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Review

Construction and Interpretation of Production and Market Metrics Used to Understand Relationships with Dietary Diversity of Rural Smallholder Farming Households

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Abstract: Indicators of agricultural production diversity and market access and/or participation have often been used to try to understand how agricultural production and markets influence dietary diversity of rural smallholder households. Based on a standardized search strategy, 37 studies investigating the association between an indicator of agricultural production diversity and any indicator of dietary diversity were reviewed. The characteristics of the indicators of agricultural production diversity, as well as indicators of market access and/or participation, were assessed. This review demonstrated the wide range of indicators; four types and 14 subtypes of indicators of agricultural production diversity were found in the 37 studies, and three types and 14 subtypes of indicators of market access and/or participation were found in 25 studies. While diversity of measurement ideas allows flexibility, it precludes comparability with other studies and might make it difficult to build a robust body of evidence of the impact of agriculture at farm household level on food security, diet, and nutrition.

Keywords: nutrition-sensitive agriculture; dietary diversity; production diversity; market access and participation; standardized indicators

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1. Introduction

While the fastest projected urbanization rates over the period 2018–2050 are expected to occur in lower-middle-income countries and low-income countries, increasing respectively from 41% to 59% and 31% to 51% of the population living in urban areas, rural smallholder farming households are and will remain a large part of the populations of these countries [1]. Furthermore, millions of rural smallholder farming households currently produce the majority of a very diverse set of commodities in sub-Saharan Africa, southeast Asia, and south Asia, with about 30% of most food commodities coming from very small farms ($\leq$2 ha) and 45% from small farms (>2–20 ha) [2].

Beyond the fact that diversification at the farm-level can offer a seasonal coping strategy, diversification of food production is considered important to improve food security, promote sustainable diets for all, increase climate resilience, and enhance the provision of ecosystem services [3]. Numerous studies over the past decade have found an overall small positive association with production diversification of rural smallholder farming households and household food security and nutrient adequacy of household members, although the magnitude depends on the agricultural context [4,5].

Despite this modest positive association, systematic reviews reveal a large heterogeneity in measurement approaches, indicators, analytic models, and correlation measures used across studies [4,5]. In addition, many studies focused on the association between agricultural practices or agricultural contexts and household food security do not follow published guidance, especially when classifying foods into food groups [6]. Verger et al. [6] highlighted the need to pay particular attention to the correct use of validated dietary diversity indicators when making conclusions about these associations so that a robust and comparable body of evidence on the impact of agricultural diversification on dietary diversification can be established.

While internationally validated indicators with comparable meanings are available to evaluate dietary diversity, this is not the case for agricultural production diversity. Different indicators are available to evaluate production diversity, but their use can result in different diagnosis of the nutritional quality of the same production system [7]. There is currently no consensus regarding the most appropriate indicators to measure the domains of diversified production, market access, and market participation [4,5].

This paper reviews published studies that, firstly, investigated the association between an indicator of agricultural production diversity and any indicator of dietary diversity measured at the individual- or household-level, and, secondly, the subset of papers within the first that took into account indicators of market access and/or market participation were described. The objectives of this review are: (1) to present a comprehensive inventory of indicators of agricultural production diversity and indicators of market access and/or market participation and their characteristics; (2) to assess the frequency and diversity of the use of these indicators of these indicators; and (3) to discuss potential issues for geographic or spatial comparative analyses. The intent of the review is not to judge the validity of the studies or their results.

2. Methods

2.1. Selection of Studies for the Review

A two-stage search strategy was used to identify studies that investigated associations between diversity of agricultural production and dietary diversity. In the first stage, we searched publications from the systematic review by Verger et al. [6], in the systematic review by Sibhatu and Qaim [5] and in the review by Jones [4]. In the second stage, we used a systematic search strategy to identify publications from June 2017 to August 2019 in PubMed, Web of Science and ScienceDirect. This search strategy was adapted from Verger et al. [6] and included the title-abstract-keywords "diet diversity, household, family, woman, child, agricultural diversity, production diversity, crop diversity, agrobiodiversity". We also examined relevant variations in keywords.

All studies identified as suitable were extracted using Zotero (version 4.0.28.7). The criteria for inclusion and exclusion were as follows. All populations and study designs were eligible for inclusion. Studies were included if: (1) they measured the associations between diversity of agricultural production and dietary diversity; and (2) were peer-reviewed articles published in English. Studies were excluded if they: (1) did not include at least one indicator of diversity of agricultural production and one indicator of dietary diversity; or (2) did not measure the diversity of agricultural production of the entire farm system (e.g., measuring only the diversity of production of homestead gardens). The selection of the studies to be fully reviewed was performed by the first author and was validated by the other authors.

