products.	Ruminant, monogastric, crops, primary crops, primary grass, primary biomass.	Common Agricultural Policy Regional Impact(CAPRI), FAOSTAT.	The concept of PPCR* adopted in this study is comprehensible. However, the specific PPCR values, which are expected to vary for each type of livestock product, remain unclear. When calculating the FSSR of livestock products, it is necessary to first calculate the FSSR of feed using PPCR. This study omits this crucial calculation process.

(19)	*Cs={q/(n/qr)}C_s*	Cs: coefficient of self-sufficiency q: factual volumes of food manufacturing n: population qr: required volumes of food production in accordance with the rational consumption rate. After the calculations Cs can be of different values depending on whether the value of the indicator is low ($Cs < 0.5$), permissible($0.5 < Cs < 0.9$) or optimal ($0.9 < Cs$).	Potatoes, vegetables, milk, meat and meat products.	Rogachev A F 2019, Fuzzy Set Modeling of Regional Food Security.	The calculation formula for FSSR in this study follows a fundamental format. This research computes FSSR for potatoes, vegetables, milk, meat, and meat products using weight as the metric. Therefore, FSSR is calculated for each item individually. Regarding livestock products, it is necessary to consider both the import of livestock products and feed. However, this study excludes this consideration from its analysis. Thus, calculating FSSR for livestock products would be meaningless.
(100)	*(G/D)100FCR=Grain input/output* Livestock Product: *FCR=(Grain Input/Output)×Product Yield* FCR: Pork 2.9, Beef 2,6, Lamb 3.1, Chicken 2.4, Eggs 1.7, Milk 0.4, Fish 1.0	G: total grain production D: total grain consumption.	Meat, poultry, eggs, milk, grain, soybeans, vegetables, fruits, aquatic production, sugar, vegetable oil.	Un clear.	This case study is based on the fact that producing one unit of secondary products, such as livestock products, requires several times the amount of raw materials from primary products. The calculation targets nine items, and the conversion rate for each item is determined. These conversion rates are then used to calculate FSSR for each item. This study uses weight as the metric for calculating the FSSR, which ultimately makes it impossible to express the overall FSSR for the entire country.
(75)	Total estimated kcal production*/total estimated kcal demand of each individual country for the years**		Rice, maize, wheat, soybean, 18 other crops. (nondisclosure)	Shared Socioeconomic Pathways(SSP),Version 2.0, D'Odorico et al. 2019.	The scale of the calculation formula in this study is based on the calorie content of 18 food items. While the specifics of these 18 items are unclear, the study excludes livestock products and conducts calculations for each item individually. However,

					the study's predictive aim for FSSR is hindered by the insufficient number of target items for calculation. To forecast FSSR effectively, it is advisable not to exclude items such as livestock products, edible oils, and sugar products from consideration.
(70)	*Pi/Zi*	Pi: production volume of product i (tons/country/year) Zi: domestic supply quantity of product i (tons/country/year).	Without specification.	FAOSTAT.	The formula is based on the weight of each agricultural product as a fundamental measure. While the specific items for calculating FSSR are unclear, they are delineated by individual products. However, this formula does not enable the comprehensive assessment of FSSR at the national or regional level.
(71)	*(Production ×100)/(Production + Imports −Exports)*	No description.	Cereals, starchy roots.	FAOSTAT.	The formula for calculating FSSR in this study also follows a basic form where the weight of each agricultural product serves as the measure. The items targeted for FSSR calculation include cereals and starchy roots, with the calculation conducted on a per-item basis. While this formula allows for the computation of FSSR for each specific item, it does not facilitate the comprehensive understanding of the overall FSSR at the national or regional level.
(72)	*(Vdi×100)/(Cpi +Cli)*	i : agricultural commodity Vdi : domestic output of a commodity i available for domestic consumption Cpi : volume of personal consumption of commodity i	Grain, sugar, vegetable oil, meat and meat products, milk and dairy products, fish,	UN Conference on Trade and Development, FAOSTAT, World Bank, the Ministry	The formula for calculating FSSR in this study is initially tailored to households, but its scope can be expanded beyond families to regions or nations. The items targeted by this formula include livestock products,

