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Needs-based food and nutrient security indices to monitor and modify the food supply and intakes: Taiwan, 1991–2010

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ABSTRACT

Background: To track Taiwanese food and nutrient supplies and population intake of them against the nutrition recommendations by food security indices that warn about food insecurity.
Methods: We used food balance sheets from 1991 to 2010 to estimate food and nutrient supplies and data from 1993–1996 ($n = 3915$) to 2005–2008 ($n = 2908$) Taiwanese Nutrition and Health Surveys to assess intake of Taiwanese population. Age-and-gender specific Food Guides and Dietary Reference Intakes were multiplied by the population size and then summed to determine food and nutrient needs. Food Security Indices (FSIs) and Nutrient Security Indices (NSIs) were defined as the geometric means of supply-to-needs ratio (*S-Nr*) and intake-to-needs ratio (*I-Nr*) with reference to an ideal of 1.0. Higher values indicate potential food insecurity.
Results: From 1997 to 2010, the *S-Nr* for most food categories and nutrients decreased; dairy products and vegetables fell below recommendations in 2010. For food intake, all except cereals/roots increased between the two surveys, but only vegetables and soy/fish/meat/egg met the needs in 2005–2008. For both surveys, high FSIs for dairy (2.16, 2.26) were due to low supply and low intake, and those for soy/fish/meat/egg (1.78, 1.91) to oversupply and overconsumption. The FSIs for fruit improved from 1.50 to 1.17, with a smaller supply but more consumption. NSIs explained the FSIs.
Conclusion: FSIs and NSIs capture composite information about the food supply, intake, and recommendations, which allows food security to be monitored with action-points of 1.0 for food and nutrition policy.

Introduction

Food security has received much attention from the international community, especially the United Nations system, which focuses primarily on food insecurity in low-income countries and households. Its dimensions are those of food availability, safety, quality, affordability, diversity, and sustainability (Wahlqvist et al., 2009), recognizing the need for sound ecosystems (Li and Wahlqvist, 2011).

Food security operates at both macro- and micro-levels (FAO, 1996). Food balance sheets (FBSs) (FAO, webpage 2015a) are commonly used to consider macro-level food security, which considers the inputs and outputs of the food system. Net availability is generally expressed as food or nutrient quantities available per capita, but does not allow subgroup analysis of the population. In contrast, nationally representative individual dietary surveys provide food and nutrient intake information that can be used for micro-level food security assessments. This allows subgroup analysis.

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The simplest food security evaluation would be to determine whether the available food supply matches the food needs of the population, but it makes more nutritional sense to determine whether the supply matches the recommended food intakes and then whether that is what is consumed. Food patterns following Food-Based Dietary Guides or Food Guides (FGs) are considered ideal to optimize health by diet in populations (WHO and FAO, webpage 2015; Wahlqvist et al., 1999; FAO RAP, webpage 2015). Similarly, Dietary Reference Intakes (DRIs) is one of the methodologies that specify the adequate level of nutrient intake; other methodologies deal with requirements, allowances, and tolerable limits (HPA Taiwan, webpage 2015a; Tzeng, 2008). If these two sets of recommendations are combined, food security evaluations should be more robust and sensitive. The food supply on one hand, and food component intakes on the other hand, can be expressed in terms of the dietary and nutrient recommendations. Provided the recommendations are sound, if discrepancies are found between them and the food supply or intake, the interpretation may include the following: the food system is inadequate, of poor quality, inefficient, or potentially unsustainable; there is wasteful consumption; and there are barriers to intake.

In this study, combining food supply and intake data in Taiwan from FGs and nutrient recommendations ("needs"), we developed a novel algorithm to identify food security trajectories and scenarios that merit attention in the short-to-medium-term future. This allows a focus on how supply meets nutrition needs and how intake corresponds with supply and needs. We also combined these so that a single expression is available for evaluation, monitoring, and setting policy.

Methods

Several databases have been used to develop both a Food Security Index (FSI) and a Nutrient Security Index (NSI). These are the FBSs of Taiwan for 1991–2010 to evaluate food supply; the actual food intake data from nationally representative nutrition surveys for 1993–1996 and 2005–2008, proportionally amplified to estimate the national intake data; and food servings and nutrients as recommended in the Taiwan FGs together with Taiwan DRIs (either Recommended Dietary Allowance [RDA] or Adequate Intake [AI]) multiplied by population size to give estimates of the whole population's food and nutrient needs.

Annual food and nutrient availability

Taiwanese FBS data are provided as daily foods, energy, macronutrients, and several micronutrients per capita. Rather than 11, as used in the FBS, we used the 6 aggregated food categories in the Taiwanese FGs (Table 1).

For a comparison with FGs, the food-serving numbers in Taiwan are estimated using back-calculation by macronutrient quantity in all the food categories but vegetables. The conversion from food supply into 6 food categories was based on one single nutrient indicator for each category. Specifically, one serving of cereals/roots corresponds to 15 g of carbohydrates; soy/fish/meat/egg, 7 g of protein; fruits, 15 g of carbohydrates; oil/nuts, 5 g of fat (from cooking and table oils and fats, spreads and nuts); and dairy, 8 g of protein. For example, the conversion for the soy/fish/meat/egg food category was based on protein, with one serving corresponding to 7 g of protein, and therefore in the case of pork, where the availability per person was 13.18 g of protein per day, it was converted to 1.88 servings (13.18/7 = 1.88). Although this category the fat content in meat, eggs, fish and sea food varies, it does not affect the conversion of food servings for this food category. For vegetables, it is an edible 100 g portion as published in the food composition databank for Taiwan (FDA Taiwan, webpage 2015a) states that a 100-g portion of vegetables is the proper serving size. The national grand total of food supplies for the six food categories, energy, and nine nutrients were the aggregates of the servings or nutrients per capita multiplied by the mid-year population for the year of the FBS.

Food and nutrient needs

Taiwan's national demographic structure served as the framework for calculating food and nutrient needs. Age-and-gender-specific subgroup numbers for the period 1991–2010 were obtained from the Taiwan Ministry of the Interior (http://www.moi.gov.tw/stat/).

Taiwan has 11 FGs to cover particular life-stages, and these relate to daily servings from six food categories (FDA Taiwan, webpage 2015b). The FGs are for infancy (0–6, 7–9, and 10–12 months), toddler (1–3 and 4–6 years), schoolchildren (6–9 and 10–12 years), adolescence (13–18 years), adulthood, pregnancy, and lactation. The annual national needs for each food category were a summation of the servings recommended for each age group multiplied by its population size.

The 2002 version of Taiwanese DRIs provide nutrient recommendations for 14 age groups, pregnancy (three trimesters), and lactation. Nutrient recommendations for each age group were multiplied by the corresponding population size for the year in question. Total national nutrient needs were the sum of all age groups (HPA Taiwan, webpage 2015a).