2.2. Descriptive Analysis of the Indicators

First, the construction of indicators of diversity of agricultural production and the indicators of market access and/or market participation were described and characterized. We described each indicator as categorical (having a finite number of categories or distinct groups), discrete (having a countable number of values between any two values), or continuous (having an infinite number of values between any two values). The second descriptive characteristic of construction was whether the indicator was a composite index. A composite index is a combination of a set of indicators. Lastly, some elements of strengths and limitations of the indicators are presented based on expert judgement from all of the authors. Disagreements among reviewing co-authors regarding the judgement of strengths and limitations were resolved through discussion until a final consensus opinion was achieved.

3. Results

3.1. Description of the Studies

Twenty-one peer-reviewed articles published in English investigating associations between diversity of agricultural production and dietary diversity indicators were selected from previous reviews [4–6]. The new search strategy spanning publications from June 2017 to August 2019 resulted in the selection of 16 additional studies. Thirty-seven studies were thus selected for the final review.

As previously observed in the nutrition-sensitive agriculture literature [4–6], there was wide heterogeneity across the 37 studies. In terms of unit of analysis concerning dietary diversity scores, four studies used indicators of dietary diversity at both the household and individual level, 14 at only the individual level, and 19 at only the household level. Nineteen studies used the Household Dietary Diversity Score (HDDS), an indicator that reflects the economic ability of a household to access a variety of foods [8]; six studies used the Minimum Dietary Diversity (MDD) indicator, which reflects adequate micronutrient density of complementary foods among young children aged 6–23 months [9]; six studies used the Women's Dietary Diversity Score (WDDS), and six studies used the Minimum Dietary Diversity for Women (MDD-W), both of which reflect the micronutrient adequacy of diets of women of reproductive age [10,11]. Four studies used other food group-based dietary diversity indicators [12–15] and three studies [16–18].

Data from 25 different countries were reported across the 37 studies: 12 from Africa, six from Asia, six from Latin America, and one from Eastern Europe. Fifteen countries were reported on only once and 10 were reported on in more than one study. Of note, Kenya and Malawi were the most frequently included countries, reported on in nine and seven studies, respectively. All 37 studies used a cross-sectional design, with 17 studies relying on original data and 20 studies relying on secondary analysis. Sample sizes greatly varied from 30 women to over 10,000 households.

Section 3.2 presents the assessment of the use of the indicators of agricultural production diversity, and the different types of indicators are described and discussed (see Table A1 in Appendix A: Indicators used to measure agricultural production diversity (n = 37) for more details). Section 3.3 presents the assessment of the use of indicators of market access and/or market participation, and the different types of indicators are described and discussed (see Table A2 in Appendix A: Indicators used to measure market access and/or market participation (n = 25) for more details). Uses of the indicators are summarized in Table 1 and the indicators were placed on a conceptual framework of agriculture–nutrition pathways adapted from Kadiyala et al. [19] (Figure 1).

3.2. Indicators of Agricultural Production Diversity

3.2.1. Descriptive Assessment of the Use of the Indicators

On average, two or more indicators related to the diversity of agricultural production were used per study (ranges from one to seven). Twenty-eight studies used simple count indicators. A majority of the studies used a count of the different crop species produced (n = 20) or a count of the different crop species produced and animal species reared (n = 13). Of note, there was a cluster of three types of simple count indicators focusing on livestock only: a dichotomous variable on having livestock or not (n = 4), a count of the different animal species reared (n = 5), and a total count of animals reared (n = 5). Fourteen studies used indicators counting groups of agricultural outputs (i.e., animals, livestock products, food crops, and non-food crops combined), mainly focusing on plant and animal production (n = 11). Of note, seven studies used a method to first group production/rearing and then count the number of groups based on the same food groups used for the calculation of the dietary diversity of children, women or households. Ten studies used richness/evenness indicators inherited from ecological research, mainly the Simpson index (*n* = 6), the Margalef index (*n* = 4), and the Shannon index (*n* = 4). These indicators were used to assess plant production only in eight studies, and plant and animal production combined in two studies. Three studies used the Nutritional Functional Diversity, a metric to summarize the nutritional diversity of food systems. The calculation of the indicator was different in each study, both in terms of type of production (two studies focused on plant production only while one focused on plant-animal production) and in terms of nutrients (ranging from seven to 17).

