



HAL
open science

Dietary Diversity Indicators and Their Associations with Dietary Adequacy and Health Outcomes : A Systematic Scoping Review

Eric O Verger, Agnes Le Port, Augustin Borderon, Gabriel Bourbon, Mourad Moursi, Mathilde Savy, François Mariotti, Yves Martin-Prével

► **To cite this version:**

Eric O Verger, Agnes Le Port, Augustin Borderon, Gabriel Bourbon, Mourad Moursi, et al.. Dietary Diversity Indicators and Their Associations with Dietary Adequacy and Health Outcomes : A Systematic Scoping Review. *Advances in Nutrition*, 2021, 12 (5), pp.1659-1672. 10.1093/advances/nmab009 . ird-03159901

HAL Id: ird-03159901

<https://ird.hal.science/ird-03159901v1>

Submitted on 4 Mar 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Dietary Diversity Indicators and Their Associations with Dietary Adequacy and Health Outcomes: A Systematic Scoping Review

Eric O Verger,¹ Agnes Le Port,¹ Augustin Borderon,¹ Gabriel Bourbon,² Mourad Moursi,³ Mathilde Savy,¹ François Mariotti,⁴ and Yves Martin-Prevel¹

¹MoISA, Univ Montpellier, CIRAD, CIHEAM-IAMM, INRAE, Institut Agro, IRD, Montpellier, France; ²Independent Consultant, Paris, France; ³Intake—FHI Solutions, Washington, DC, USA; and ⁴Université Paris-Saclay, AgroParisTech, INRAE, UMR PNCA, Paris, France

ABSTRACT

Dietary diversity has long been recognized as a key component of diet quality and many dietary diversity indicators (DDIs) have been developed. This systematic scoping review aimed to present a comprehensive inventory of DDIs and summarize evidence linking DDIs and dietary adequacy or health outcomes in adolescents and adults. Two search strategies were developed to identify peer-reviewed articles published in English up until June 2018 and were applied to Medline, Web of Science, and Scopus. A 2-stage screening process was used to select the studies to be reviewed. Four types of DDIs were identified among 161 articles, the majority of them belonging to the food group–based indicator type ($n = 106$ articles). Fifty studies indicated that DDIs were proxies of nutrient adequacy, but there was a lack of evidence about their relation with nutrients to limit. Associations between DDIs and health outcomes were largely inconsistent among 137 studies, especially when the outcomes studied were body weight ($n = 60$) and noncommunicable diseases ($n = 41$). We conclude that the ability of DDIs to reflect diet quality was found to be principally limited to micronutrient adequacy and that DDIs do not readily relate to health outcomes. These findings have implications for studies in low- and lower-middle-income economies where DDIs are often used to assess dietary patterns and overall diet quality. *Adv Nutr* 2021;00:1–14.

Keywords: dietary diversity, indicators, nutrition, diet quality, health outcomes, body weight, noncommunicable diseases, adolescent, adult

Introduction

Food diversity has long been recognized as a key element of high-quality diets, based on the principle that no single food can provide the right amount of nutrients necessary to maintain optimal health. This theory has been historically documented on many occasions, such as the high prevalence of beriberi, as well as night blindness and scurvy, among

the Imperial Japanese Army during the first half of the 20th century, due to rice-based rations that included little or no other foods (1). Eating a variety of foods has been a longstanding recommendation of US dietary guidelines since 1980, initially phrased as “select foods each day from each of several major groups,” then as “choose a variety of nutrient-dense foods across and within all food groups in recommended amounts” (2, 3). Many other national and international food-based dietary guidelines have included dietary diversity as a key feature, albeit with slightly different definitions depending on the country or countries and cultural dietary patterns (4, 5). One result of these historical evolutions and national differences was a lack of consensus about what dietary diversity represents and how to measure and operationalize it (6).

Dietary diversity indicators (DDIs) have been identified as promising measurement tools, particularly for use in developing countries, because of their simplicity of implementation and their potential to be used at a large scale compared with other food-consumption indicators involving the collection of complex quantitative information (6).

This manuscript evolved from content for an invited presentation made at a 2018 meeting convened by Intake—Center for Dietary Assessment, at which YM-P was an invited speaker and Intake-funded participant. Open-access charges were supported by the Bill & Melinda Gates Foundation, Seattle, Washington.

Author disclosures: The authors report no conflicts of interest.

Supplemental Figures 1 and 2, Supplemental Tables 1–7, and Supplemental Results are available from the “Supplementary data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/advances/>.

Address correspondence to EO (e-mail: eric.verger@ird.fr).

Abbreviations used: DDI, dietary diversity indicator; DGI, dietary guidelines–based indicator; FFQ, food-frequency questionnaire; FGI, food group–based indicator; FII, food item–based indicator; HFD, Healthy Food Diversity; HIE, high-income economy; LIE, low-income economy; LMIE, lower-middle-income economy; NCD, noncommunicable disease; OI, other indicator; PICOS, Population, Interventions, Comparators, Outcomes, and Study; PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews; UMIE, upper-middle-income economy.

Thereafter, significant progress has been made in developing and validating simple DDIs with consistent and relevant meaning across different contexts and over time. As a result, many DDIs have been developed and used in the literature, either as proxies of nutritional adequacy of the diet or as recommendations to maintain optimal health (6–10). The most recent example is the Minimum Dietary Diversity for Women of Reproductive Age, which is calculated based on a single 24-h recall (11) and has been shown to be effective in predicting adequacy for 11 micronutrients in 9 large datasets from different countries (12).

While several comprehensive or systematic reviews have been carried out, the most recent ones focusing on obesity and body adiposity (8–10), there is a lack of comprehensive information about how dietary diversity is conceptualized and measured across contexts, and whether the proposed indicators are associated with dietary adequacy and health outcomes. Scoping reviews aim at identifying, mapping, and synthesizing the available evidence in a given field of interest (13) and are particularly relevant for the following purposes: 1) clarify key concepts and definitions, 2) identify key characteristics or factors related to a concept, and 3) highlight knowledge gaps (14). The objectives of the present systematic scoping review are therefore as follows: 1) to present a comprehensive inventory of DDIs developed for adolescents and adults, 2) to summarize the evidence of the associations between DDIs and measures of dietary adequacy, and 3) to summarize the evidence of the associations between DDIs and health outcomes.

Methods

Search strategies

Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines (15), 2 structured search strategies were developed to include title-abstract-keywords in 2 different search strings. The first search strategy focused on articles studying dietary diversity in association with measures of the dietary adequacy and included the title-abstract-keywords “diet diversity, diet variety, food diversity, food variety, nutrient intake, nutrient adequacy, diet quality,” including relevant variations in keywords. The second search strategy focused on articles studying dietary diversity in association with health outcomes and included the title-abstract-keywords “diet diversity, diet variety, food diversity, food variety, health outcome, risk factor, life expectancy, mortality, morbidity, comorbidity, cancer, disease, overweight, obesity, adiposity, anthropometric status, diabetes, blood glucose, cardiometabolic, metabolic syndrome, hypertension, blood pressure, dyslipidemia, anemia, low birth weight, incidence, vascular,” including relevant variations in keywords. The searches were limited to peer-reviewed articles published in English up until June 2018 and were run using 3 databases: Medline, Web of Science, and Scopus. Additionally, we examined reference lists in papers from the studies included to identify other relevant studies.

Data extraction

All studies identified as suitable were extracted using Zotero (version 4.0.28.7). We conducted a 2-stage screening process to select the studies to be fully reviewed. During the first stage, titles and abstracts were examined by 2 authors (EOV and AB) and irrelevant studies were excluded from further review. At the second stage, a full-text screen was performed by 2 authors (EOV and ALP) and evaluated using the Population, Interventions, Comparators, Outcomes, and Study design (PICOS) criteria for inclusion and exclusion (16). All disagreements regarding eligibility were resolved by discussion.

Inclusion and exclusion criteria

The PICOS criteria for inclusion and exclusion for title, abstract, and full-text screening are described in **Table 1**. Because our intent was to present a comprehensive inventory of DDIs developed for adolescents and adults, we did not exclude articles based on their methodological quality. Furthermore, our scoping review was not meant to assess the validity or quality of the studies, nor of the indicators they used.

Synthesis of the results

Due to the wide heterogeneity among DDIs, measures of dietary adequacy, health outcomes, study designs, and statistical models, we used a qualitative and descriptive approach to review the available evidence regarding whether dietary diversity is associated with dietary adequacy and various health outcomes. The association between DDIs and any measure of dietary adequacy was described as “positive” (the higher the DDI, the higher the dietary adequacy), “mixed” (significance and direction of the association varied depending on subgroups or type of DDIs that were used), “null” (no association), or “negative” (the higher the DDI, the lower the dietary adequacy). The association between DDIs and any health outcome was described as “favorable” (e.g., the higher the DDI, the lower the risk for metabolic syndrome or the lower the risk for wasting), “mixed” (significance and direction of the association varied depending on subgroups or type of DDIs used), “null” (no association), or “unfavorable” (e.g., the higher the DDI, the higher the risk for obesity).

Results

Comprehensive inventory of dietary diversity indicators

Based on the 2 structured search strategies, 50 articles studying the association between dietary diversity and dietary adequacy and 137 articles studying the association between dietary diversity and any health outcomes were included (**Figure 1**). Cross-referencing the 2 sets of papers led to 161 unique studies published from 1989 to June 2018. From these, 4 types of DDI have been identified: the “food item–based indicators” (FIIs), the “food group–based indicators” (FGIs), the “dietary guidelines–based indicators”

TABLE 1 PICOS criteria for inclusion and exclusion of studies¹

Parameter	Description
Population	Inclusion criteria: adults and adolescents (age ≥ 10 y) Exclusion criteria: children (age < 10 y)
Interventions	Inclusion criteria: any study measuring participants' dietary variety or dietary diversity using an indicator based on the number of foods or food groups ² consumed over a reference period, regardless of the mathematical operation required to compute this information
Comparators	Inclusion criteria: participants with higher dietary diversity compared with participants with lower dietary diversity
Outcomes	Inclusion criteria: 1) Any measure of dietary adequacy, including nutrient intake, nutrient adequacy index, and food-based diet quality index 2) Any health outcome, including (but not restricted to) body weight and body composition, noncommunicable diseases and intermediate biomarkers of health, biomarkers of nutritional status, mental health and cognitive functions, and mortality
Study design	Inclusion criteria: all study designs Exclusion criteria: reviews, expert opinion, comments, letters to the editor, studies on animals, conference reports

¹ PICOS, Population, Interventions, Comparators, Outcomes and Study design criteria.