		Cli : volume of industrial consumption of commodity i	potato, fruit and berries, eggs.	of Health of the Russia.	edible oils, and sugar products, while excluding seafood. Specific items are not clearly defined. This study utilizes PPCR to compute the calorie-based FSSR and provides fundamental concepts for its calculation. However, the formula remains incomplete at present.
(76)	*(Cp/Cf)×100*	Cp: monthly calorie supply from own household food production Cf: monthly calorie supply from total consumed food of household	Crops(specific items are unclear).	FAO, UniProt (2000), Interview.	The formula for calculating FSSR in this study is tailored to households, but its scope can be expanded beyond families to regions or nations. The items targeted by this formula include livestock products, edible oils, and sugar products, while excluding seafood. Specific items are not clearly defined. This study utilizes FCR to compute the calorie-based FSSR and provides fundamental concepts for its calculation. However, the formula remains incomplete at present.
(73)	*Production/ (Production +Imports + Exports)*	No description.	Cereals, starchy roots.	FAOSTAT, World Bank, Ethiopian government.	The formula for calculating FSSR in this study follows a basic format. The items targeted for FSSR calculation are cereals (excluding beers) and starchy roots, with the calculation based on the weight of each individual item. Livestock products are excluded, so PPCR is not considered. Specific items within the cereals category are not specified. While this study can compute FSSR for specific items, it cannot grasp the integrated FSSR after combining items.

(74)	*Pi/Ci*	Pi:$\sum_{j=1}^{m} AijYjWj$ Ci:$\sum_{j=1}^{m}\sum_{k=1}^{p} CjkNik$ Total food production in the ith region (Pi) is equal to the product of the farmland area (or number of animals) in the ith region (Aj) and of the jth food type, the associated yield (kg/ha or/animal) for the jth food (Yj), and the proportion of estimated waste associated with the jth food type (Wj), summed for m foods. Total food consumption in the ith region (Ci) is equal to the product of food consumption of the jth food category for that age/sex category (Cjk) and number of people in that age/sex category within the region (Nik).	It contains livestock products, but the items are unclear.	2006 Census of Agriculture in the study area.	The food self-sufficiency rate in this study includes livestock products, but does not use PPCR. The idea is to add up the weight of each item to be calculated (the specific item name is unknown) for each consumption and production volume, and then divide the numerator (production volume) by the denominator (consumption volume). Livestock products are included in the calculation, but imports of livestock products and feed are not taken into account.
(42)	*∑(Country DEP× Population) /∑Country* This formula is used for calculating the global Dietary Energy Production (DEP), rather than the food self-sufficiency rate.	No description.	Unclear.	Unclear.	This study employs Dietary Energy Production (DEP) as an index to predict the per capita daily calorie demand globally by 2050. This indicates that the global calorie supply will be insufficient to meet demand if current consumer lifestyles, and the demand for grains as oil substitutes persist. This study considers previous studies on DEP; however, the calculation formula does not incorporate secondary product conversion rates, such as PPCR.
(40)	This study uses the	No description.	Crops, livestock products, fish.	FAOSTAT.	This study raises the following issues: By combining the energy available in

	FAO's global population-weighted average dietary energy requirement (2353 kcal/p/d).				crops and the energy that humans directly consume, a total of 3116 kcal kcal/p/d can be used for human consumption before processing and distribution.
(77)	The formula for calculating FCR is not explicitly stated. 154countries, 2013 data. Highest FCR (least efficient countries): 100 (Dominica, Ethiopia) lowest FCR (most efficient countries): 1.1 (Trinidad and Tobago) average for 154 countries: 3.9	No description.	32items: barley, cassava, groundnuts, maize, Millet, oil palm, potatoes, pice, rye, sorghum, soybeans, sugar beet, sugarcane, wheat, beef, chicken meat, goat meat, pig meat, sheep meat, eggs, milk, offals, animal fat, other meats, etc.	FAOSTAT.	This study examines the balance between food demand and supply in 2030 and 2050. It assumes a daily calorie intake of 3,000 kcal per person, of which 20% is derived from animal sources. The factors identified as potential problems are the use of animal feed and cereals for fuel production. The PPCR value used is the average of livestock products in each country based on 2013 data.
(41)	*DES×100* */DEP*	DES(t):$(\sum_{i} FSQi(t)Ci)$ / $365P(t)$ DEP(t):$(\sum_{iFPOi(t)Ci)/365P(t)}$ FSQ (kg):Food supply quantities. FPQ (kg):Food production quantity of each product, i: item. c: conversion factors (kcal/kg).	Over 70 items.	FAOSTAT.	The underlying assumptions (kcal/cap/d): Low supply: DES of 2000–2500. Adequate supply: DES of 2500–3000. High supply: DES of over 3000. Insufficient production: DEP of 2000–2500. Sufficient production: DEP of 2500–3000. High production: DEP of over 3000. This study focuses on the calculation of dietary energy production (DEP), measured in kcal/p/d, and dietary energy supply (DES). The DES/DEP ratio in this study can be transformed into a formula for calculating FSSR.