Table 1. Summary of the use of indicators of agricultural production diversity and of market access and/or participation.

Domain of the Indicator	Type of Indicator	Indicator	Frequency of Use	Characteristics of the Indicator	
Agricultural production diversity (*n* = 37)	Food count indicators	Crop diversity	20	Simple	Discrete
		Crop and livestock diversity	13	Simple	Discrete
		Livestock diversity	5	Simple	Discrete
		Livestock units	5	Simple	Discrete
		Livestock ownership	4	Simple	Categorical
		Vegetable diversity	1	Simple	Discrete
		Cash crop	1	Simple	Categorical
	Group count indicators		15	Simple	Discrete
	Richness/evenness indicators	Simpson index	6	Composite	Continuous
		Margalef index	4	Composite	Continuous
		Shannon diversity / Shannon-Wienner index	4	Composite	Continuous
		Shannon evenness	1	Composite	Continuous
	Nutritional Functional Diversity		3	Composite	Continuous
Market access and/or participation (=25)	Physical access to the market	Distance to nearest market	11	Simple	Continuous
		Presence of a food market	4	Simple	Categorical
		Distance to nearest town	2	Simple	Continuous
		Distance to the nearest major road	2	Simple	Continuous
		Mode of transport	2	Simple	Categorical
		Cost of transporting a 50 kg of wheat	1	Simple	Continuous
		Frequency of visits to market	1	Simple	Discrete
	Market participation	Orientation of the farm	8	Simple	Categorical
		Agricultural income	5	Simple	Continuous
		Sell vegetable production	1	Simple	Continuous
	Availability of foods	Contribution of the purchased foods	6	Composite	Continuous
		Count of purchased foods	2	Composite	Continuous
		Food expenditure	2	Simple	Continuous
		Availability of foods in the market	1	Composite	Continuous