² A food group is a collection of foods that share similar nutritional properties or biological classifications.

(DGIs) and the “other indicators” (OIs). **Table 2** summarizes the characteristics of these 4 types of DDI, further described in the following sections.

FII of dietary diversity.

The FIIs were based on the number of different food items consumed over a reference period. FIIs were used in 56 studies and were usually a simple count of food items

that had been consumed ($n = 49$). In 7 studies, the FII was also a simple count of food items but only those considered by the authors as healthy (17–22), unhealthy (19–21), or traditional (23). We observed a large variability across studies in the number of different food items included in the FIIs (**Figure 2**), as well as variations in the reference periods (25 studies covered periods of 1–7 d, while 29 covered periods ranging from 7 d to 1 y).

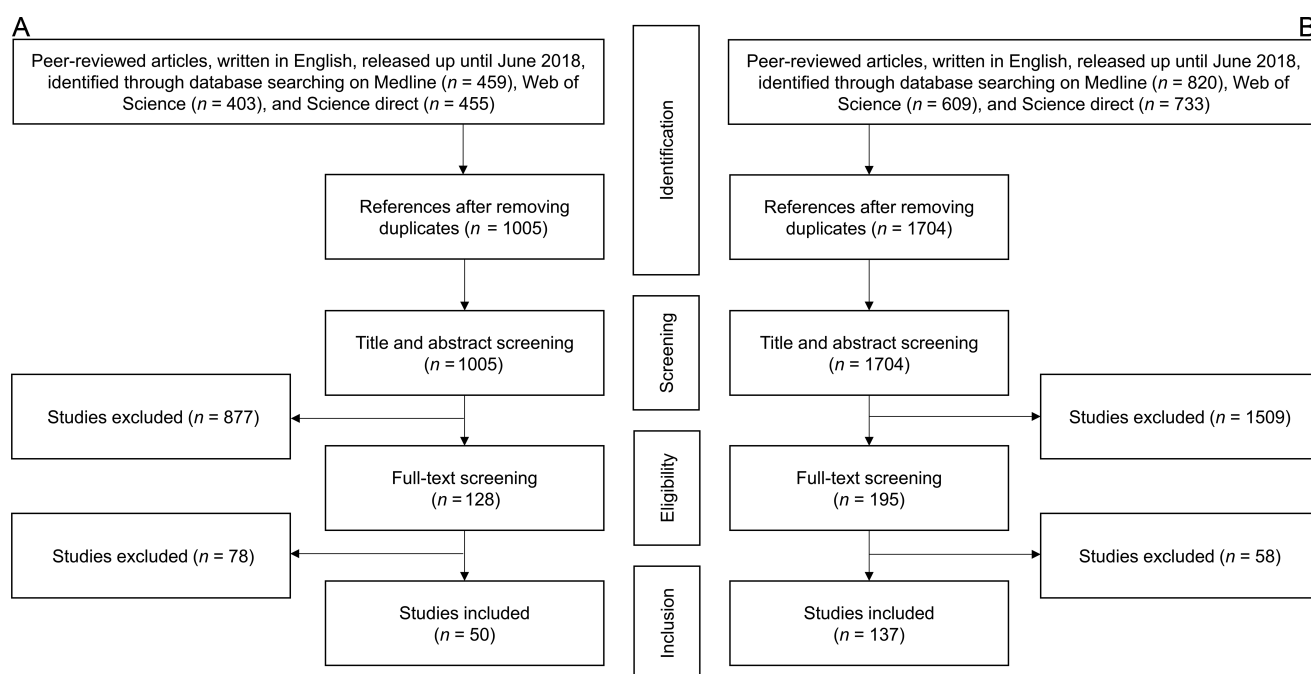


FIGURE 1 Systematic literature review flowchart for article selection. (A) Flowchart for selection and inclusion of studies in the systematic review of the evidence of dietary diversity and its relation with measures of dietary adequacy. (B) Flowchart for selection and inclusion of studies in the systematic review of the evidence of dietary diversity and its relationship with health outcomes.

FGIs of dietary diversity.

The FGIs were based on the number of different food groups consumed over a reference period, without allocating any weight to food groups. The way food groups were delineated varied greatly across the studies (resulting in varied numbers of food categories, of food items within categories, and of level of heterogeneity within the food groups). We decided to keep authors' food groups, even when they were debatable. FGIs were used in 106 studies and were usually a simple count of the different groups consumed over a reference period ($n = 90$). Another approach was to first assess the diversity of food consumed among 5 main food groups, weighted by intra-food-group diversity (24–34). We observed a large variability across studies in the number of food groups considered (Figure 3). In the 55 studies that reported the rule to count a group in the indicator, we found large differences in the way to set the minimum amount (e.g., 15 or 25 g), or the serving size (e.g., half a serving or a serving), or the frequency of food consumption (e.g., once a week or once a day).

DGIs of dietary diversity.

The DGIs assessed the number of different food groups consumed over a reference period and allocated different weights to each food group according to national food-based dietary guidelines or international recommendations. DDIs were used in only 11 studies and the most frequently used was the Healthy Food Diversity (HFD) index. First developed for the German context (35, 36) and later adapted to the US context (37–40), the HFD index is calculated by multiplying the Berry index (defined as 1 minus the sum of the squares of the share of each food in the total amount of energy intake) by the “health value” of the diet of each individual (calculated using health factors attributed to food groups according to the food-based dietary guidelines). Another type of DGI was based on the count of different groups consumed over a reference period, but in order for a food group to be counted in the index, individuals had to eat the minimum recommended number of servings according to national dietary guidelines (e.g., 3 servings daily for vegetables). This kind of DGI was used in the United States (41, 42), Sri Lanka (43, 44), and Malaysia (45).

OIs of dietary diversity.

The OIs, which relied on different concepts, were used in 12 studies (see **Supplemental Results** for more details). Briefly, 1 main type of OI was used in 6 studies to reflect the distribution of foods consumed, like the Berry (or Simpson) index (35, 46, 47), the QUANTIDD index (48, 49), the Entropy index (50), and the Dissimilarity index (46). The other main type of OI was based on the ratio between the “variety” (defined by the authors as the percentage of different food items consumed) within some food groups and the “variety” within other food groups (51–54). Another type of OI was a composite score similar to a DDI but with different weights arbitrarily attributed to food groups (55, 56). Last, 1 OI was called the Functional Diversity, a

complex indicator reflecting the diversity in the nutrient composition of species (plant, livestock, and fish) consumed by each individual (47).

Use of indicators of dietary diversity over time and across contexts.

A first analysis indicated a growing use of DDIs with time (Figure 4A), with a higher use of these indicators occurring in the context of high-income economies (HIEs) as compared with low-, lower-middle-, and upper-middle-income economies (LIEs, LMIEs, and UMIEs, respectively; Figure 4B). A second analysis of the 161 articles that took the type of DDI into account showed that FIIs and FGIs were the most frequent types of indicators. While their use began at the same time, with a similar occurrence of use over time, a shift in 2010 resulted in FGIs becoming the current most frequently used type of indicator (Figure 4A). In terms of country income classification, studies in the contexts of LIEs, LMIEs, and UMIEs have mainly used FGIs over the other types of DDI, whereas the use of the 4 types of DDI was more balanced in HIEs (Figure 4B).

Review on the relation of DDIs with dietary adequacy

Fifty studies assessed the association between a DDI and a measure of dietary adequacy (**Supplemental Table 1**). Most of the studies used a cross-sectional design, were located in HIEs and UMIEs (Figure 5A), and calculated DDIs from either 24-h recalls or food-frequency questionnaires (FFQs; Figure 5B). The FGIs were the most frequently used indicators ($n = 32$), followed by FIIs ($n = 24$), DGIs ($n = 5$), and OIs ($n = 4$). There was a wide variation in terms of measures of dietary adequacy (Figure 5C) and in the number of nutrients used in the measures of dietary adequacy (Figure 5D).

Among the 50 studies reviewed, all found some positive associations between the DDIs and the measures of dietary adequacy, except for 3 studies that found no associations with FIIs (57–59) and 3 others that found mixed associations with FIIs and OIs (19, 20, 46) (Figure 6A and **Supplemental Figure 1A**). Studies reporting mixed associations are those showing contradictory results (either significant or not and positive or negative associations) according to age groups (19) or to the type of DDIs used (20, 46) (see Supplemental Results for more details).

We found 19 studies that investigated the relation between DDIs and dietary adequacy with accounting for energy intake. When energy intake was controlled for, the relations were attenuated but still significant in 7 studies (25, 28, 60–64), became nonsignificant in 2 studies (58, 59), and were not attenuated in 2 studies (37, 47). However, while higher energy intake has long been recognized as a potential confounding factor when studying the relation between micronutrient intakes and indexes of overall diet quality (7), it could also play a mediating role in that relation. Indeed, some studies have shown that higher food and energy intakes come along with higher variety of foods consumed (65–67).