(54)	Calculation formula for FCR: *kg of feed/kg of grain.* FCR:\ Common\ carp\ 1. 7 Grass carp 1.7: Atlantic salmon: 1.3 Whiteleg shrimp: 1.7 Beef cattle: 8.0 Pigs: 3.9 Chicken 1.9	No description.	Unclear.	United States Department of Agriculture (USDA) National Nutrient Database.	Consideration of the variable PPCR in the calculation formula for supply-based FSSR. There are multiple research studies on the PPCR for various secondary products. The PPCR for individual product categories closely align between several research studies and the official PPCR reported by the Japanese government.
(57)	Calculation formula for FCR: *Livestock output calories/Plant input calories* FCR: Pork 11.0, Poultry 8.1, Eggs 5.9, Dairy 5.9, Beef 33.3, average for livestock products 14.3	No description.	Unclear.	US feed caloric flux.	In this study, the PPCR is considerably higher compared to other research cases. One reason for this may be that, although the specific dressing percentage is unknown, it has been taken into account. This suggests that the rationale lies in reducing the output to the level of consumption.
(78)	Although this study does not directly address food self-sufficiency, it provides in-depth knowledge about FCR. The feed required for the production of edible parts (FCR): Dairy products 2.5, Eggs: 4.6, Poultry: 8.3, Pork: 10, Beef :33.0	No description.	41 items.	FAOSTAT.	The relatively high values are due to the assumption of a 60% dressing percentage. The basis for the PPCR values is derived from Smil, V. (2000). Feeding the World: A Challenge for the 21st Century.This study warns that, under current conditions, food will become a source of competition between humans and livestock.

Table 5 SFSSR and CFSSR of each country (%, 2021)

	SSFSSR	CFSSR
Afghanistan	48.9	55.3
Albania	43.4	54.3
Algeria	15.9	16.3
Angola	62.6	59.9
Antigua Barbuda	0.3	0.0
Azerbaijan	57.4	65.9
Argentina	160.5	277.1
Australia	245.3	388.8
Austria	42.8	79.8
Bahamas	3.9	1.8
Bahrain	0.2	0.0
Bangladesh	72.4	91.3
Armenia	19.8	20.3
Barbados	7.0	0.0
Belgium	14.0	28.9
Bhutan	23.2	24.6
Bolivia	97.7	90.7
Bosnia and Herzegovina	41.8	64.9
Botswana	11.4	15.0
Brazil	131.4	109.6
Belize	63.9	93.8
Solomon Islands	95.6	3.4
Bulgaria	145.1	284.6
Myanmar	117.9	119.2
Burundi	89.4	72.1
Belarus	78.2	95.3
Cambodia	95.7	106.5
Cameroon	84.2	63.9
Canada	137.1	127.8
Cabo Verde	6.4	0.0
Central African	89.1	98.3
Sri Lanka	75.2	90.5
Chad	89.1	87.7
Chile	26.3	41.6
China, mainland	74.5	90.7
China, Taiwan Province	13.6	22.2

Colombia	62.5	35.1
Comoros	23.9	19.0
Congo	38.5	5.4
Democratic Republic of the Congo	97.2	77.9
Costa Rica	60.3	12.4
Croatia	75.8	135.1
Cuba	29.9	12.9
Cyprus	7.4	6.9
Czechia	76.0	173.7
Benin	77.0	56.5
Denmark	54.0	105.6
Dominica	33.0	0.0
Dominican Republic	41.0	38.1
Ecuador	91.3	61.6
El Salvador	36.9	50.9
Ethiopia	83.6	92.1
Estonia	91.9	216.1
Fiji	42.7	7.9
Finland	46.3	82.9
France	102.9	181.8
French Polynesia	12.5	0.0
Djibouti	0.4	0.0
Gabon	27.5	12.9
Georgia	28.2	39.3
Gambia	11.5	9.7
Germany	48.5	103.9
Ghana	75.9	64.0
Kiribati	92.5	0.0
Greece	42.0	69.9
Grenada	5.6	0.0
Guatemala	68.8	45.8
Guinea	76.7	68.6
Guyana	103.5	229.2
Haiti	29.1	21.4
Honduras	65.7	35.6
Hungary	98.4	143.5
Iceland	59.4	4.8
India	101.5	111.9