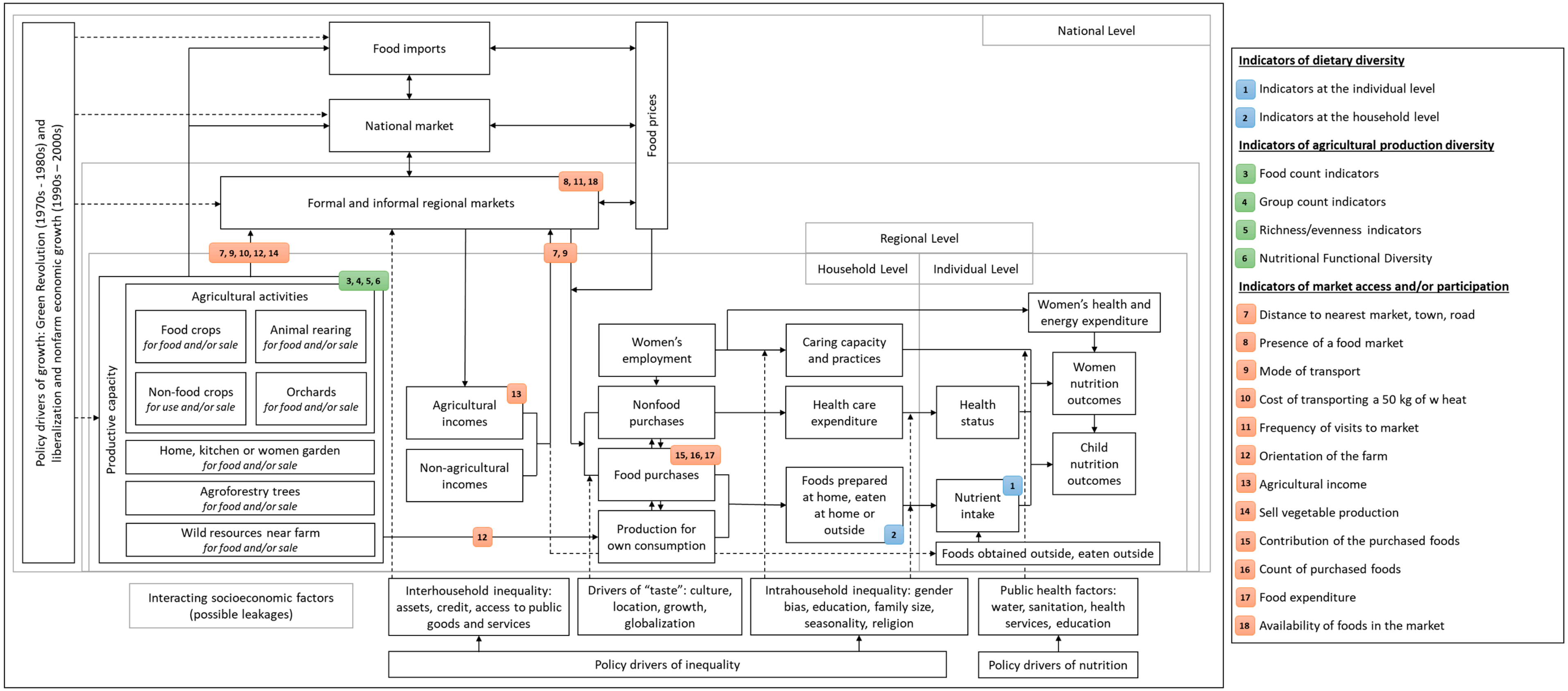

Figure 1. Mapping the indicators of agricultural production diversity and the indicators of market access and/or participation in the agriculture–nutrition pathways.

3.2.2. Description of the Indicators

Simple count indicators. A discrete indicator based on a simple sum of the number of different crop species produced by each farm was the most commonly used across the literature for assessing agricultural biodiversity. Different authors used different names for this indicator including: crop species richness [20], crop diversity [21], and on-farm diversity [22]. Because this indicator gives the same weight to each species regardless of its nutritional composition, its use has been debated when studying nutrition-sensitive agriculture in the sense that adding corn and wheat to a farm growing only rice will result in the same score as adding beans and spinach, but not the same nutritional quality [23]. Similar versions of this indicator have been proposed, including a simple sum of the number of different vegetable species produced on each farm [12], a simple sum of the number of different animal species reared on each farm (e.g., livestock species richness in Oduor et al. [24]), or a simple sum of the number of different crop species produced and animal species reared by each farm (e.g., farm production diversity in Murendo et al. [14]). Other simple count indicators have been used like the livestock unit, a simple and discrete indicator based on a sum of the total number of different animals reared by each farm, using specific coefficients to take into account the age and species of the animals. The livestock unit is considered as a reference unit which facilitates the aggregation of livestock [25]. Of note, two simple and categorical indicators were found among the articles. The first one is based on livestock ownership (yes or no) and the other one is based on producing cash crops (yes or no). While these indicators seemed relatively easy to use in terms of data collection and analysis, their interpretation varies according to the context.

Group count indicators. Four studies published in 2015 introduced the concept of considering crop species produced and animal species reared by each farm in terms of groups, either based on common agronomic traits [26,27] or based on similar nutrient composition [13,28]. Ten other studies using similar concepts were published afterwards. These simple and discrete indicators are always based on a sum of the number of crop and/or animal groups produced by each farm. Their use could be challenging considering the number of groups and the rationale for defining groups. For example, any indicator using the same groups as the MDD-W has to classify vegetables and fruits according to their vitamin A content (providing at least 60 retinol activity equivalents per 100 g [29]). Because these indicators overcome the issue of counting species with similar nutrient composition multiple times [23], they might be considered as more adapted when studying nutrition-sensitive agriculture, especially if they are based on the same groups used for the calculation of the MDD, WDDS, or MDD-W which are dietary diversity indicators that have been validated against multi-site quantitative food intake datasets as proxies of nutrient adequacy of the diet [6]. It should be noted that among the 14 studies using group count indicators, seven used indicators based on the same groups used for the calculation of the MDD, WDDS, or MDD-W, while the other seven used indicators based on various classifications, which might limit the comparability with other studies.

Richness/evenness indicators. Three main different indicators inherited from ecological research have been used to assess diversity of agricultural production: (i) Simpson index; (ii) Margalef index; and (iii) Shannon diversity (also known as Shannon-Wienner index). While these composite and continuous indicators differ mathematically (Table 2), they all rely on counting the different crop species (and sometimes also counting the animal species) while also considering a measure of relative abundance (e.g., area of cultivation as compared to the total area under cultivation, the number of plants as compared to the total number of plants, or the amount harvested as compared to the total amount harvested). Collecting and combining information about the number of species with a measure of how much of each species is grown compared to the total could be challenging. Because these indicators give the same weight to each species regardless of nutritional composition, like the simple count indicators described previously, their use could be debated when studying nutrition-sensitive agriculture.