The additional needs of pregnancy are estimated from the number of newborns in a given year and the sum of the recommended extra needs for three trimesters. Additional needs for lactation consider published national breastfeeding rates, duration, and the number of infants in that year (HPA Taiwan, webpage 2015b).

Population food and nutrient intakes

The relevant individual dietary surveys in Taiwan are the Nutrition and Health Surveys in Taiwan (NAHSIT) (Pan et al., 2011) which use one 24-h recall to obtain individual food intake information. We considered that the data obtained from the 24 h recall of a random sample of the target population as unbiased estimates (Block, 1982), and therefore data obtained from representative NAHSIT subjects can be used to represent the mean intakes of the nation. The mean gender-and-age-specific food and nutrient intakes for 1993–1996 NAHSIT (19–30, 31–50, and 51–64 years old) and for 2005–2008 NAHSIT (19–30, 31–50, 51–70, and >70 years old) were multiplied by the corresponding population size to obtain the total national intakes. The food-serving intakes were derived with the same macro-nutrient values as those for supplies.

Data management and statistical analysis

All food serving and food intake values are presented as means. NAHSIT data were weighted to ensure that they were representative of the population (Tu et al., 2011). Trends over time were evaluated using linear regression. All data management, statistical analyses, and graphics were performed using Microsoft Excel 2007 and R 3.1.1 statistical software (http://www.R-project.org/).

Theory/calculation

Food Security Index and Nutrient Security Index algorithms and formulae

We used both foods (FSIs) and nutrients (NSIs) to evaluate nutritional security (Fig. 1). In each case a global (e.g., plant/animal

Table 1
Conversion of 2010 food balance sheet food availability into food servings to correspond to food guides.

Food category[a]	Six food categories as in food guides (servings)[b]						Energy	Protein	Fat	Carbohydrates
	Cereals/roots	Vegetables	Fruits	Soy/fish/meat/eggs	Dairy	Oil/nuts	kcal (%)[c]	g (%)[c]	g (%)[c]	g (%)[c]
Cereals	11.5						792.7 (28.8)	18.70 (21.0)	0.84 (0.7)	173.0 (51.9)
Starchy roots	1.68						106.4 (3.9)	0·95 (1.1)	0.16 (0.1)	25.2 (7.6)
Sugars & honey							244.1 (8.9)	0.00 (0.0)	0.00 (0.0)	63.1 (18.9)
Pulses & oilseeds				1.97		0.88	220.2 (8.0)	17.60 (19.9)	10.60 (9.3)	15.4 (4.6)
Vegetables		2.87					86.9 (3.2)	4.55 (5.1)	1.08 (1.0)	16.5 (5.0)
Fruits			2.11				126.8 (4.6)	2.04 (2.3)	0.67 (0.6)	31.7 (9.5)
Meat				3.60			365.6 (13.3)	25.20 (28.4)	28.60 (25.1)	0.34 (0.1)
Eggs				0.71			59.8 (2.2)	4.99 (5.6)	4.22 (3.7)	0.17 (0.0)
Fish & sea food				1.45			71.8 (2.6)	10.10 (11.4)	2.72 (2.4)	1.44 (0.4)
Dairy					0.57		73.1 (2.7)	4.52 (5.1)	3.33 (2.9)	6.35 (1.9)
Oils & fats						12.3	547.2 (19.9)	0.02 (0.0)	61.60 (54.1)	0.15 (0.0)
Wine & beer							59.3 (2.2)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
Total	13.2	2.87	2.11	7.72	0.57	13.2	2754 (100)	88.60 (100)	114.00 (100)	333.00 (100)

[a] Classified according to Taiwan food balance sheets.
[b] One serving: cereals/roots = 15 g of carbohydrates, soy/fish/meat/eggs = 7 g of protein, fruits = 15 g of carbohydrates, oil/nuts = 5 g of fat, dairy food = 8 g of protein.
[c] (%): contribution of each food category to energy and nutrient supply.

and energy) or food- and nutrient-specific analysis can be made. We used energy as a global measure, the six food categories as used in FGs, the macronutrient protein, and eight indicator micronutrients: calcium, phosphorus, iron, vitamins A and C, thiamin, riboflavin, and niacin.

As a first step, the supply-to-needs ratio (*S-Nr*) is a macro-level food or nutrient index that uses FBS and FGs or DRIs. Similarly, the intake-to-needs ratio (*I-Nr*) is a micro-level index that uses surveys and FGs or DRIs. The ratios have as their denominator food (FG values) or nutrient (DRI) recommendations about needs. Ratios may exceed or not reach 1.0, which allows interpretations of excess or inadequate supply, excess or inadequate intake, inappropriate reference values for needs, or combinations of these possibilities. Each of these ratios is useful in its own right, which is particularly relevant where both the *S-Nr* and *I-Nr* can be generated.

As a second step, an FSI and an NSI were generated by calculating the geometric means (GMs) of the *S-Nr* and *I-Nr* as follows:

$$\mathrm{GM} = \sqrt{\exp\sqrt{\ln(S\text{-}Nr)^2} \times \exp\sqrt{\ln(I\text{-}Nr)^2}}$$

The GM is the geometric distance from the *S-Nr* (*X* axis) and *I-Nr* (*Y* axis) vectors in a natural log scale of the given food to the ideal [1,1], the intersection of the two axes. The GMs will always be $\geqslant 1$. The greater the number, the more likely that there will be a food security problem. In this way, it is possible to compare food categories and evaluate time trends. A visual illustration of how this was derived, using fruit as an example, is shown in Fig. 2(a). A background of concentric diamonds indicates that any point on the same diamond line has the same GM.

In this study, the FSIs applied to all or to any one of the six food categories, and the NSIs to any of the nutrients available during a particular period. The populations represented by the *S-Nr* and *I-Nr* may or may not fully match each other, depending on the information available. For example, we evaluated the *S-Nr* in the nationally weighted population of all age groups and reproductive statuses, whereas the *I-Nr* was evaluated in a nationally representative sample of adults. For the *I-Nr*, we did not have the option of including anyone <19 years old. Although a population mismatch is a limitation, it does not preclude the generation of a more integrative index.

Results

Food and nutrient availabilities in 2010

More soy/fish/meat/eggs and oil/nuts, but less dairy products and vegetables, were supplied than needed (Table 1). The 2754 kcal per capita supply exceeded by 31% the minimal energy intake of 2100 kcal suggested by the FAO (FAO and WFP, webpage). Energy from protein, fat, and carbohydrates was 12.9%, 37.2%, and 48.4%, respectively (data not shown). Wine and beer potentially contributes 59.3 kcal (2.2% of total energy) per person per day.