TABLE 2 Summary of the characteristics of the 4 types of dietary diversity indicators identified from the 161 articles included in the systematic literature review¹

Type of dietary diversity indicator	Number of studies	Description
Food item-based indicators (FIs)	56	Simple count of the different food items consumed. Consuming the same food item 1 or more times scored 1; not consuming a food item scored 0. Most of the time, any food item was counted, except in 7 studies where only food items considered by the authors as healthy, unhealthy, or traditional were counted.
Food group-based indicators (FGIs)	106	Simple count of the different food groups ² consumed. Most of the time, foods were classified in 5, 9, 10, or 12 groups. Most of the time, consuming some foods from the same group 1 or more times scored 1; not consuming a food group scored 0. In a few cases, intra-food-group diversity was taken into account (24–34).
Dietary guidelines-based indicators (DGIs)	11	Two subtypes: <ul style="list-style-type: none"> – Healthy Food Diversity (HFD): multiplication of the Berry index by the health value of the individual's diet (33–38) – Count of different food groups consumed with the minimum recommended number of servings consumed to be included in the count (39–43)
Other indicators (OIs)	12	Four subtypes: <ul style="list-style-type: none"> – Indicators reflecting how the foods consumed were distributed: Berry index (35, 46, 47), QUANTIDD index (48, 49), Entropy index (50), and Dissimilarity index (46) – Indicators calculated as a ratio between the “variety” (defined by the authors as percentage of different food items consumed) of some food groups and the variety of other food groups (51–54) – Composite score based on consumption of food groups and relative importance of each food group, with or without taking into account frequency of consumption (55, 56) – Functional Diversity: a complex indicator reflecting the diversity in nutrient composition of species (plant, livestock, and fish) consumed (47)

¹ See Supplemental Results for more details about the “Other indicators”.

² A food group is a collection of foods that share similar nutritional properties or biological classifications.

Only 14 studies explored how DDIs were associated with nutrients that can be unhealthy if consumed in excess, like SFAs or added sugars (called excess nutrients in the rest of the article). Four studies found that DDIs were negatively related to excess nutrients (i.e., the higher the DDIs, the lower the intakes) (37, 57, 68, 69), 4 found positive associations (41, 70–72), and 6 found mixed (17, 21, 35, 46) or null (58, 73) associations. There was no clear pattern to explain these contrasting results (Figure 6B and Supplemental Figure 1B). Two DDIs

provided interesting results. First, the Dissimilarity index was found to be negatively related to various food-based diet-quality indicators, providing a specific measure of “unhealthy dietary diversity” due to its design which incorporated 12 different foods likely to have cardiometabolic effects (46). Next, the HFD index seemed to be the most suitable DDI to provide a specific measure of “healthy dietary diversity”, being both positively related to measures of dietary adequacy and inversely related to excess nutrients (35, 37).

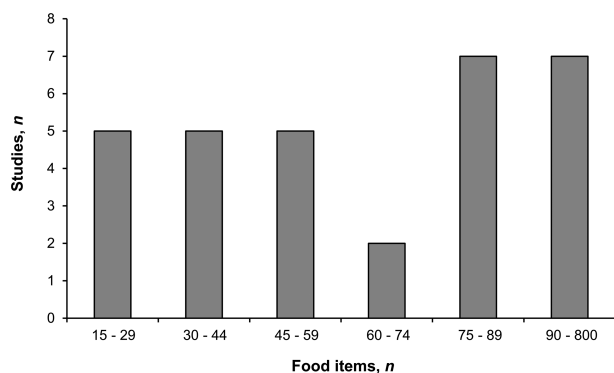


FIGURE 2 Distribution of studies according to the range of the theoretical maximum number of food items used in the food item-based indicators (when information available: $n = 27$ out of 56 studies).

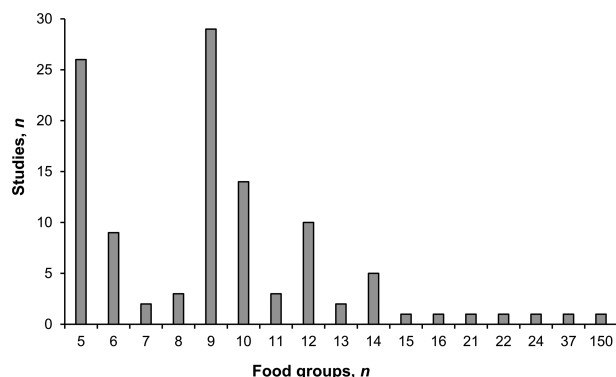


FIGURE 3 Distribution of studies according to the number of food groups used in the food group-based indicators (when information available: $n = 102$ out of 106 studies).

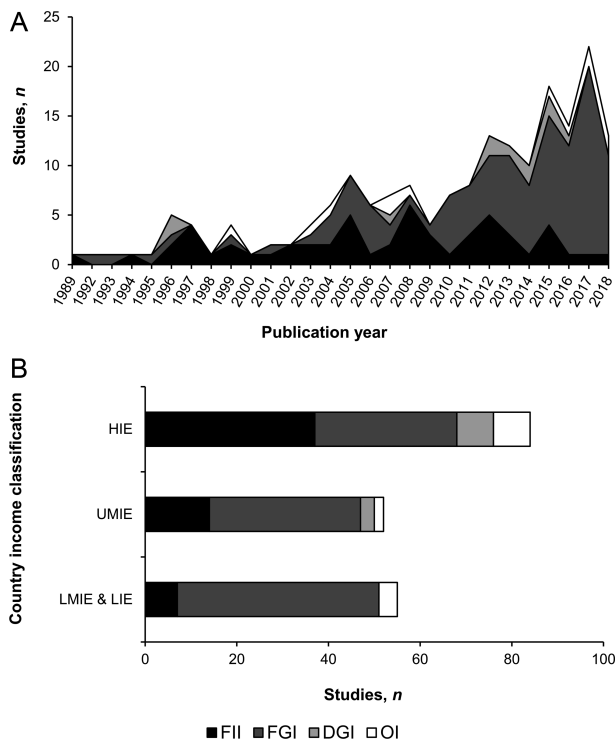


FIGURE 4 Number of studies using the different types of dietary diversity indicators for adolescents and adults across the 161 articles included in this review. (A) Number of studies per type and per year. (B) Number of studies per type and per country income classification. DGI, dietary guidelines–based indicator; FGI, food group–based indicator; FII, food item–based indicator; HIE, high-income economies; LIE, low-income economies; LMIE, lower-middle-income economies; OI, other indicator; UMIE, upper-middle-income economies.

Review on the associations of DDIs with health outcomes

The 137 studies included in the review on the association between DDIs and health outcomes were further classified into 6 categories of health outcomes: 1) body weight and body composition ($n = 60$), 2) noncommunicable diseases (NCDs) and intermediate biomarkers of health ($n = 41$), 3) biomarkers of nutritional status ($n = 19$), 4) mental health and cognitive functions ($n = 17$), 5) mortality ($n = 10$), and 6) other health outcomes ($n = 18$).

Most studies used a cross-sectional design and were located in HIEs (Figure 7A). While body-weight and body-composition outcomes have been studied across different economical categories of countries, the number of studies investigating other health outcomes varied according to those categories (Figure 7C). For example, NCDs and intermediate biomarkers of health have been studied in HIEs more frequently than in UMIEs, and in UMIEs more than in LMIEs and LIEs, whereas biomarkers of nutritional status have been more frequently studied in LMIEs and LIEs than in UMIEs and HIEs. FGIs were by far the most frequently used indicators ($n = 89$), followed by FIIs ($n = 43$), DGIs

($n = 8$), and OIs ($n = 10$). The predominance of FGIs was noticeable across the 6 categories of health outcomes, except for NCDs and intermediate biomarkers of health, and for mental health and cognitive functions outcomes where FIIs were used just as much (Figure 7B). Thus, the analysis of the association between DDIs and health outcomes was driven by the economical context of the studies (Figure 8) rather than by the types of DDIs (Supplemental Figure 2). The following sections present a global analysis of each health outcome (except for the category “other health outcomes”) but their detailed presentation can be found in the Supplemental Results and Supplemental Tables 2–7.

DDIs and body weight and body composition.

Fifty-one studies evaluated the association between DDIs and outcomes that were related to excess body weight (weight gain, being overweight, or obesity); there was a similar proportion of studies finding favorable, mixed, null, or unfavorable associations. Of note, the proportion of studies finding an unfavorable association was higher in UMIEs compared with other contexts (Figure 8A). Only 6 studies used a longitudinal design, finding either a favorable (40, 74), mixed (46, 75), null (76), or unfavorable (51) association. Furthermore, only 2 of them had a sample size > 1000 participants and used multi-adjusted regressions (46, 76). Nevertheless, 3 studies using a specific DDI provided interesting results that deserve to be highlighted. The food variety ratio could be considered as corresponding to some “(un)balanced dietary diversity”: defined by the “variety” of snacks divided by the “variety” of grains and meats, it was found to be associated with an increased risk of becoming overweight (51) or obese (52), while defined by the “variety” of vegetables divided by the “variety” of sweets, snacks, condiments, lunch and dinner entrées (e.g., beef, fried fish, pizza), and carbohydrates, it was found to be inversely associated with body fatness (54).

There were only 9 studies related to being undernourished [defined as a BMI (kg/m^2) < 18.5 among adults], with similar proportion of studies finding favorable, mixed, or null associations. The sole study using a longitudinal design found a favorable association of increased dietary diversity over undernourishment (77). These 9 studies represented about half of the studies conducted in LMIEs and LIEs (Figure 8A).

DDIs and NCDs and intermediate biomarkers of health.