Table 2. Summary of the use of indicators of agricultural production diversity and of market access and/or participation.

Indicator	Description	Method of Calculation
Simpson index	Quantifies the probability that two crops or foods randomly selected from a defined population will be the same type.	$SI_i = 1 - \sum S_j^2$ where S_j is the fraction of the entire population i made up of food j
Margalef index	Increases when there are more species in a determined area or when the same amount is maintained but the area of the farm decreases.	$D_{Mg} = \frac{S-1}{\ln N}$ where S is the number of species on farm and $\ln N$ is the natural logarithm of the farm area
Shannon diversity *	Quantifies the uncertainty in predicting the type of food crop randomly selected from a defined population.	$H = \sum_{i=1}^{S} -(P_i \times \ln P_i)$ where P_i is the fraction of the entire population made up of species i and S is numbers of foods encountered

* (also known as Shannon-Wienner index).

Nutritional Functional Diversity. The Nutritional Functional Diversity (NFD) was first developed by Remans et al. [30] in order to provide insights in nutrient diversity of farming systems, and also used by Ng'endo et al. [31] and Luna-González and Sørensen [32]. This composite and continuous indicator is based on a matrix of plant and/or animal species produced and/or reared in the different farms and a matrix of the nutritional composition of all of the plant and/or animal species produced and/or reared in the study. From these two matrices, multivariate distances between species according their nutrient composition and content are calculated and used to cluster species into a dendrogram. Based on the species present at a given farm, the branch lengths of the dendrogram are summed to provide the final score of the NFD. Remans et al. [30] have found the NFD to be relevant to studying nutrition-sensitive agriculture through their demonstration "that depending on the original composition of species on farm or village, adding or removing individual species can have radically different outcomes for nutritional diversity" (in abstract of the article). Nevertheless, because it relies on both on a matrix of local production and a matrix of nutritional composition (Ng'endo et al. used a matrix with 7 macro- and micronutrients [31], Luna-González and Sørensen with 15 macro- and micronutrients [32] and Remans et al. with 17 micronutrients [30]), the NFD is strongly dependent on the area of study and on the skills and resources of the research team.

3.2.3. Additional Considerations

Among the 37 articles, ten specifically mentioned that home, kitchen, or women-led gardens were taken into account when calculating the production diversity indicators [12,15,24,30,32–37], eight specifically mentioned that wild resources were taken into account [12,16–18,22,24,32,35], and three specifically mentioned that trees were taken into account [17,20,38]. Inclusion or exclusion of these production and acquisition resources will affect the results of a study and limits comparability across studies.

Among the 37 articles, seven specifically mentioned that the production diversity was assessed based on the previous year [15,34,36,39–42], twelve were based on the previous season [20–22,24,27,28,37,38,43–46], one was based on the current production [30], and sixteen were not clear about the reference period [12–14,16–18,26,31–33,35,47–51]. While almost all of the studies relied on interviews to assess the production diversity, only four mentioned that they partially or completely used field observations to assess the production diversity [17,24,30,32]. Most of the time, longer reference periods of agricultural production were compared to dietary data based on shorter reference periods, either a recall period of 24 h (n = 19) or a recall period of 7 days (n = 14). Of note, the article from Somé and Jones used repeated dietary data to represent dietary diversity across the year, data that were compared to the seasonal production [52]. Issues of seasonality and comparing one-day or one-week recall with 12 months of production might affect the results of a study and limit comparability with other studies.

3.3. Indicators of Market Access And/or Participation

3.3.1. Descriptive Assessment of the Use of the Indicators

Twenty-five of the 37 studies used indicators related to market access and/or market participation. On average, more than two indicators were used per study (ranges from one to five). More specifically, 18 studies used indicators related to the physical access to the market, mainly by evaluating the distance to the nearest market in km (n = 8) and/or travel time (n = 4) or by asking if a food market is in the immediate environment of the household (n = 4). Most of the time, the nature of the market and the purpose of accessing the market were not clearly identified (e.g., to buy agricultural inputs, to sell agricultural production and/or to buy food). Fourteen studies used indicators related to the market participation of the household (the interaction with a market to sell agricultural production), mainly by evaluating the orientation of the farm based on proportion of production sold as compared to consumed (n = 7) or by evaluating income from agricultural (n = 5). Eleven studies used indicators related to the availability of foods that can be bought by the household, mainly by considering the foods that were effectively bought by the household (n = 10) rather than considering the availability of foods at the market level (n = 1).