Nutrients available from the FBSs were considered in accordance with the DRI schema. From all 11 food categories, vitamin A was 2.4 times greater than were the DRIs; vegetables and meat contributed most (Fig. 3). Calcium was the only nutrient for which the supply (55%) fell below the Taiwan DRI nutrient needs. Supplies of energy, protein, thiamin, and ascorbic acid were 1.5–1.8 times higher than the Taiwan DRI nutrient needs. Plant-derived versus animal-derived food provided 3.0 times the food energy (119% vs. 40%), the similar amount of protein (85% vs. 87%), one-third more calcium (33% vs. 23%), and twice as much iron (74% vs. 34%) iron based on DRIs. Plants provided more phosphorus, thiamin, and ascorbic acid; and animal foods provided more vitamin A, riboflavin, and niacin.

Trends in FBS foods and nutrients, 1991–2010

S-Nrs decreased annually from 1997 for all food items, with the steepest ratio drop in soy/fish/meat/eggs (−0.026) and the flattest in cereals/roots (−0.008) (Fig. 4(a)). Dairy was the food category with the least secure supply (with a starting point below 1.0), followed by vegetables (dropped below 1.0 in 2005). Both soy/fish/meat/eggs and oil/nuts had downward slopes but remained appreciably above 1.0 in 2010, and their current trajectories suggest that they should remain above 1.0 for several years.

The trends in the ratios of available nutrients from FBSs to their age- and gender-weighted DRIs (*S-Nrs* for nutrients) between 1997 and 2010 were linear and decreased appreciably for all of energy and for the nine nutrients studied except iron (Fig. 4(b)).

Food and nutrient intakes and their relation to needs (I-Nr) from 1993–1996 to 2005–2008

For all six food categories except cereals/roots, mean *I-Nrs* increased between the two surveys (Table 2). Where excessive *I-Nrs* for food occurred, this was principally with the soy/fish/meat/eggs category. These excesses increased over time as the corresponding *S-Nrs* decreased (Fig. 4). In daily servings per capita, the increased intakes for these primarily protein sources were from 5.73 to 7.25. The overall *I-Nrs* for vegetables were around 1.0

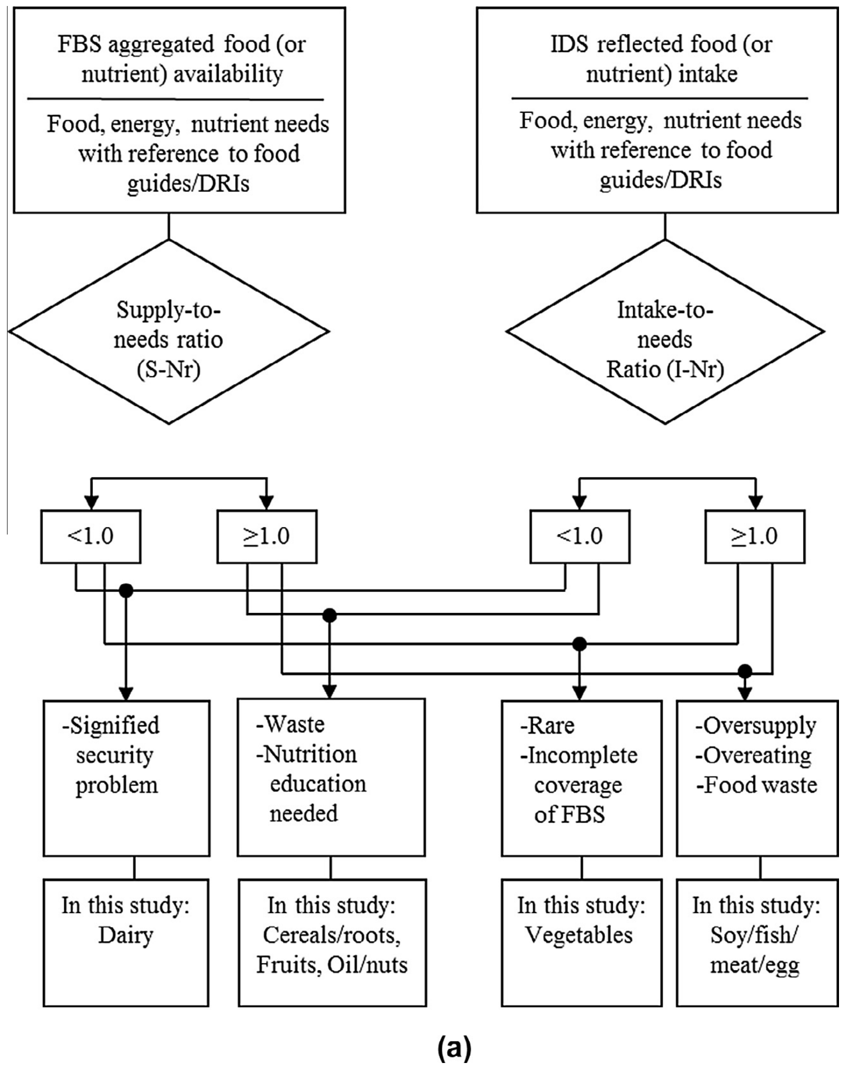

Fig. 1. Food Security Index (FSI) and Nutrient Security Index (NSI) algorithms (a) and formulae (b). FSI takes into account macro- and micro-level food supply security. Macro-level food/nutrient security is represented by the supply-to-needs ratio (*S-Nr*), and micro-level food and nutrient security is represented by the intake-to-needs ratio (*I-Nr*). IDS = individual dietary surveys.

(about 3 servings) and stayed there for more than a decade. Dairy intake was also low in all age groups.

Vitamin A intake was excessive, as was the intake of foods that contain vitamin A. Although vitamin C intake was excessive, the intake of fruit and vegetables, foods that contain the vitamin, was not. Except for calcium, the source of which is dairy in this analysis, in men and women, and for iron in women, all nutrient intakes met their DRIs.

Food and Nutrient Security Indices

For all food categories except vegetables, the *S-Nr* decreased from 1993–1996 to 2005–2008 (Table 3), while *I-Nr* increased in all except the cereals/roots category (Table 4).

The FSI (GMs of *S-Nr*s and *I-Nr*s) had the highest values for milk (2.16, 2.26) in both surveys because of its low supply and low intake. This followed by the oil/nuts, soy/fish/meat/eggs, fruits, cereals/roots, and vegetables categories in the 1993–1996 survey. In the 2005–2008 survey, this order changed. With a smaller supply but greater consumption, in the fruits category the FSI value fell from 1.50 to 1.17, and the oil/nuts category value fell from 1.84 to 1.57. In the soy/fish/meat/eggs category, the value rose from 1.78 to 1.91.