Forty-one studies evaluated the association between DDIs and NCDs and intermediate biomarkers of health, with half of them finding a favorable association and the other half finding a mixed or null association. The number of studies and their types of results differed by country income classification (Figure 8B) and by type of DDI (Supplemental Figure 2B). Only 5 studies used a longitudinal design with large sample sizes and multi-adjusted regressions, of which 1 study found a favorable association with diabetes (78), 3 found null associations with diabetes (21, 46, 79)

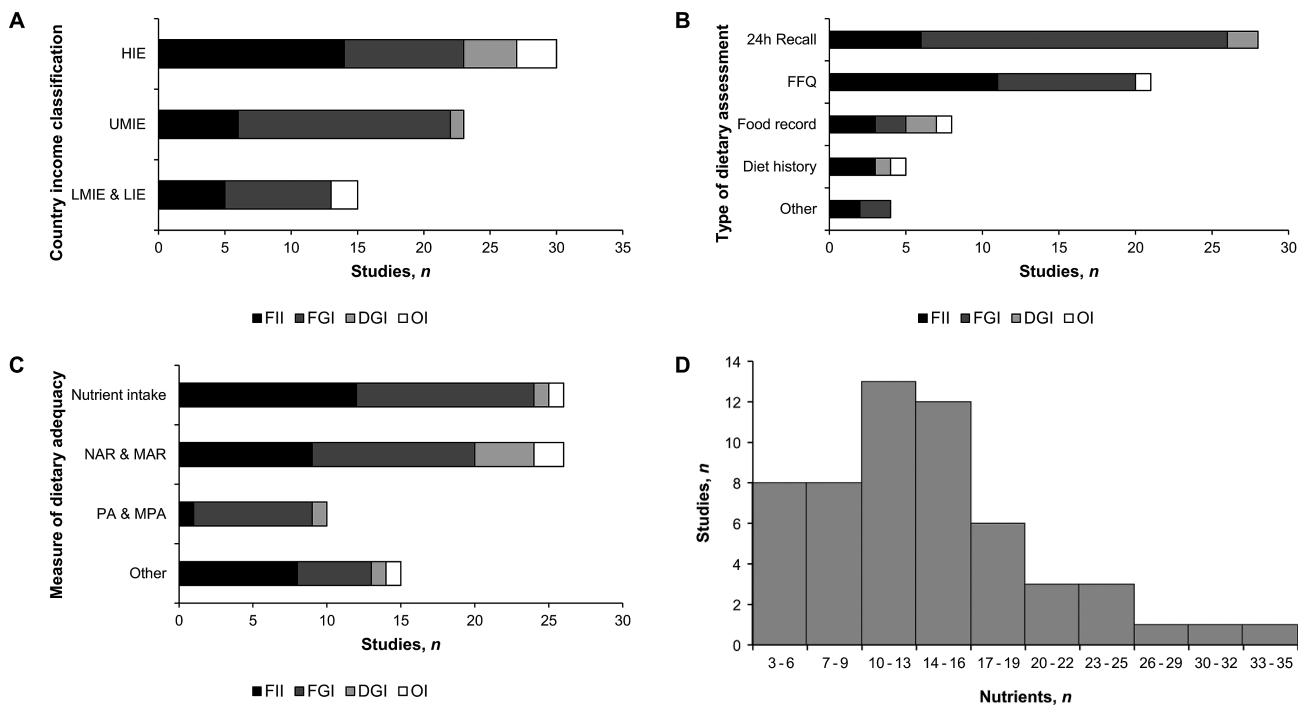


FIGURE 5 Studies investigating the relation between dietary diversity indicators and dietary adequacy ($n = 50$) by country income classification (A), type of dietary assessment (B), and measure of dietary adequacy (C). (D) Number of nutrients used in the measures of dietary adequacy. DGI, dietary guidelines–based indicator; FGI, food group–based indicator; FII, food item–based indicator; HIE, high-income economies; LIE, low-income economies; LMIE, lower-middle-income economies; MAR, mean adequacy ratio; MPA, mean probability of adequacy; NAR, nutrient adequacy ratio; OI, other indicator; PA, probability of adequacy; UMIE, upper-middle-income economies.

and 1 study found a mixed association with cardiovascular disease (80).

DDIs and biomarkers of nutritional status.

Nineteen studies evaluated the association between DDIs and biomarkers of nutritional status, with about half of them finding a favorable association and the other half finding a mixed or null association. Most of these studies were conducted in LMIEs and LIEs (Figure 8C) and used

FGIs (Supplemental Figure 2C). Only 3 studies used a longitudinal design with moderate sample sizes and multi-adjusted regressions, finding either favorable (81), mixed (82) or null (83) associations with anemia.

DDIs and mental health and cognitive functions.

Seventeen studies evaluated the association between DDIs and mental health and cognitive functions, about two-third finding a favorable association and one-third finding a mixed

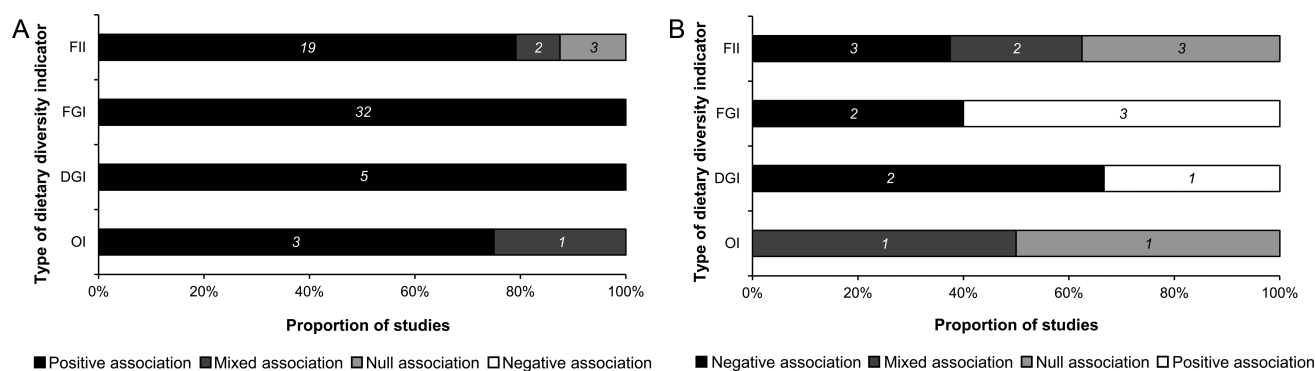


FIGURE 6 Results of studies investigating the relation between dietary diversity indicators and measures of dietary adequacy ($n = 50$) (A) or of excess nutrients ($n = 14$) (B), according to the type of indicator. DGI, dietary guidelines–based indicator; FGI, food group–based indicator; FII, food item–based indicator; OI, other indicator.

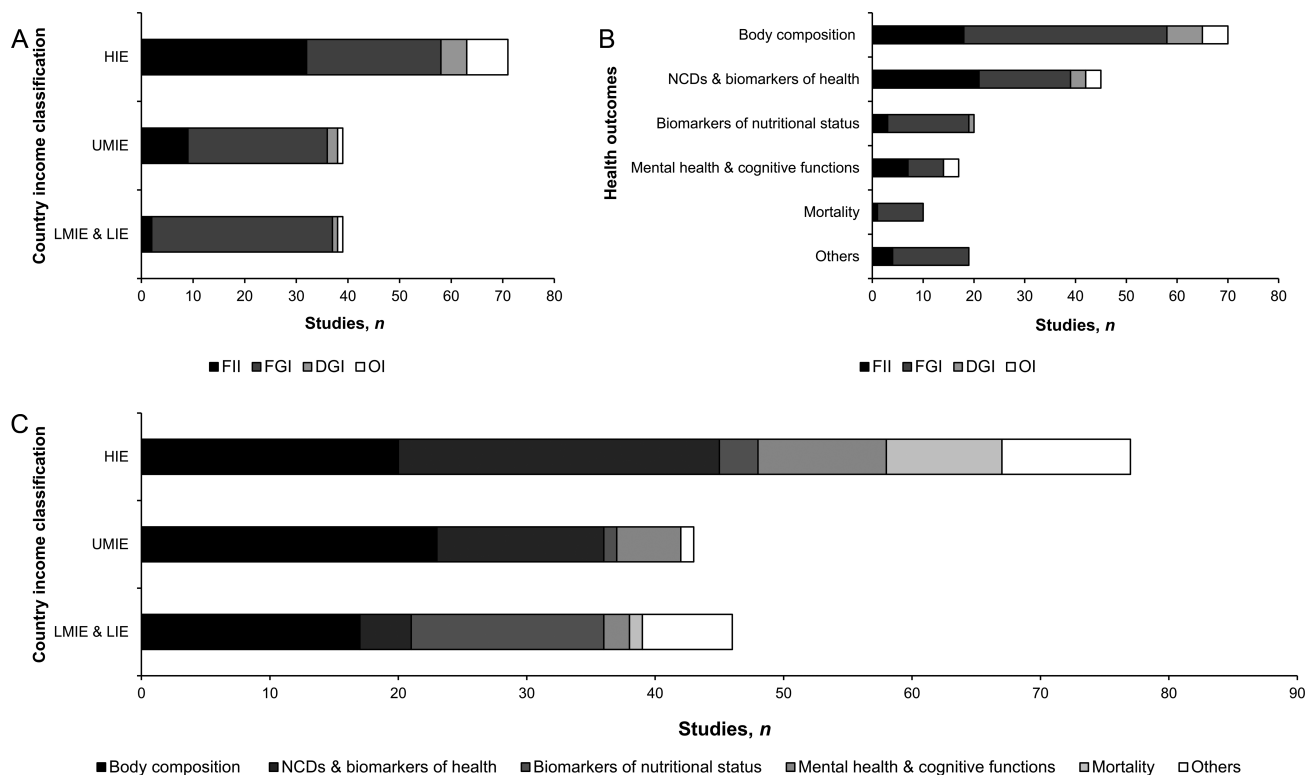


FIGURE 7 Studies investigating the associations between dietary diversity indicators and health outcomes ($n = 137$) by country income classification (A) or health outcomes (B). (C) Number of health outcomes studied by country income classification. DGI, dietary guidelines–based indicator; FGI, food group–based indicator; FII, food item–based indicator; HIE, high-income economies; LIE, low-income economies; LMIE, lower-middle-income economies; NCD, noncommunicable diseases; UMIE, upper-middle-income economies.

or null association. Most of these studies were conducted in HIEs (Figure 8D). Only 3 studies used a longitudinal design with moderate sample sizes and multi-adjusted regressions, finding a favorable association with cognitive function (48, 49, 84).

DDIs and mortality.