3.3.2. Description of the Indicators

Physical access to the market. The most common indicator across the literature was the distance to the nearest market. This simple and continuous indicator relies on the estimation in km of the distance to the nearest market, information which seemed relatively easy to use and analyze. The use of this indicator seems to be based on the hypothesis that the greater the distance, the harder the physical access to the market. This indicator does not provide any information about the importance of having access to this market in terms of incomes and/or food purchases, nor information about the individual private and public transportation and the quality of the transport infrastructure, or the elevation of the terrain. As a result, the interpretation of this indicator is strongly dependent on the area of study. Similar versions of this indicator have been proposed, including: (i) a version relying on the estimation in travel time of the distance to the nearest market (time required to reach the market by walking or other forms of transport (bike, bus, car/motorcycle); (ii) a version relying on the estimation in distance (km) or travel time required (hours or minutes) to the nearest town (with different threshold of inhabitants); and (iii) a version relying on the estimation in distance to the nearest road. Two other simple and categorical indicators addressed very similar points (one being based on the presence of a food market close to the household and the other one being based on the mode of transport to access to the market to buy food). Two indicators seemed to overcome several limitations of other indicators. The first one is a simple and discrete indicator based on the frequency of visits to the market [32]. The other one is a simple and continuous indicator based on the cost of transporting 50 kg of wheat to the nearest market and was used by Zanello et al. as proxies of the distance to the market, of the quality of the road infrastructure and the competitiveness of local transport companies [15]. Nevertheless, neither of these indicators provide any information about the importance of having access to this market in terms of household incomes or food purchases.

Market participation of rural smallholder farming households. A common indicator across the literature was the orientation of the farm production. This simple and categorical indicator relies on the estimation of the proportion of the farm production that is sold or consumed. This estimation was mainly based on the quantities of food produced (or consumed), but in one study, was based once on the proportion of cropped land area devoted to market crops. Although the estimation of the proportion of the farm production that is sold or consumed is commonly performed in household surveys, collecting such data could be challenging. This indicator considers a global proportion of the farm production without taking into account the number of species sold (or consumed) and does not provide any information about how the associated incomes could be used to buy food. Although the comparability in terms of percentage of on-farm production devoted to market crops might be high as the question is clear, the comparability in terms of livelihood significance might depend on the size of the farm and the level of production. A similar version of this indicator was used in one study, where the percentage of women selling their vegetable production was assessed [12]. Other studies directly assessed the total agricultural income, a quantitative and simple indicator. While this indicator provides information about a source of incomes that could be used to buy food, it does not provide information about the contribution of this income to the food budget. Of note, the level of comparability of this indicator within country should be high, but unless currency is standardized cross-country comparison would be low.

Availability of foods that can be bought by rural smallholder farming households. Six studies explored the contribution of purchased foods to the total diet of the respondents. Sibhatu et al. [48], Islam et al. [36], and Zanello et al. [15] calculated different indicators of dietary diversity with respect to purchased foods only, and Romeo et al. used Shannon and Simpson indexes to estimate the relative concentration or spread of food expenditures [49]. These composite and continuous indicators could be challenging to use, sharing the same logistical issues as the group count indicators and richness/evenness indicators. In other studies, Jones [20] and Oyarzun et al. [17] calculated the proportion of food consumed coming from purchases. All of these indicators reflect the importance of food markets to the diet of rural smallholder farming households, taking the nutritional quality of the purchased food products more or less into account. Other indicators attempted to reflect the importance of food markets to the diet. Two studies considered the purchased foods by counting the number of different purchased food items consumed by the respondents [12,22], and two others assessed total food expenditures [43,52]. Nevertheless, these indicators provided less information than the previous ones, either by not exploring the relative importance of the different purchased food items in the diet or not considering the nutritional quality of the purchased food products at all. Of note, Zanello et al. developed the Market Food Availability Index (MFAI) which captures the regional availability of a basket of food items contributing to a large proportion of diets of local households [15]. This indicator is based on an estimation of the level of availability (not available, moderately available, and abundantly available) of nine key food items. While this composite and continuous indicator could be challenging to use, it seemed to provide interesting information about the potential nutritional interest of local markets, even if does not take into account some foods or food groups like pulses.