All NSI values exceeded 1.0, and all but the value for iron exceeded 1.3 (Table 4). The only nutrient with a low *S-Nr* was calcium, whose high NSI reflected this whereas, for other nutrients, it reflected mismatches of *S-Nr* and *I-Nr* because of high and excessive *S-Nr*s, except for iron, at least in the 1993–1996 survey (most dietary iron in Taiwan comes from plant sources, and there are bioavailability considerations) (see Fig. 4(b)). The highest NSIs in both surveys were for protein and vitamin A, which shared animal-derived foods as sources of these nutrients.

Discussion

Food and Nutrient Security Indices

FSI and NSI can be used to assess, monitor, and compare food security problems. The endpoint values can be used to modify current food security policy or create new policy, if necessary, in order to ensure adequate supplies of foods and nutrients for the population. We have developed an FSI and an NSI that combine food supply, food intake, and food-needs information, and they can be used to assess past and current trends in how the food supply has been meeting the needs of the population. They also can be used to consider food and nutrient insecurity situations that arise when actual

$$\text{FSI(i)} = \sqrt{\exp\sqrt{\ln(S-Nr)^2} \times \exp\sqrt{\ln(I-Nr)^2}}$$

$$\text{S-Nr(i)} = \frac{\Sigma\ \text{FBS food serving per capita}_{(i)(j)}\ \text{x FBS addressed population}_{(j)}}{\Sigma\ \text{food guide}_{(h)(i)}\ \text{x population size}_{(h)(j)}}$$

$$\text{I-Nr(i)} = \frac{\Sigma\ \text{mean food intake}_{(i)(j)(k)}\ \text{x population}_{(j)(k)}}{\Sigma\ \text{food guide}_{(i)(k)}\ \text{x population size}_{(j)(k)}}$$

h=age range (this study: 11 food guide corresponding age ranges)
i = food group (this study: cereals/roots, dairy, soy/fish/meat/egg, vegetables, fruits, oil/nuts)
j = IDS period (this study: 1993–1996 or 2005–2008)
k = IDS population coverage (this study: age 19-70 for 1993–1996 period; age 19+ for 2005–2008)

$$\text{NSI(i)} = \sqrt{\exp\sqrt{\ln(S-Nr)^2} \times \exp\sqrt{\ln(I-Nr)^2}}$$

$$\text{S-Nr(i)} = \frac{\Sigma\ \text{FBS nutrient per capita}_{(i)(j)}\ \text{x FBS addressed population}_{(j)}}{\Sigma\ \text{DRIs}_{(h)(i)}\ \text{x population size}_{(h)(j)}}$$

$$\text{I-Nr(i)} = \frac{\Sigma\ \text{mean nutrient intake}_{(i)(j)(k)}\ \text{x population}_{(j)(k)}}{\Sigma\ \text{DRIs}_{(i)(k)}\ \text{x population size}_{(j)(k)}}$$

h=age range (this study: 12 DRI corresponding age ranges)
i = energy or nutrient (this study: energy, protein, calcium, phosphorus, iron, vitamin A, thiamin, riboflavin, niacin, ascorbic acid) of particular year i
j = IDS period (this study: 1993–1996 or 2005–2008)
k = IDS population coverage (this study: age 19-70 for 1993–1996 period; age 19+ for 2005–2008)

(b)

Fig. 1 (*continued*)

intakes exceed or fall below needs. Our indices are simple and specific for food and nutrients, and provide a method for comparing among countries, time periods, and severity (Fig. 1). The method considers various scenarios, such as a limited supply with low intake (e.g., dairy) and a marginal supply with low intake (e.g., fruits); each could have various explanations, and each might have to be managed in different ways. The solutions might require reviewing food and nutrient guidelines and professional recommendations, reconsidering the food supply chain, and engaging and educating the population to make better food choices. The most important use for these indices is for monitoring, detecting, and dealing with a current or predictable case of imminent food insecurity.

Some food security indices are more comprehensive than ours, but they are more complex, which makes them less useful. For example, the Global Food Security Index (GFSI) of the Economist Intelligence Unit (The Economist Intelligence Unit, webpage 2015) uses 25 indicators including agricultural, road, port, and governmental infrastructure to assess food security across affordability, availability, quality, and safety. Another example is the Maplecroft Food Security Risk Index (FSRI) (Maplecroft, webpage 2015), which uses 12 indicators of the availability, access, and stability of food supplies. The scope of the information required for the GFSI and FSRI is broad, and the information is often not available.

The FAO uses the Food Security Information and Early Warning System (FSIEWS) (FAO, webpage 2015b), which provides country, regional, and global levels of timely information on the incidence and causes of food insecurity, malnutrition, and vulnerability. Our method is similar, but we do require NAHSIT-type survey information and relate both supply and intakes to needs. Moreover, the *S-Nr* and *I-Nr* ratios can each be used separately to detect food insecurity with either FBS or survey data, provided that the data are entered as agreed-upon recommended numerical food and nutrient intakes, as we have done.

From practical and food policy points of view, the FSI is more relevant than the NSI, because it can be interpreted within the context of the local food culture. However, many nutrition programs are focused on nutrients, especially micronutrients; thus, both indices can be helpful on their own, but they are more helpful when combined. The NSI has the value of capturing the contribution of several foods or a food pattern to a particular nutrient's status and function. A precarious nutrient security problem is that one food category might be offset or compounded by another, and monitoring the NSI might be a valuable option in this circumstance. With pre-formed vitamin A, multiple sources might make