Ten studies used a longitudinal design with medium to large sample sizes and multi-adjusted regressions to evaluate the association between DDIs and all-cause or cause-specific mortality. Half found a favorable association (83–87) and the other half a mixed (21, 76, 88) or null (89, 90) association. The studies were mainly conducted in HIEs (Figure 8E) and mainly used FGIs (Supplemental Figure 2E).

Discussion

To the best of our knowledge, this is the first systematic scoping review presenting an extensive and comprehensive inventory of DDIs developed for adolescents and adults worldwide and summarizing the evidence of the associations between these indicators and 1) some measures of the dietary adequacy and 2) some health outcomes. The first finding of this review is that there is a large number of DDIs used in the literature, greatly varying in their structure. While almost all DDIs were found to be positively associated with some measures of dietary adequacy, their inconsistent relation with

nutrients to limit was of concern, which underlines their limit to reflect overall diet quality. Overall, higher DDIs tended to be associated with benefits for various health outcomes, except in contexts such as HIEs and UMIEs where higher DDIs were found to be associated with higher risk of overweight and obesity. However, many studies found mixed or null results. In addition, only one-quarter of the studies used longitudinal designs.

Three decades of development of DDIs

The results of this review should be interpreted in the historical context of the evolution of DDIs. Originating in the late 1980s, DDIs have been extensively developed and used, as dietary diversity is recognized as a key feature of high-quality diets. Nevertheless, due to the lack of consensual definition of dietary diversity (or variety), a wide range of DDIs has been proposed with many more variations in terms of format (e.g., number of foods or food groups, based on single 24-h recall or FFQ) rather than concept (the vast majority of DDIs relied on counting foods or food groups consumed over a period of time).

A shift occurred in the late 2000s, with several research projects aiming to develop and validate simple FGIs based on single 24-h recalls for women of reproductive age that remain relevant and consistent across different contexts and

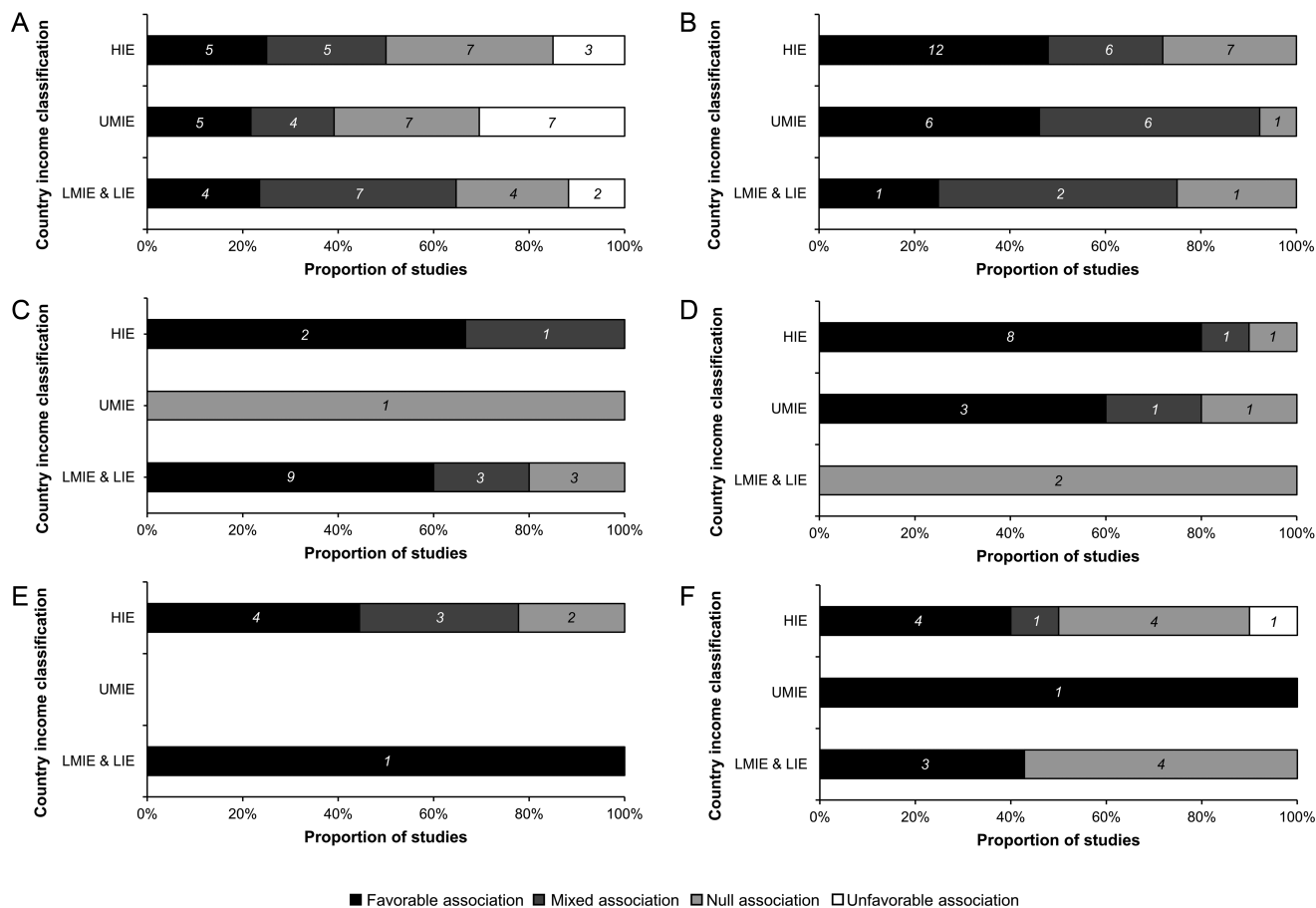


FIGURE 8 Results of studies investigating the associations between dietary diversity indicators and body composition ($n = 60$) (A), noncommunicable diseases and intermediate biomarkers of health ($n = 41$) (B), biomarkers of nutritional status ($n = 19$) (C), mental health and cognitive functions ($n = 17$) (D), mortality ($n = 10$) (E), and other health outcomes ($n = 18$) (F), according to country income classification. HIE, high-income economies; LIE, low-income economies; LMIE, lower-middle-income economies; UMIE, upper-middle-income economies.

over time (60). These methodological efforts are ongoing (12, 91).

Because some countries face a dramatic lack of expertise, infrastructure, and financial support (92), the Women's Dietary Diversity Score (93) and the Minimum Dietary Diversity for Women of Reproductive Age (11) have paved the way for simple assessments of dietary diversity at the population level. Subsequently, they have favored the implementation of nutrition and health interventions, and also of nutrition-sensitive agriculture interventions, since these DDIs can be used to assess changes in the populations' diet before and after an intervention or to compare communities undergoing an intervention with control communities (94, 95). Nevertheless, these 2 FGIs for women of reproductive age were validated as proxies of nutrient adequacy but not as proxies of moderation. While LIEs and LMIEs are undergoing an accelerated (although heterogeneous) nutrition transition characterized by increased intakes of unhealthy fats, refined carbohydrates, and added sugar (96), focusing solely on DDIs may be a major limitation in these contexts.

Indeed, concerns regarding the excessive intake of certain nutrients and foods in LIEs and LMIEs were raised 20 y ago, questioning the need of a shift in the definition of dietary quality to include both concepts of nutrient deficiency and overnutrition (6).

DDIs and diet quality

This review found that the ability of DDIs to reflect overall diet quality was limited. Only 14 out of 50 studies explored how DDIs were associated with nutrients to limit, and only 4 studies found that DDIs could be considered as a proxy of moderation (37, 57, 68, 69).

In many HIEs, the food-based dietary guidelines changed from presenting separately the traditional concepts of dietary diversity, adequacy, moderation, and balance to including all these dimensions in each food-group recommendation (97). This shift was therefore also noticeable in the diet quality indices constructed from food-based dietary guidelines. For example, while US dietary guidelines evolved and specified the most advantageous types of variety, the original Healthy

Eating Index (HEI), featuring dietary variety as a separate component, evolved into the HEI-2005, which no longer recognizes dietary variety as a separate component but instead includes new components that reflect the types of variety deemed to be the most beneficial (98).

A recent systematic review focusing on LIEs and LMIEs reported that individual DDIs were good proxies of nutrient adequacy, but also highlighted the necessity of accounting for moderation dimensions (99). The authors recommended evaluating healthy and unhealthy diet components separately, since using a single score for both components might reduce their ability to reflect diet quality and underestimate their associations with health outcomes (99). The development of a targeted systematic review and meta-analysis focusing on the strength of associations between DDIs and measures of diet quality would be of interest to better understand to what extent DDIs could reflect overall diet quality.

The use of simple DDIs may be convenient and relevant in many contexts, but such indicators should not be overinterpreted as reflecting other dimensions of dietary quality like moderation. Several DDIs providing more specific/detailed measurements of dietary diversity have been flagged throughout this review. The HFD index provides a specific measure of “healthy dietary diversity” (35, 37), the Dissimilarity index a specific measure of “unhealthy dietary diversity” (46), and the food variety ratio a specific measure of “(un)balanced dietary diversity” (51, 52, 54). However, these indicators were only used in specific contexts (Germany and United States for the HFD index, United States for the Dissimilarity index, and United States and Hong Kong for the food variety ratio) and their performances in other contexts would need to be tested. Furthermore, these indicators require intensive quantitative dietary data collection and sometimes demand high-skilled resources for data processing (HFD index and Dissimilarity index), thus limiting their use.

Dietary diversity, food-group diversity, and health outcomes

This review found that the associations between DDIs and health outcomes were largely inconsistent. Less than one-quarter of the studies included in this review were based on a longitudinal design, which is more conducive than cross-sectional or case-control designs to establish the relation with health-related outcomes. When considering the sole studies based on a longitudinal design with a large sample size and multi-adjusted regression analysis, most of them found mixed or null associations between DDIs and health outcomes. Also, DDIs were mostly assessed from a single 24-h recall, multiple 24-h recalls, or FFQs. Therefore, some studies explored the relation with health outcomes using a 1-d dietary diversity while others used a “usual” dietary diversity. These differences could affect the nature and magnitude of the associations.