3.3.3. Additional Considerations

The indicators related to the market access and/or market participation were based on various reference periods. Globally, indicators related to the market participation were based on the same reference period as the agricultural production. Indicators related to the availability of foods on markets were based on short reference periods, presenting a temporary difference with long reference periods of agricultural production, which was similar to the one between agricultural production dietary data (see Section 3.2.3). Of note, the article from Somé and Jones used repeated weekly household food expenditures across the year [52]. Finally, indicators related to the physical access to the market were not based on a specific reference period whereas difficulties to access market could vary according the seasons (e.g., flooding of areas could increase the time needed to the reach the nearest market and modify the location of the nearest market).

4. Discussion

This review demonstrated the wide range of indicators of agricultural production diversity, physical access to the market, and market participation in use in recent peer reviewed literature. Up to sixteen different indicators of agricultural production diversity and 14 different indicators of market access and/or participation were found, and large heterogeneity was found for the use and implementation of some indicators. While the diversity of measurement ideas allows flexibility in terms of budget and research aims, it precludes comparability with other studies and might make it difficult to build a robust body of evidence of the impact of agriculture on food security, diet quality, and nutritional status.

4.1. Inter- and Intra-Variation of the Indicators

This review highlighted the wide variation of agricultural production diversity indicators, not only between the indicators but also within each indicator. We found 16 different indicators that we considered as more or less adapted when studying nutrition-sensitive agriculture based on their ability to take into account the differences in nutritional composition of the species grown and/or reared. While this issue has already been discussed by different authors [23,53], Bogard et al. have demonstrated how applying different types of production diversity indicators to aquaculture production sub-systems in Bangladesh resulted in different diagnosis of the nutritional quality of these sub-systems [7].

For some of the 16 different indicators of agricultural production diversity, we observed a large heterogeneity in terms of implementation. For example, the number of groups and the classification used for the Group Count Indicators were highly variable. In some studies, the classification was based on nutritional consideration, using the same food group classification as dietary diversity indicators, whereas in others studies, the classification was based on agricultural consideration, including groups of non-food crops like tobacco and cotton [27] or fiber crops [41]. Another example concerned the NFD for which the implementation was systematically different across the studies, in terms of number of nutrients and standardization of the nutritional composition [30–32].

We also observed differences of implementation according to the type of production. For example, most of the authors computed richness/evenness indicators based on plant production only, while taking into account animal production as a separate variable like livestock ownership [36,41] or as a part of a simple count indicator [31,38,48] or group count indicator [46]. Oyarzun et al. [17] and Walingo and Ekesa [18] computed different richness/evenness indicators based on plant and animal production. Finally, we observed differences in terms of study parameters. While all of the studies assessed smallholder farming household production, some of them specifically mentioned including production from home, kitchen, or women-led gardens, from wild resources and/or from trees. Restricting production to the field or not doing so could provide a very different picture of the diversity of the production. Jones et al. found an average crop species richness of 2.5 ± 1.4 based on field crops and an average crop species richness of 7.2 ± 4.6 based on garden crops [37]. Inclusion or exclusion of various sources of food production can have a large impact on the results.

To a lesser extent, inter- and intra-variation in indicators of market access and/or participation were observed across the 14 indicators we identified. The most notable variations concerned the distance to the nearest market (either estimated in km or in travel time in hours/minutes). Taken together, all these inter- and intra-variation of the indicators, including the variations in use and interpretation of dietary diversity indicators previously highlighted [6], pose a major challenge when comparing studies to build a robust body of evidence.

4.2. Additional Considerations

While the intent of the review was to assess the characteristics of indicators that measure agricultural production diversity and market access and/or participation, and not to judge the validity of the studies or their results, several issues have to be discussed.

4.2.1. Temporal Variability

Beyond the format of the indicator, this review revealed an important issue related to seasonality and mismatch of reference period between domains. Indeed, dietary diversity was mostly based on short reference periods (24-hour recall or 7-day recall) whereas agricultural production diversity was mostly based on long reference periods (one season or one year). Short reference periods (e.g., 24 h or 7 days) in dietary assessments are a poor estimation of habitual dietary patterns over a season or a year. One solution is to conduct multiple 24-hour recalls across this period [54]. Among other factors, habitual dietary patterns depend on food availability, which varies according to seasons, agricultural cycle, food processing (e.g., shelf-stable products), and food trade. Somé and Jones explored how the intersections of agricultural diversification and production orientation with seasonality influenced household dietary diversity in Burkina Faso and highlighted that this topic requires further research [52].