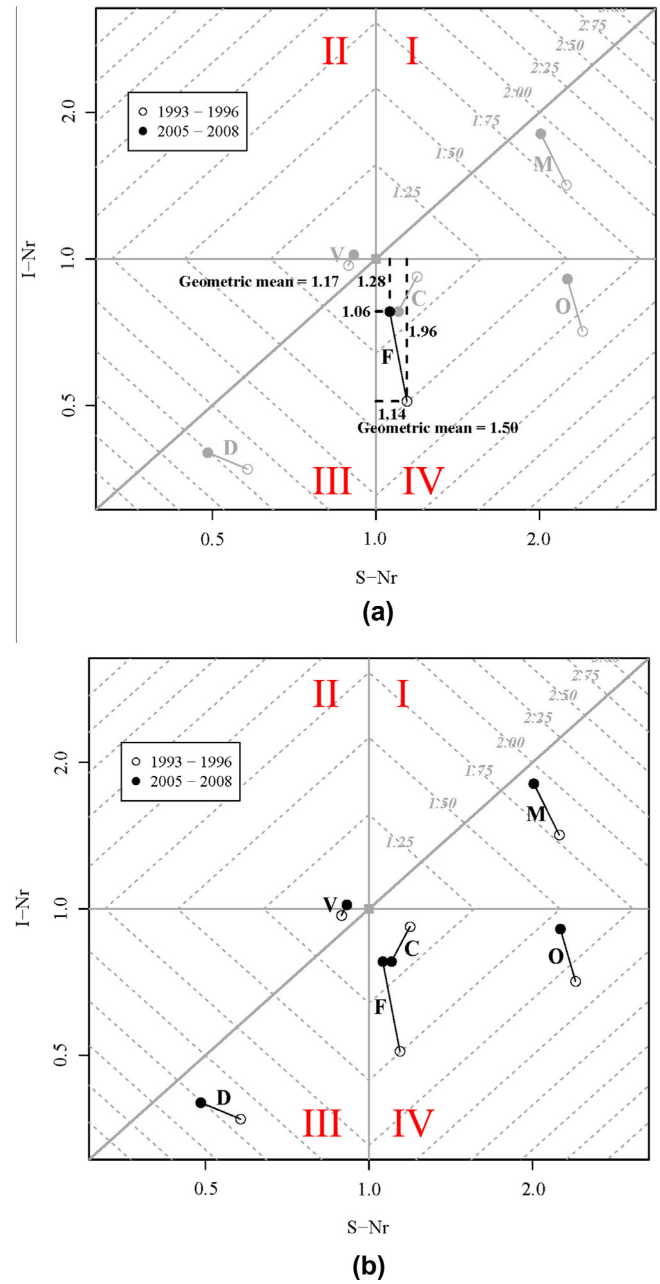

Fig. 2. Scatter plots of supply-to-needs ratios (*S-Nr*) to intake-to-needs (*I-Nr*) for 1993–1996 and 2005–2008. (a) Demonstration of Food Security Index (FSI) calculation using fruit as an example; (b) FSI of 6 food categories and changes from 1993–1996 to 2005–2008. Open circle (○): 1993–1996 data, solid circle (●): 2005–2008 data. "C" = (cereals/roots); "D" = (dairy); "F" = (fruits); "M" = (soy/fish/meat/eggs); "O" = (oil/nuts); "V" = (vegetables). *X*–*Y* axes are in natural log (ln) scale. Quadrant I: oversupply and overeating; Quadrant II: undersupply and overeating; Quadrant III: undersupply and underfeeding; Quadrant IV: oversupply and underfeeding.

a deficiency less likely and an excess more likely. Water-soluble B group vitamins (thiamin, riboflavin, and niacin), share, to some extent, whole grains and dairy products as sources, and these may be eaten together in some food cultures (e.g., at breakfast in Western culture), but because dairy consumption is not traditional in Chinese food culture, the likelihood of there being a consistent linkage between the two is small. In the present study, the NSIs for these B-group vitamins were relatively high in the 2nd survey and higher than in the 1st survey for riboflavin and niacin, which might indicate changing patterns of consumption of B-group vitamin-containing foods with associated food and nutrient insecurity.

Food commodities from food balance sheets, the Food Security Index, and the needs-based algorithms

In our analysis, both the food supply and dairy intake were much lower than recommended, and this may push the bounds of sustainability and affordability. This raises questions about whether the dairy recommendation for a culture that has no tradition of eating dairy foods is appropriate and about other sources of dairy-food-supplied nutrients.

For fruits, the FBSs showed no security issue, but intakes suggest possible waste (including spoilage and rejection because of blemishes), a lack of desire by people to eat the recommended quantity, or a market failure. There was apparently an oversupply of oils and nuts, but intake was below recommended levels in both surveys. One explanation might be that deep-frying with oil deep-frying is wasteful, and another is that used cooking oil is discarded for food safety reasons.

Foods in the soy/fish/meat/eggs category were oversupplied, and Taiwanese ate much more than was recommended in both surveys, which might threaten the sustainability and security future food supplies (Wahlqvist et al., 2012). We found major differences in the trajectories of food groups that have different environmental footprints. These differences were captured in the trends for plant- and animal-derived nutrients depicted in Fig. 3, and these trends merit review.

The supply of cereals and roots was 10–20% above needs. However, the ratio of intake to needs was lower than 1.0 in both surveys. FSIs increased from 1.14 to 1.19 between the two surveys, which may not represent a food security problem. However, the *S-Nr* of the cereals/roots category decreased during the 20-years observation period, which might be interpretable as a food security alert.

The FSIs for vegetables, for which the *S-Nr* and *I-Nr* were close to 1.0, were the lowest. The vegetable *S-Nr* tracked downwards from the year 2000. In a country prone to natural disaster and with seasonal variation in vegetable production, the prevailing vegetable FSIs suggest a precarious supply. However, the *I-Nr* for vegetables exceeded 1.0. Home and community vegetable gardens and small vegetable farms, cultivated by families for their own consumption or for sharing with the neighborhood, are common in Taiwan.

Discrepancies in supply data

*S-Nr*s reflect the degree of food abundance. A value close to 1.0 indicates a sufficient supply without much wastage, but it might obscure an unbalanced distribution and not identify shortfalls in intake in vulnerable subgroups. This emphasis is important when food supplies have declined as they did in Taiwan from 1997 to 2010. The distribution discrepancy includes the wastage that occurs after food has been supplied to consumers. This includes spoilage, leftovers, and decorative food. Major progress was made on this front in Taiwan from 2001 and during the period of study, with strong community support for recycling of potentially wasted food as fertilizer and pig feed (Huang, 2010).

The *S-Nr*s for fruits exceeded 1.0, but the *I-Nr*s were below 1.0, which suggested wastage in both surveys, but with an improving trend. The FSIs for fruit, based on the GMs of the *S-Nr* and *I-Nr*, make this clear.

Appreciation of mismatch between supply and the recommendations contained in FGs and DRIs is one of the useful outcomes of our method. The problem is not what information we have, but the source of mismatch, whether it be it in the food supply, intake

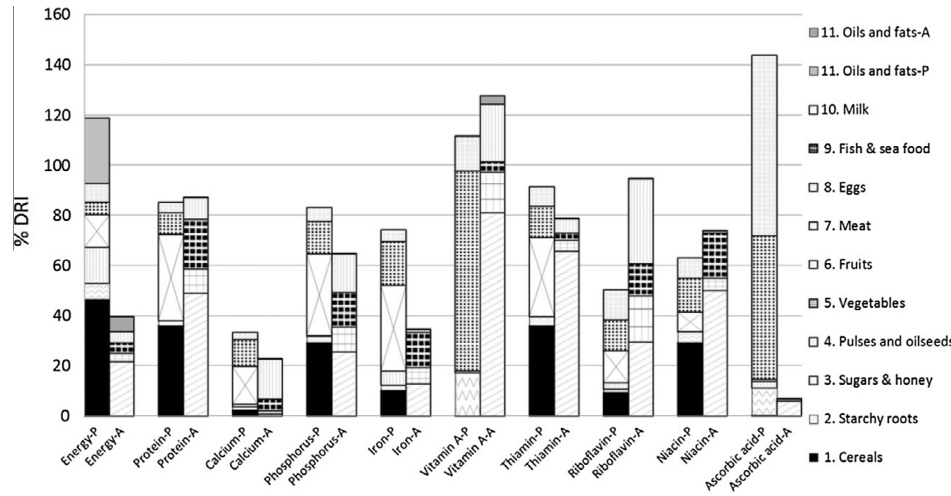

Fig. 3. The percentage of nutrients provided from 11 food categories in 2010 Taiwan food balance sheets (FBS) that meet population nutrient Dietary Reference Intake (DRI) needs. Nutrient needs obtained from aggregating age-and-gender specific DRIs of food energy and nutrients multiplied by the number of people in age-and-gender subgroups. P: plant-derived foods or nutrients; A: animal-derived foods or nutrients.

recommendations (which might be incorrect), or consumer intakes. In each regard, there are alerts for responsible stakeholders.