Although the design and context of the studies are important to take into account, it is also important to consider

the conceptual framework linking the dietary diversity to health outcomes. In most studies, it is quite unclear whether the authors used a DDI because they hypothesized a benefit of dietary diversity in their particular study setting or because they simply took a DDI as a general proxy for diet quality.

About half of the studies analyzing the associations between DDIs and NCDs, intermediate biomarkers of health, or mortality found mixed or null results. For these health outcomes, the consumption of specific food groups seemed to be more important than the overall diversity of the diet. For example, fruits and vegetables contain numerous nutrients, phytochemicals, and other unidentified compounds that are likely to act synergistically via several biological mechanisms in reducing the risk of chronic diseases and premature mortality. Some studies found that vegetable diversity was more strongly associated with a decreased risk of cancer than total dietary diversity (see Supplemental Results) (100–105). A recent dose–response meta-analysis of 95 studies found that the consumption of several types of fruits and vegetables was individually and inversely associated with coronary artery disease, stroke, cardiovascular diseases, total cancer, and all-cause mortality (106).

Regarding the associations between DDIs and body weight and body composition, the results were highly heterogeneous, but a majority of studies found mixed or null results. Two previous reviews reported that dietary diversity was inconsistently associated with body adiposity in diverse populations (8) or not significantly associated with BMI status (9), and both questioned the definition of dietary diversity and the construction of the DDIs. According to Vadiveloo et al. (8), associations with body adiposity were more consistent when dietary diversity focused on recommended and low-energy foods alone (i.e., foods that do not increase the odds of overweight and obesity) or when dietary diversity focused on less healthful, energy-dense foods alone (i.e., foods increasing the odds of overweight and obesity). This suggests that the diversity within specific food groups is of higher importance than the overall diversity of the diet. Recently, the American Heart Association stated that existing evidence does not support greater dietary diversity as an effective strategy to promote healthy body weight, and emphasized the need for further data to formulate adequate recommendations on dietary diversity (10).

Limitations

Some limitations of this review have to be mentioned. Despite the use of the PRISMA-ScR guidelines, multiple structured search strategies, and PICOS criteria, this systematic scoping review may not be exhaustive due to the broad nature of the initial objective to provide an inventory of the DDIs and their associations with the dietary adequacy and/or various health outcomes. Additional and more focused structured search strategies may have led to greater completeness. However, we believe the method we used struck the right balance between feasibility and completeness. Another limitation is

that the review only included articles published in English. Scoping reviews usually provide a descriptive overview without critically appraising individual studies, and the need for quality assessment of included studies in the scoping review process is still debated (13). Because this systematic scoping review encompasses very heterogeneous studies in terms of objectives, outcomes, designs, and statistical models, it would have been difficult to provide a consistent quality assessment and we decided not to assess the validity or the quality of the studies nor that of the indicators used. However, when focusing on health outcomes, we chose to describe the results of studies that used a longitudinal design with moderate/large sample sizes and multi-adjusted regressions. Nevertheless, only rigorous systematic reviews and meta-analysis would enable drawing conclusions as to what extent DDIs are associated with measures of diet quality and specific health outcomes.

Conclusions

The ability of DDIs to reflect diet quality was found to be principally limited to micronutrient adequacy. Furthermore, DDIs do not readily relate to health outcomes. Echoing the appeals from different authors, our findings call for the development and rigorous evaluation of a global diet quality index for use in LIEs and LMIEs (99, 107, 108). Developing sound, easy-to-collect, and easy-to-use indicators of “healthy dietary diversity”, “unhealthy dietary diversity”, and “(un)balanced dietary diversity” (which could be analyzed in conjunction or combined into a global diet quality index) could be a way forward to measuring the impact of nutrition policies and programs aiming to tackle malnutrition in all its forms and track progress made to achieve Sustainable Development Goal number 2 by 2030.

Acknowledgments

We thank Mary Arimond and Megan Deitchler for their constructive feedback. We also thank the 2 anonymous reviewers whose valuable comments and suggestions helped improve and clarify this manuscript. The authors' responsibilities were as follows—EOV, FM, and YM-P: designed the study; EOV, ALP, and AB: conducted the literature search and selected relevant articles; EOV, ALP, and GB: cross-checked data extracted from articles included in the review; EOV and ALP: drafted the figures, tables, and manuscript; FM, MM, MS, and YM-P: provided critical review; and all authors: read and approved the final manuscript.

References

- Hawk A. The great disease enemy, Kak'ke (beriberi) and the Imperial Japanese Army. *Mil Med* 2006;171:333–9.
- US Department of Agriculture; US Department of Health and Human Services. Nutrition and your health: dietary guidelines for Americans. Home and Garden Bulletin No. 232. Washington (DC): US Department of Agriculture; US Department of Health and Human Services; 1980.
- US Department of Agriculture; US Department of Health and Human Services. 2015–2020 Dietary guidelines for Americans. 8th ed.

- Washington (DC): US Department of Agriculture; US Department of Health and Human Services; 2015.
- Montagnese C, Santarpia L, Buonifacio M, Nardelli A, Caldara AR, Silvestri E, Contaldo F, Pasanisi F. European food-based dietary guidelines: a comparison and update. *Nutrition* 2015;31:908–15.
- World Health Organization. Preparation and use of food-based dietary guides: report of a joint FAO/WHO Expert Consultation, Nicosia, Cyprus. Preparation and use of food-based dietary guidelines: report of a joint FAO/WHO Consultation. Geneva (Switzerland): World Health Organization; 1996.
- Ruel MT. Operationalizing dietary diversity: a review of measurement issues and research priorities. *J Nutr* 2003;133:3911S–26S.
- Kant AK. Indexes of overall diet quality: a review. *J Am Diet Assoc* 1996;96:785–91.
- Vadiveloo M, Dixon LB, Parekh N. Associations between dietary variety and measures of body adiposity: a systematic review of epidemiological studies. *Br J Nutr* 2013;109:1557–72.
- Salehi-Abargouei A, Akbari F, Bellissimo N, Azadbakht L. Dietary diversity score and obesity: a systematic review and meta-analysis of observational studies. *Eur J Clin Nutr* 2016;70:1–9.
- de Oliveira Otto MC, Anderson CAM, Dearborn JL, Ferranti EP, Mozaffarian D, Rao G, Wylie-Rosett J, Lichtenstein AH; American Heart Association Behavioral Change for Improving Health Factors Committee of the Council on Lifestyle and Cardiometabolic Health and Council on Epidemiology and Prevention; Council on Cardiovascular and Stroke Nursing; Council on Clinical Cardiology; Stroke Council. Dietary diversity: implications for obesity prevention in adult populations: a science advisory from the American Heart Association. *Circulation* 2018;138:e160–8.
- FAO; FHI 360. Minimum dietary diversity for women: a guide for measurement. Rome (Italy): FAO; 2016.
- Women's Dietary Diversity Project (WDDP) Study Group. Development of a dichotomous indicator for population-level assessment of dietary diversity in women of reproductive age. *Curr Dev Nutr* 2017;1:cdn.117.001701.
- Pham MT, Rajić A, Greig JD, Sargeant JM, Papadopoulos A, McEwen SA. A scoping review of scoping reviews: advancing the approach and enhancing the consistency. *Res Syn Meth* 2014;5:371–85.
- Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med Res Methodol* 2018;18:1–7.
- Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 2018;169:467–73.
- Centre for Reviews and Dissemination. Systematic reviews. CRD's guidance for undertaking reviews in health care [Internet]. York (UK): NHS Centre for Reviews and Dissemination; 2009. [Accessed 2020 Aug 4]. Available from: www.york.ac.uk/media/crd/Systematic_Reviews.pdf.
- Kant AK, Thompson FE. Measures of overall diet quality from a food frequency questionnaire: National Health Interview Survey, 1992. *Nutr Res* 1997;17:1443–56.
- Kant AK, Graubard BI. A comparison of three dietary pattern indexes for predicting biomarkers of diet and disease. *J Am Coll Nutr* 2005;24:294–303.
- Roberts SB, Hajduk CL, Howarth NC, Russell R, McCrory MA. Dietary variety predicts low body mass index and inadequate macronutrient and micronutrient intakes in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* 2005;60:613–21.
- Gregory CO, McCullough ML, Ramirez-Zea M, Stein AD. Diet scores and cardio-metabolic risk factors among Guatemalan young adults. *Br J Nutr* 2008;101:1805–11.
- Masset G, Scarborough P, Rayner M, Mishra G, Brunner EJ. Can nutrient profiling help to identify foods which diet variety should