Indonesia	94.3	84.5
Iran	41.0	49.7
Iraq	23.9	40.2
Ireland	24.5	42.1
Israel	6.2	4.2
Italy	32.6	62.2
Côte d'Ivoire	80.4	49.7
Jamaica	12.7	0.3
Japan	19.5	33.0
Kazakhstan	124.1	184.5
Jordan	5.7	3.0
Kenya	54.4	45.8
Korea	14.3	23.3
Kuwait	1.0	2.4
Kyrgyzstan	62.3	67.4
Lao PDR	107.1	102.0
Lebanon	14.1	9.4
Lesotho	19.4	30.1
Latvia	116.0	261.4
Liberia	43.5	27.7
Libya	7.2	6.9
Lithuania	123.2	252.1
Luxembourg	13.5	60.2
Madagascar	77.9	77.1
Malawi	103.0	107.0
Malaysia	60.0	24.5
Maldives	6.7	0.0
Mali	87.9	90.3
Malta	1.0	0.0
Mauritania	23.8	44.6
Mauritius	27.3	0.3
Mexico	50.8	62.8
Mongolia	47.1	73.9
Moldova	176.2	221.6
Montenegro	2.4	2.3
Morocco	49.5	57.2
Mozambique	71.4	49.8
Oman	4.4	5.0

Namibia	30.2	20.2
Nauru	60.5	0.0
Nepal	65.0	76.0
Netherlands	5.5	7.8
New Caledonia	6.8	9.6
Vanuatu	82.5	4.2
New Zealand	32.9	54.1
Nicaragua	74.0	50.9
Niger	76.5	64.0
Nigeria	89.7	83.0
Norway	26.8	24.3
Micronesia	70.6	0.0
Pakistan	100.2	117.7
Panama	41.5	34.9
Papua New Guinea	83.3	2.3
Paraguay	180.5	175.6
Peru	54.3	48.3
Philippines	64.5	70.9
Poland	87.8	124.9
Portugal	14.9	17.8
Guinea-Bissau	73.1	47.6
Timor-Leste	26.6	28.5
Qatar	0.3	0.2
Romania	144.2	204.8
Russia	116.8	143.4
Rwanda	70.5	68.0
Saint Kitts and Nevis	7.0	0.0
Saint Lucia	5.6	0.0
Saint Vincent and the Grenadines	14.9	3.6
Sao Tome and Principe	32.7	6.7
Saudi Arabia	5.2	4.8
Senegal	73.6	54.9
Serbia	123.1	162.8
Seychelles	23.4	0.0
Sierra Leone	94.8	99.4
Slovakia	71.8	154.5
Viet Nam	76.3	86.2
Slovenia	27.8	68.7

South Africa	89.1	108.6
Zimbabwe	65.5	80.2
Spain	48.5	67.9
South Sudan	78.8	75.0
Sudan	72.5	63.7
Suriname	57.9	112.8
Eswatini	65.4	28.9
Sweden	48.3	132.5
Switzerland	20.5	34.4
Syria	44.6	46.1
Tajikistan	48.9	52.9
Thailand	110.2	123.6
Togo	81.6	76.1
Trinidad Tobago	3.4	0.0
United Arab Emirates	0.4	0.7
Tunisia	30.1	27.7
Türkiye	58.1	57.7
Turkmenistan	77.6	83.6
Uganda	80.2	108.4
Ukraine	228.5	367.5
North Macedonia	38.3	77.6
Egypt	48.9	58.7
United Kingdom	39.9	76.1
Tanzania	102.2	112.0
USA	116.2	123.3
Burkina Faso	84.5	0.0
Uruguay	138.0	177.3
Uzbekistan	63.5	70.8
Venezuela	43.3	43.6
Samoa	18.8	0.0
Yemen	7.2	13.8
Zambia	110.0	133.1

974 Source: Created by the author using each formula and common data.