There may be room for improved food selection guides and the related nutrition education. In Taiwan, the dairy recommendations for adults are between 1.5 and 2 servings per day, which provide less than 40% of the calcium DRIs. However, only 0.6 servings of dairy per capita per day were available. A solution to this might be increasing agricultural production to promote accessibility to dairy and increasing nutrition education to select more nondairy calcium-dense foods. The likelihood of success with such a strategy can be monitored using the *S-Nr* and *I-Nr* data.

Dietary surveys and the Food Security Index

The *I-Nr* can represent the ideal diet if the needs-based denominators are determined using the best available evidence. Further, the FSI and NSI equations show the divergence from an ideal of 1.0 for both the *S-Nr* and the *I-Nr*. Because national surveys use data from the entire population, the FSI/NSI approach can embrace both dietary adequacy and quality in the whole country as nutrition and health security objectives.

Dietary guidance and needs

Both FSI and NSI ratios take account of FGs and DRIs as denominators, and this adds to their impact. Low ratios of both might occur if the recommendations are inappropriately high, and vice versa. We found that both the supply and the intake of dairy products were low throughout the two study periods, the supply and intake of soy/fish/meat/eggs were high. The recommendations for these foods and their nutrients require review.

Population considerations

Although the food and nutrient supply derived from FBS does not provide age- and gender-specific information, the secular trends we have considered are population-relevant. This is because they have been related to the population characteristics on an annual basis.

International population shifts in Taiwan of travelers, businessmen, students, laborers, and professionals may have altered the validity of our indices. However, the incoming and outgoing population bulletins issued by the National Immigration Agency and Tourism Bureau, weighted by estimated durations of stay, revealed somewhat balanced shifts between 3.6% incomings and 4.2% outgoings. Thus, the flow of people would be unlikely to have significantly affected our conclusions.

Sustainability

There is a growing appreciation of the role of food in health security and the relevance of sustainable food systems to sustainable health systems (Wahlqvist, 2009). In the case of our FSI and NSI, the focus on the quantity of the food supply, regardless of source, may overlook self-sufficiency as an indicator of national food security. For example, the indices do not in themselves show that Taiwan is only about 30% self-sufficient in food production (Huang et al., 2009). Moreover, agricultural production decreased from 21.9% in 1998 to 17.1% in 2010 for cereals (21.9–17.1%), vegetables (97–90.2%), and meat (86.9–81.8%).

Another sustainability problem is that of environmentally friendly food, such as that suggested by the ratio of plant- to animal-derived food, which collateral calculations can provide (Wahlqvist et al., 2012; Huang, 2010). Taiwanese FBSs have shown a steady decrease in the ratios of plant- to animal-derived food energy in 1990 (79.2% vs. 20.8% of the energy supply [4.0:1]), 2000 (77.2% vs. 22.8% [3.5:1]), and 2010 (75.9% vs. 24.1% [3.0:1]) (for 2010 data, see Fig. 3). The apparently excessive intake from the soy/fish/meat/eggs category in this study is striking and unabated despite declines in supply, which threatens its sustainability and, in times of financial crisis, affordability. FSI and NSI can help us identify such trends.

Limitations

Our study has some limitations. FSIs and NSIs consist of three elements and rely on FBSs, dietary surveys, and recommendations. FBSs relate to the overall population and do not allow for differences in dietary habits based on gender, age, or other demographic variables. We tried to overcome this in part by weighting the FBSs with demographic information and taking subgroup recommendations into account. We also included actual intake data of the populations listed in the FBSs. A dietary survey is a costly undertaking, however, and it depends upon a governmental or an institutional commitment.