- be encouraged? Results from the Whitehall II cohort. *Br J Nutr* 2015;113:1800–9.
22. Milte CM, Thorpe MG, Crawford D, Ball K, McNaughton SA. Associations of diet quality with health-related quality of life in older Australian men and women. *Exp Gerontol* 2015;64:8–16.
 23. Roche ML, Creed-Kanashiro HM, Tuesta I, Kuhnlein HV. Traditional food diversity predicts dietary quality for the Awajún in the Peruvian Amazon. *Public Health Nutr* 2008;11:457–65.
 24. Mirmiran P, Azadbakht L, Esmailzadeh A, Azizi F. Dietary diversity score in adolescents—a good indicator of the nutritional adequacy of diets: Tehran Lipid and Glucose Study. *Asia Pac J Clin Nutr* 2004;13:56–60.
 25. Azadbakht L, Mirmiran P, Azizi F. Variety scores of food groups contribute to the specific nutrient adequacy in Tehranian men. *Eur J Clin Nutr* 2005;59:1233–40.
 26. Azadbakht L, Mirmiran P, Azizi F. Dietary diversity score is favorably associated with the metabolic syndrome in Tehranian adults. *Int J Obes* 2005;29:1361–7.
 27. Azadbakht L, Mirmiran P, Esmailzadeh A, Azizi F. Dietary diversity score and cardiovascular risk factors in Tehranian adults. *Public Health Nutr* 2006;9:728–36.
 28. Mirmiran P, Azadbakht L, Azizi F. Dietary diversity within food groups: an indicator of specific nutrient adequacy in Tehranian women. *J Am Coll Nutr* 2006;25:354–61.
 29. Azadbakht L, Akbari F, Esmailzadeh A. Diet quality among Iranian adolescents needs improvement. *Public Health Nutr* 2015;18:615–21.
 30. Azadbakht L, Mohammadifard N, Akhavanzanjani M, Taheri M, Golshahi J, Haghghatdoost F. The association between dietary glycemic index, glycemic load and diet quality indices in Iranian adults: results from Isfahan Healthy Heart Program. *Int J Food Sci Nutr* 2016;67:161–9.
 31. Tavakoli S, Dorosty-Motlagh AR, Hoshiar-Rad A, Eshraghian MR, Sotoudeh G, Azadbakht L, Karimi M, Jalali-Farahani S. Is dietary diversity a proxy measurement of nutrient adequacy in Iranian elderly women? *Appetite* 2016;105:468–76.
 32. Nachvak SM, Abdollahzad H, Mostafai R, Moradi S, Pasdar Y, Rezaei M, Eksndari S. Dietary diversity score and its related factors among employees of Kermanshah University of Medical Sciences. *Clin Nutr Res* 2017;6:247–55.
 33. Farhangi MA, Jahangiry L. Dietary diversity score is associated with cardiovascular risk factors and serum adiponectin concentrations in patients with metabolic syndrome. *BMC Cardiovasc Disord* 2018;18:68.
 34. Karimbeiki R, Pourmasoumi M, Feizi A, Abbasi B, Hadi A, Rafie N, Safavi SM. Higher dietary diversity score is associated with obesity: a case-control study. *Public Health* 2018;157:127–34.
 35. Drescher LS, Thiele S, Mensink GBM. A new index to measure healthy food diversity better reflects a healthy diet than traditional measures. *J Nutr* 2007;137:647–51.
 36. Truthmann J, Richter A, Thiele S, Drescher L, Roosen J, Mensink GB. Associations of dietary indices with biomarkers of dietary exposure and cardiovascular status among adolescents in Germany. *Nutr Metab (Lond)* 2012;9:92.
 37. Vadiveloo M, Dixon LB, Mijanovich T, Elbel B, Parekh N. Development and evaluation of the US Healthy Food Diversity index. *Br J Nutr* 2014;112:1562–74.
 38. Vadiveloo M, Parekh N, Parkeh N, Mattei J. Greater healthful food variety as measured by the US Healthy Food Diversity index is associated with lower odds of metabolic syndrome and its components in US adults. *J Nutr* 2015;145:564–71.
 39. Vadiveloo M, Dixon LB, Mijanovich T, Elbel B, Parekh N. Dietary variety is inversely associated with body adiposity among US adults using a novel food diversity index. *J Nutr* 2015;145:555–63.
 40. Vadiveloo M, Sacks FM, Champagne CM, Bray GA, Mattei J. Greater healthful dietary variety is associated with greater 2-year changes in weight and adiposity in the Preventing Overweight Using Novel Dietary Strategies (POUNDS Lost) Trial. *J Nutr* 2016;146:1552–9.
 41. Song WO, Schuette LK, Huang Y-L, Hoerr S. Food group intake patterns in relation to nutritional adequacy of young adults. *Nutr Res* 1996;16:1507–19.
 42. Schuette LK, Song WO, Hoerr SL. Quantitative use of the Food Guide Pyramid to evaluate dietary intake of college students. *J Am Diet Assoc* 1996;96:453–7.
 43. Rathnayake KM, Madushani P, Silva K. Use of dietary diversity score as a proxy indicator of nutrient adequacy of rural elderly people in Sri Lanka. *BMC Res Notes* 2012;5:469.
 44. Jayawardena R, Byrne NM, Soares MJ, Katulanda P, Yadav B, Hills AP. High dietary diversity is associated with obesity in Sri Lankan adults: an evaluation of three dietary scores. *BMC Public Health* 2013;13:314.
 45. Tiew KF, Chan YM, Lye MS, Loke SC. Factors associated with dietary diversity score among individuals with type 2 diabetes mellitus. *J Health Popul Nutr* 2014;32:665–76.
 46. Otto MC de O, Padhye NS, Bertoni AG, Jacobs DR, Mozaffarian D. Everything in moderation—dietary diversity and quality, central obesity and risk of diabetes. *PLoS One* 2015;10:e0141341.
 47. Lachat C, Raneri JE, Smith KW, Kolsteren P, Van Damme P, Verzelen K, Penafiel D, Vanhove W, Kennedy G, Hunter D, et al. Dietary species richness as a measure of food biodiversity and nutritional quality of diets. *Proc Natl Acad Sci U S A* 2018;115:127–32.
 48. Otsuka R, Kato Y, Nishita Y, Tange C, Nakamoto M, Tomida M, Imai T, Ando F, Shimokata H, Suzuki T. Dietary diversity and 14-year decline in higher-level functional capacity among middle-aged and elderly Japanese. *Nutrition* 2016;32:784–9.
 49. Otsuka R, Nishita Y, Tange C, Tomida M, Kato Y, Nakamoto M, Imai T, Ando F, Shimokata H. Dietary diversity decreases the risk of cognitive decline among Japanese older adults. *Geriatr Gerontol Int* 2017;17:937–44.
 50. Tian X, Wu M, Zang J, Zhu Y, Wang H. Dietary diversity and adiposity in Chinese men and women: an analysis of four waves of cross-sectional survey data. *Eur J Clin Nutr* 2017;71:506–11.
 51. Woo J, Cheung B, Ho S, Sham A, Lam TH. Influence of dietary pattern on the development of overweight in a Chinese population. *Eur J Clin Nutr* 2008;62:480–7.
 52. Sea MM-M, Woo J, Tong PC-Y, Chow C-C, Chan JC-N. Associations between food variety and body fatness in Hong Kong Chinese adults. *J Am Coll Nutr* 2004;23:404–13.
 53. Woo J, Ho SC, Sham A, Sea MM, Lam KSL, Lam TH, Janus ED. Diet and glucose tolerance in a Chinese population. *Eur J Clin Nutr* 2003;57:523–30.
 54. McCrory MA, Fuss PJ, McCallum JE, Yao M, Vinken AG, Hays NP, Roberts SB. Dietary variety within food groups: association with energy intake and body fatness in men and women. *Am J Clin Nutr* 1999;69:440–7.
 55. Masa R, Chow G, Nyirenda V. Socioeconomic correlates of dietary diversity and its association with adherence and psychosocial functioning of people living with HIV in rural Zambia. *Nutr Health* 2018;24:93–102.
 56. Benefice E, Lopez R, Monroy SL, Rodríguez S. Fatness and overweight in women and children from riverine Amerindian communities of the Beni River (Bolivian Amazon). *Am J Hum Biol* 2007;19:61–73.
 57. Drewnowski A, Henderson SA, Driscoll A, Rolls BJ. The Dietary Variety Score: assessing diet quality in healthy young and older adults. *J Am Diet Assoc* 1997;97:266–71.
 58. Löwik MR, Hulshof KF, Brussaard JH. Food-based dietary guidelines: some assumptions tested for The Netherlands. *Br J Nutr* 1999;81(Suppl 2):S143–9.
 59. Bernstein MA, Tucker KL, Ryan ND, O'Neill EF, Clements KM, Nelson ME, Evans WJ, Fiatarone Singh MA. Higher dietary variety is associated with better nutritional status in frail elderly people. *J Am Diet Assoc* 2002;102:1096–104.
 60. Arimond M, Wiesmann D, Becquey E, Carriquiry A, Daniels MC, Deitchler M, Fanou-Fogny N, Joseph ML, Kennedy G, Martin-Prevel Y, et al. Simple food group diversity indicators predict micronutrient