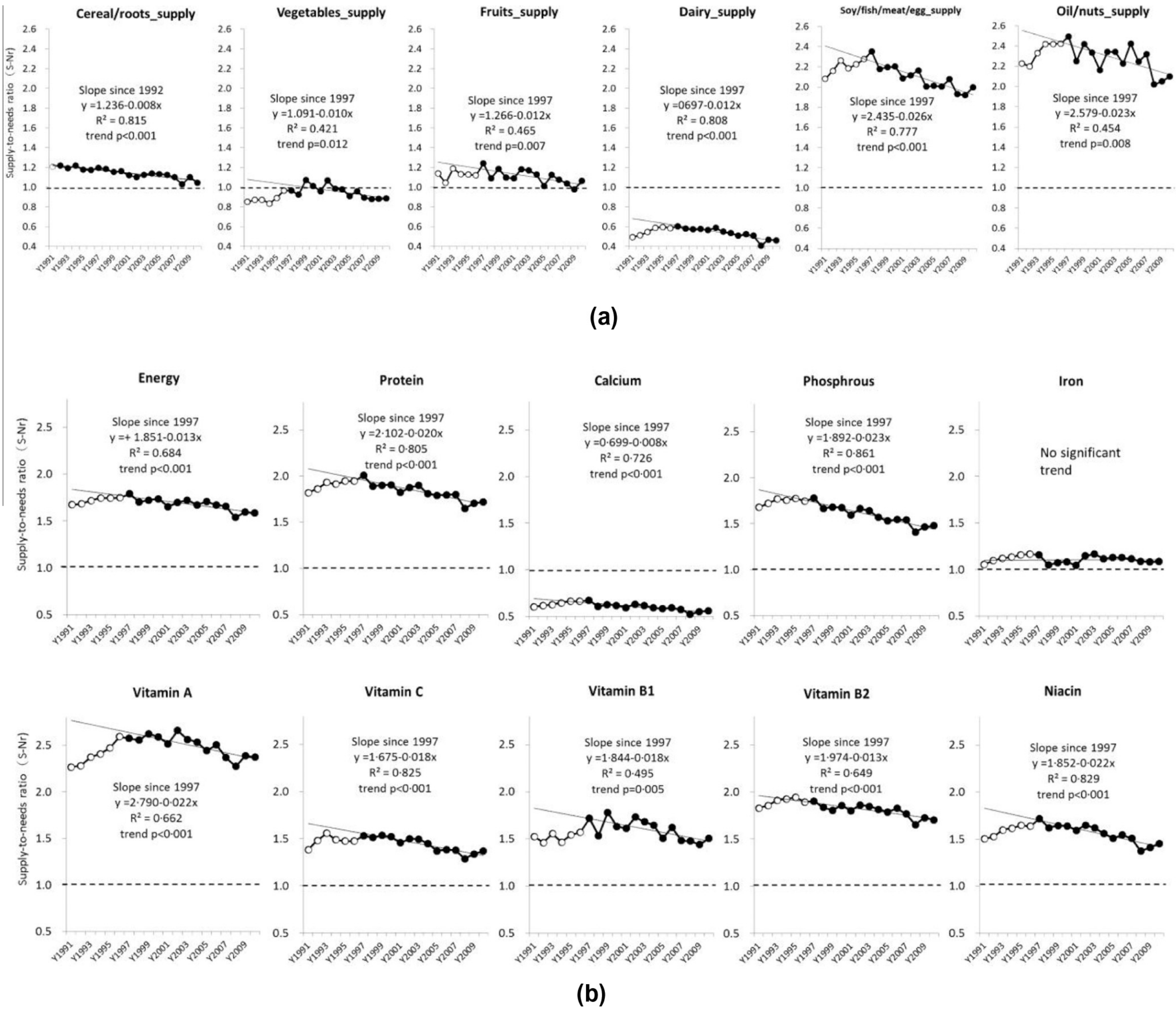

Fig. 4. Trends in food and nutrient supply-to-needs ratios (*S-Nrs*) of Taiwan food balance sheet food servings in relation to the national food guides (a) and nutrients in relation to Dietary Reference Intakes (DRIs) (b) from 1991 to 2010. Lines and dots in open circles (○) indicate 1991–1997; lines and dots in solid circles (●) indicate 1997–2010 where most (except the cereals/roots food category) of the declines started to occurred. Trend analysis covered all food categories from 1997 to 2010, except for the cereals/roots food category, which was covered only from 1992 to 2010. The resultant regression lines with the prediction equations with intercepts, slopes, R^2, and significance of trends are shown in plots. All food categories and energy and nutrient levels except for iron showed significant downward trends.

There are further limitations about intranational extrapolations from FSIs and NSIs. NAHSIT cycles do not correspond to the annual FBS cycle; thus, approximations are required when generating FSIs and NSIs.

We tacitly assumed for the purposes of this study that the dietary guidelines and DRIs have contemporary scientific validity. These assumptions may be challenged in and because of the present work. Our conclusion that Taiwan is dairy- and calcium-insecure is at odds with riboflavin not being a problem, and there being a controversy about how health-protective dairy foods are in Taiwan (Lee et al., 2009), where less than one serving a day may be associated with less all-cause and stroke mortality (Huang et al., 2014). Nevertheless, there are qualitative similarities in dietary dairy characteristics, including calcium, between Taiwan and the USA, as judged by the DASH diet (Lin et al., 2013). This also speaks to a shift in the conceptualization of food security away from quantity and toward quality (defined as *food diversity*) (Lee et al., 2011; Wahlqvist, 2014). The question is increasingly one of how little we need and how sustainable the food supply is. The current Taiwanese dietary guidelines reflect this trend (Tzeng, 2008; Huang, webpage 2015), and so will subsequent generations of FSIs.

DRIs as references for nutrient needs may overestimate deficiency where they are not population probabilistic (Murphy and Barr, 2013). Nevertheless, the trends we describe remain indicative of changes in nutrient security.

The potential food and nutrient security problems identified with supply and intake-need mismatches and with trends to and away from the ideal 1.0 values are of particular relevance to vulnerable groups: minority groups, mothers and children, the elderly, and the chronically ill. Such deductions can be made by perceptive juxtaposition of other information available in public health nutrition partnerships.

The tolerance limits above 1.0 for FSIs and NSIs will depend upon the food and nutrient in question, the peculiar threats to food and nutrient security that operate in a particular setting, and a keen and intimate knowledge of local food culture and its health

Table 2
Intake-to-needs ratios (*I-Nrs*) for food categories, energy, and nutrients for 1993–1996 and 2005–2008 NAHSITs.

Food category/nutrient	NAHSIT	19–30-year-olds		31–50-year-olds		51–70-year-olds		71+-year-olds[a]		M[b]	C[c]	W[b]	C[c]
		Men	Women	Men	Women	Men	Women	Men	Women				
Cereals/roots (FC)	1993–1996	1.14	0.69	1.12	0.79	1.07	0.84			1.12		0.76	
	2005–2008	0.85	0.73	0.93	0.62	0.92	0.72	0.83	0.69	0.90	↓	0.68	↓
Dairy (FC)	1993–1996	0.24	0.23	0.23	0.30	0.19	0.35			0.22		0.29	
	2005–2008	0.15	0.21	0.21	0.23	0.37	0.43	0.52	0.43	0.26	↑	0.29	-
Soy/fish/meat/eggs (FC)	1993–1996	1.93	1.15	1.64	1.26	1.39	1.02			1.68		1.17	
	2005–2008	2.30	1.72	2.28	1.61	1.99	1.23	1.26	0.97	2.13	↑	1.49	↑
Vegetables (FC)	1993–1996	0.80	0.70	1.02	1.10	1.18	1.11			0.99		0.97	
	2005–2008	0.78	0.71	1.04	1.07	1.22	1.23	1.22	1.00	1.03	↑	1.01	↑
Fruits (FC)	1993–1996	0.44	0.59	0.47	0.59	0.47	0.56			0.46		0.58	
	2005–2008	0.47	0.57	0.83	0.91	0.88	0.99	0.90	0.57	0.75	↑	0.81	↑
Oil/nuts (FC)	1993–1996	0.56	0.50	0.61	0.66	0.55	0.47			0.58		0.57	
	2005–2008	0.89	0.70	0.86	0.67	0.74	0.57	0.59	0.44	0.82	↑	0.64	↑
Energy	1993–1996	1.05	0.83	1.00	0.94	0.99	0.83			1.01		0.88	
	2005–2008	1.03	1.04	1.14	0.94	1.04	0.87	0.89	0.78	1.07	↑	0.94	↑
Protein (Nutr.)	1993–1996	1.50	1.12	1.44	1.38	1.34	1.25			1.44		1.27	
	2005–2008	1.58	1.53	1.77	1.52	1.71	1.41	1.21	1.09	1.66	↑	1.46	↑
Calcium (Nutr.)	1993–1996	0.50	0.41	0.51	0.54	0.50	0.53			0.50		0.50	
	2005–2008	0.53	0.50	0.62	0.56	0.69	0.66	0.70	0.56	0.62	↑	0·.57	↑
Phosphorus (Nutr.)	1993–1996	1.49	0.98	1.33	1.15	1.18	1.03			1.35		1.07	
	2005–2008	1.58	1.31	1.67	1.31	1.59	1.29	1.32	1.03	1.60	↑	1.28	↑
Iron (Nutr.)	1993–1996	1.61	0.71	1.36	0.82	1.21	1.06			1.41		0.84	
	2005–2008	1.83	1.01	1.83	1.03	1.75	1.42	1.35	1.06	1.77	↑	1.12	↑
Vitamin A (Nutr.)	1993–1996	1.89	1.90	2.16	2.53	2.41	3.14			2.13		2.46	
	2005–2008	1.49	1.35	1.79	1.92	2.06	2.37	2.12	2.14	1.80	↓	1.91	↓
Vitamin C (Nutr.)	1993–1996	1.67	1.66	1.66	1.82	1.74	1.77			1.68		1.76	
	2005–2008	1.65	1.35	1.83	1.80	2.08	1.95	1.75	1.27	1.84	↑	1.68	↓
Thiamin (Nutr.)	1993–1996	1.33	1.02	1.26	1.32	1.12	1.17			1.25		1.19	
	2005–2008	1.27	1.22	1.27	1.20	1.37	1.17	1.11	1.06	1.28	↑	1.19	↓
Riboflavin (Nutr.)	1993–1996	1.22	1.05	1.03	1.18	0.99	1.12			1.08		1.12	
	2005–2008	1.38	1.24	1.28	1.23	1.36	1.30	1.48	1.23	1.34	↑	1.25	↑
Niacin (Nutr.)	1993–1996	1.23	0.93	1.10	1.04	1.07	0.93			1.14		0.98	
	2005–2008	1.57	1.57	1.74	1.67	1.76	1.38	1.43	1.15	1.68	↑	1.53	↑

FC: food category; Nutr.: nutrient; NAHSIT: the Nutrition and Health Surveys in Taiwan. M: mean; W: weighted; C: change.
[a] 1993–1996 NAHSIT sampled 19–70-year-olds only.
[b] Mean intake-to-needs ratios were weighted by age-and-gender populations.
[c] Change from 1993–1996 NAHSIT to 2005–2008 NAHSIT: ↑: an increase ↓: a decrease.

Table 3
Food security indices comparing 1993–1996 and 2005–2008 NAHSITs.

	NAHSIT period	Cereals/roots	Vegetables	Fruits	Dairy	Soy/fish/meat/eggs	Oil/nuts
a. Food supply [a] to needs[b] ratio (*S-Nr*)	1993–1996	1.19	0.89	1.14	0.58	2.24	2.40
	2005–2008	1.10	0.91	1.06	0.49	2.01	2.25
b. Food intake[c] to needs[d] ratio (*I-Nr*)	1993–1996	0.92	0.97	0.51	0.37	1.42	0.71
	2005–2008	0.78	1.02	0.78	0.40	1.81	0.91
c. Food Security Index $(\mathrm{FSI}) = \sqrt{\exp\sqrt{\ln(S\text{-}Nr)^2} \times \exp\sqrt{\ln(I\text{-}Nr)^2}}$	1993–1996	1.14	1.08	1.50	2.16	1.78	1.84
	2005–2008	1.19	1.06	1.17	2.26	1.91	1.57

NAHSIT: Nutrition and Health Surveys in Taiwan.
[a] Aggregates of national food availability from food balance sheets for NAHSIT period.
[b] Aggregates of national food needs from food guides for NAHSIT period.
[c] Estimated food intake of population for NAHSIT period.
[d] Estimated food needs of population for NAHSIT period.

relationships. This study provides a number of examples of deviations from 1.0 in Taiwan, but more data are needed to further systematize these findings or to generalize them to other locales.

Implications

The trend graphics for *S-Nr* (Fig. 4(a)) relate to the prevailing finding, except for the cereals/roots category, of an inflection point in the curves in 1997. We draw attention to when the Asian Financial Crisis, which can be viewed as a possible natural experiment in food security, began: 5 years after Taiwan joined the World Trade Organization. It is possible that governmental and nongovernmental organizations and private companies acted individually to limit food supplies, or it may simply represent changes in consumer demand. Of greatest interest is when a trajectory will cross the 1.0 ratio line to become <1.0.

Table 4
Nutrient security indices comparing 1993–1996 and 2005–2008 NAHSITs.

	NAHSIT	Energy	Protein	Calcium	Phosphorus	Iron	Vit A	Vit C	Thiamin	Riboflavin	Niacin
a. Nutrient supply[a] to needs[b] ratio (*S-Nr*)	1993–1996	1.78	1.93	0.65	1.76	1.14	1.61	1.53	1.92	1.62	1.50
	2005–2008	1.68	1.76	0.57	1.51	1.12	1.62	1.52	1.76	1.48	1.35
b. Nutrient intake[c] to needs[d] ratio (*I-Nr*)	1993–1996	1.11	1.36	0.50	1.21	1.07	1.56	1.72	1.40	1.26	1.23
	2005–2008	1.27	1.71	0.65	1.57	1.50	2.01	1.92	1.53	1.60	2.01
c. Nutrient Security Index $(\text{NSI}) = \sqrt{\exp\sqrt{\ln(S\text{-}Nr)^2} \times \exp\sqrt{\ln(I\text{-}Nr)^2}}$	1993–1996	1.41	1.62	1.75	1.46	1.1	1.58	1.62	1.64	1.43	1.36
	2005–2008	1.46	1.73	1.64	1.54	1.3	1.8	1.71	1.64	1.54	1.65

NAHSIT: Nutrition and Health Surveys in Taiwan.
[a] Aggregates of national nutrient supply from food balance sheets for NAHSIT period.
[b] Aggregates of national nutrient needs from Dietary Reference Intakes for NAHSIT period.
[c] Estimated nutrient intake of population for NAHSIT period.
[d] Estimated nutrient needs of population for NAHSIT period.

We can envisage that similar incipient threats to food security might be recognized more readily if existing FBSs and survey data are used as we have used them. Where such data do not exist, our findings make a case for their acquisition.

Other settings

These quantitative and collective FSI and NSI allow comparisons over time and between food categories, and they provide an overview of the state of national food security as well as some of the details required for policy development. The method can be applied to various types of administrative zones, from villages to continents, provided that three requirements are met: (1) available FBSs, (2) accessible nutritional surveys, and (3) recommendations are agreed on and made for optimal food and nutrient intakes in the target zone. Even if only FBS or dietary survey data are available, a useful *S-Nr* or *I-Nr* can be estimated.

Conclusions

We evaluated the food and nutrient supply trajectories against nutrition recommendations and actual intakes by generating novel indices to warn of food and nutrient insecurity. These indices allow national food and nutrient security status to be established and monitored.

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