- adequacy of women's diets in 5 diverse, resource-poor settings. *J Nutr* 2010;140:2059S–69S.
61. Henjum S, Torheim LE, Thorne-Lyman AL, Chandyo R, Fawzi WW, Shrestha PS, Strand TA. Low dietary diversity and micronutrient adequacy among lactating women in a peri-urban area of Nepal. *Public Health Nutr* 2015;18:3201–10.
 62. Arsenault JE, Yakes EA, Islam MM, Hossain MB, Ahmed T, Hotz C, Lewis B, Rahman AS, Jamil KM, Brown KH. Very low adequacy of micronutrient intakes by young children and women in rural Bangladesh is primarily explained by low food intake and limited diversity. *J Nutr* 2013;143:197–203.
 63. Nguyen PH, Huybregts L, Sanghvi TG, Tran LM, Frongillo EA, Menon P, Ruel MT. Dietary diversity predicts the adequacy of micronutrient intake in pregnant adolescent girls and women in Bangladesh, but use of the 5-group cutoff poorly identifies individuals with inadequate intake. *J Nutr* 2018;148:790–7.
 64. Foote JA, Murphy SP, Wilkens LR, Basiotis PP, Carlson A. Dietary variety increases the probability of nutrient adequacy among adults. *J Nutr* 2004;134:1779–85.
 65. Rolls BJ, Rowe EA, Rolls ET, Kingston B, Megson A, Gunary R. Variety in a meal enhances food intake in man. *Physiol Behav* 1981;26:215–21.
 66. Rolls BJ, Van Duijvenvoorde PM, Rolls ET. Pleasantness changes and food intake in a varied four-course meal. *Appetite* 1984;5:337–48.
 67. Roe LS, Meengs JS, Birch LL, Rolls BJ. Serving a variety of vegetables and fruit as a snack increased intake in preschool children. *Am J Clin Nutr* 2013;98:693–9.
 68. Vandevijvere S, De Vriese S, Huybrechts I, Moreau M, Van Oyen H. Overall and within-food group diversity are associated with dietary quality in Belgium. *Public Health Nutr* 2010;13:1965–73.
 69. Murphy SP, Foote JA, Wilkens LR, Basiotis PP, Carlson A, White KKL, Yonemori KM. Simple measures of dietary variety are associated with improved dietary quality. *J Am Diet Assoc* 2006;106:425–9.
 70. Ponce X, Ramirez E, Delisle H. A more diversified diet among Mexican men may also be more atherogenic. *J Nutr* 2006;136:2921–7.
 71. Bianchi CM, Egnell M, Huneau J-F, Mariotti F. Plant protein intake and dietary diversity are independently associated with nutrient adequacy in French adults. *J Nutr* 2016;146:2351–60.
 72. Poorrezaeian M, Siassi F, Milajerdi A, Qorbani M, Karimi J, Sohrabi-Kabi R, Pak N, Sotoudeh G. Depression is related to dietary diversity score in women: a cross-sectional study from a developing country. *Ann Gen Psychiatry* 2017;16:39.
 73. Thiele S, Mensink GBM, Beitz R. Determinants of diet quality. *Public Health Nutr* 2004;7:29–37.
 74. Florêncio T, Bueno NB, Clemente APG, Albuquerque FCA, Britto RPA, Ferriolli E, Sawaya AL. Weight gain and reduced energy expenditure in low-income Brazilian women living in slums: a 4-year follow-up study. *Br J Nutr* 2015;114:462–71.
 75. Haws KL, Liu PJ, Redden JP, Silver HJ. Exploring the relationship between varieties of variety and weight loss: when more variety can help people lose weight. *J Market Res* 2017;54:619–35.
 76. Lee M-S, Huang Y-C, Su H-H, Lee M-Z, Wahlqvist ML. A simple food quality index predicts mortality in elderly Taiwanese. *J Nutr Health Aging* 2011;15:815–21.
 77. Savy M, Martin-Prével Y, Traissac P, Eymard-Duvernay S, Delpuech F. Dietary diversity scores and nutritional status of women change during the seasonal food shortage in rural Burkina Faso. *J Nutr* 2006;136:2625–32.
 78. Conklin AI, Monsivais P, Khaw K-T, Wareham NJ, Forouhi NG. Dietary diversity, diet cost, and incidence of type 2 diabetes in the United Kingdom: a prospective cohort study. *PLoS Med* 2016;13:e1002085.
 79. Gicevic S, Gaskins AJ, Fung TT, Rosner B, Tobias DK, Isanaka S, Willett WC. Evaluating pre-pregnancy dietary diversity vs. dietary quality scores as predictors of gestational diabetes and hypertensive disorders of pregnancy. *PLoS One* 2018;13:e0195103.
 80. Fung TT, Isanaka S, Hu FB, Willett WC. International food group-based diet quality and risk of coronary heart disease in men and women. *Am J Clin Nutr* 2018;107:120–9.
 81. Zerfu TA, Umata M, Baye K. Dietary diversity during pregnancy is associated with reduced risk of maternal anemia, preterm delivery, and low birth weight in a prospective cohort study in rural Ethiopia. *Am J Clin Nutr* 2016;103:1482–8.
 82. Roba KT, O'Connor TP, Belachew T, O'Brien NM. Seasonal variation in nutritional status and anemia among lactating mothers in two agro-ecological zones of rural Ethiopia: a longitudinal study. *Nutrition* 2015;31:1213–8.
 83. Rawat R, McCoy SI, Kadiyala S. Poor diet quality is associated with low CD4 count and anemia and predicts mortality among antiretroviral therapy-naïve HIV-positive adults in Uganda. *J Acquir Immun Defic Syndr* 2013;62:246–53.
 84. Chen RC-Y, Chang Y-H, Lee M-S, Wahlqvist ML. Dietary quality may enhance survival related to cognitive impairment in Taiwanese elderly. *Food Nutr Res* 2011;55:7387.
 85. Kant A, Schatzkin A, Harris T, Ziegler R, Block G. Dietary diversity and subsequent mortality in the 1st National-Health and Nutrition Examination Survey Epidemiologic Follow-up Study. *Am J Clin Nutr* 1993;57:434–40.
 86. Huang Y-C, Wahlqvist ML, Kao M-D, Wang J-L, Lee M-S. Optimal dietary and plasma magnesium statuses depend on dietary quality for a reduction in the risk of all-cause mortality in older adults. *Nutrients* 2015;7:5664–83.
 87. Huang Y-C, Wahlqvist ML, Lee M-S. Appetite predicts mortality in free-living older adults in association with dietary diversity: a NAHSIT cohort study. *Appetite* 2014;83:89–96.
 88. Wahlqvist ML, Xiu L, Lee M-S, Chen RC-Y, Chen K-J, Li D. Dietary diversity no longer offsets the mortality risk of hyperhomocysteinaemia in older adults with diabetes: a prospective cohort study. *Asia Pac J Clin Nutr* 2016;25:414–23.
 89. Kant AK, Schatzkin A, Ziegler RG. Dietary diversity and subsequent cause-specific mortality in the NHANES I epidemiologic follow-up study. *J Am Coll Nutr* 1995;14:233–8.
 90. Letois F, Mura T, Scali J, Gutierrez L-A, Féart C, Berr C. Nutrition and mortality in the elderly over 10 years of follow-up: the Three-City Study. *Br J Nutr* 2016;116:882–9.
 91. Nguyen PH, Martin-Prevel Y, Moursi M, Tran LM, Menon P, Ruel MT, Arimond M. Assessing dietary diversity in pregnant women: relative validity of the list-based and open recall methods. *Curr Dev Nutr* 2019;4:nzz134
 92. Pisa PT, Landais E, Margetts B, Vorster HH, Friedenreich CM, Huybrechts I, Martin-Prevel Y, Branca F, Lee WTK, Leclercq C, et al. Inventory on the dietary assessment tools available and needed in Africa: a prerequisite for setting up a common methodological research infrastructure for nutritional surveillance, research, and prevention of diet-related non-communicable diseases. *Crit Rev Food Sci Nutr* 2018;58:37–61.
 93. Food and Agriculture Organization. Guidelines for measuring household and individual dietary diversity. [Internet]. Rome (Italy): FAO; 2011. [Cited 2016 May 24]. Available from: http://www.fao.org/fileadmin/user_upload/wa_workshop/docs/FAO-guidelines-dietary-diversity2011.pdf.
 94. Herforth A, Ballard TJ. Nutrition indicators in agriculture projects: current measurement, priorities, and gaps. *Global Food Security* 2016;10:1–10.
 95. Verger EO, Ballard TJ, Dop MC, Martin-Prevel Y. Systematic review of use and interpretation of dietary diversity indicators in nutrition-sensitive agriculture literature. *Global Food Security* 2019;20:156–69.
 96. Popkin BM, Corvalan C, Grummer-Strawn LM. Dynamics of the double burden of malnutrition and the changing nutrition reality. *Lancet North Am Ed* 2020;395:65–74.
 97. Schneeman BO. Evolution of dietary guidelines. *J Am Diet Assoc* 2003;103:5–9.
 98. Guenther PM, Reedy J, Krebs-Smith SM, Reeve BB, Basiotis PP. Development and evaluation of the Healthy Eating Index-2005:

- technical report. [Internet]. Washington (DC): Center for Nutrition Policy and Promotion, US Department of Agriculture; 2007. [Accessed 2020 Aug 4]. Available from: <https://vtechworks.lib.vt.edu/handle/10919/18682>.
99. Trijbsburg L, Talsma EF, de Vries JHM, Kennedy G, Kuijsten A, Brouwer ID. Diet quality indices for research in low- and middle-income countries: a systematic review. *Nutr Rev* 2019;77:515–40.
100. Fernandez E, D'Avanzo B, Negri E, Franceschi S, La Vecchia C. Diet diversity and the risk of colorectal cancer in northern Italy. *Cancer Epidemiol Biomark Prev* 1996;5:433–6.
101. La Vecchia C, Muñoz SE, Braga C, Fernandez E, Decarli A. Diet diversity and gastric cancer. *Int J Cancer* 1997;72:255–7.
102. Levi F, Pasche C, La Vecchia C, Lucchini F, Franceschi S, Monnier P. Food groups and risk of oral and pharyngeal cancer. *Int J Cancer* 1998;77:705–9.
103. Garavello W, Giordano L, Bosetti C, Talamini R, Negri E, Tavani A, Maisonneuve P, Franceschi S, La Vecchia C. Diet diversity and the risk of oral and pharyngeal cancer. *Eur J Nutr* 2008;47:280–4.
104. Lucenteforte E, Garavello W, Bosetti C, Talamini R, Zambon P, Franceschi S, Negri E, La Vecchia C. Diet diversity and the risk of squamous cell esophageal cancer. *Int J Cancer* 2008;123:2397–400.
105. Garavello W, Lucenteforte E, Bosetti C, Talamini R, Levi F, Tavani A, Franceschi S, Negri E, La Vecchia C. Diet diversity and the risk of laryngeal cancer: a case-control study from Italy and Switzerland. *Oral Oncol* 2009;45:85–9.
106. Aune D, Giovannucci E, Boffetta P, Fadnes LT, Keum N, Norat T, Greenwood DC, Riboli E, Vatten LJ, Tonstad S. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—a systematic review and dose-response meta-analysis of prospective studies. *Int J Epidemiol* 2017;46:1029–56.
107. Walls HL, Johnston D, Mazalale J, Chirwa EW. Why we are still failing to measure the nutrition transition. *BMJ Glob Health* 2018;3:e000657.
108. Arimond M, Deitchler M. Measuring diet quality for women of reproductive age in low- and middle-income countries: towards new metrics for changing diets. [Internet]. Washington (DC): Intake—Center for Dietary Assessment/FHI 360; 2019. [Accessed 2020 Aug 4]. Available from: <https://www.intake.org/resource/measuring-diet-quality-women-reproductive-age-low-and-middle-income-countries-towards-new>.