4.2.2. Agricultural Production Diversity at the Farm-Level

We found that an average of two indicators of agricultural production diversity were used per study. The use of multiple indicators is welcomed in this research field. Indeed, Bogard et al. demonstrated the importance of using a combination of different indicators of production diversity to comprehensively evaluate the nutrition-sensitivity of food production systems [7]. Furthermore, it would be of interest to assess agricultural production diversity to evaluate the environmental benefits of farm diversity [55,56]. Optimal nutrition-sensitive production diversity might be different from optimal environment-sensitive production diversity. Finally, Groot et al. highlighted the importance of considering the landscape-level for a more comprehensive and holistic understanding of how communities, within a landscape, produce, access, and consume foods [57]. Indeed, previous studies have shown that the relationship between farm-level and landscape-level crop diversity might not be straightforward [58].

4.2.3. Market Access and/or Participation

Beyond the choice of indicator, there is a more important methodological issue when considering market access and/or participation. Market access and/or participation play an important role in the relationship between farm production diversity and dietary diversity. When markets fail, as is frequently the case in rural areas of developing countries [59], transaction costs increase and limit market participation. In this configuration, household decisions about their production and consumption are non-separable [60,61]. From a methodological point of view, the reciprocal dependence of these two decisions implies ambiguity of the meanings of causality and leads to biased estimation. Treatment of endogeneity requires a more extensive specification of econometric models and resolution by instrumental variables strategy [15,26,46], simultaneous systems of equations [22], or fixed effects in panel survey [36,41].

4.3. Limitations and Perspectives

While this review relies on a selection of articles previously identified in systematic reviews [4–6] and on a systematic search strategy for publications from June 2017 to August 2019, it does not meet all of the standards for a systematic review [62]. As a result, this review may not be exhaustive. Nevertheless, if the inclusion of additional articles might have allowed for the identification of new indicators and would have changed the frequency of use of the indicators we identified, it would not have changed the main finding, which is the wide variation and lack of standardization across studies.

This review is an initial attempt to document and describe the wide variation and lack of standardization across studies. While it could serve as a basis to define a standardized set of indicators measuring agricultural production diversity and market access and/or participation, we do not propose a standardized set of indicators. Defining a standardized set of indicators is methodologically challenging. Indeed, there are no cardinal rules or set procedures to be followed when developing indicators [63]. Among others, the criteria for selecting indicators is a significant issue. While some criteria are common to any type of indicator (e.g., being generally relevant, scientifically sound, and applicable to users), more specific criteria could be defined [63], and these specific criteria might not be compatible with each other. For example, trade-offs might be needed between having indicators reflecting local circumstances and being appropriate for inter-country comparisons. Compatibility issues might also occur between the different domains of the indicators and prevent researchers from using multi-method approaches, like the approach used by Timler et al. to identify solutions to simultaneously improve household income, nutrition and resource management [64]. Selection of relevant criteria to systematically assess the strengths and weaknesses of available indicators, as a first step to define a standardized set of indicators, should involve a larger group of experts and a rigorous process of discussion. From this point of view, the Delphi approach, which is a systematic and interactive method to gather information from experts in various scientific fields to reach group consensus and ensure a breadth of unbiased participation, seems to be highly appropriate for such work [65,66].

5. Conclusions

This paper provides a comprehensive inventory of indicators of agricultural production diversity and indicators of market access and/or market participation used in the literature investigating the positive association between production diversification of rural smallholder farming households and household food security or nutrient adequacy of household members. The findings of this review reveal a plethora of indicators currently in use and a variability in the implementation of some indicators, which makes cross-study comparisons of findings extremely challenging to build a robust body of evidence. Furthermore, some indicators were found to be strongly dependent on the area of study, posing major issues for comparative analyses across countries or regions, and also within countries or regions. Having a comparable body of evidence can form the basis for policy and programming related to the relative and differentiated importance of production diversity, market access, and/or participation on food security, diet quality, and nutritional status outcomes. From this perspective, defining a standardized set of indicators measuring agricultural production diversity and market access and/or participation could be of great use.

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Appendix A

Table A1. Indicators used to Measure Agricultural Production Diversity (n = 37).

Study	Simple Count Indicators	Group Count Indicators	Richness/Evenness Indicators	Nutritional Functional Diversity
Ekesa et al., 2008 [16]	* Count of crop and livestock species			
Remans et al., 2011 [30]	* Count of crop species (named "species richness")			* Nutritional functional diversity (based on 17 nutrients)
Keding et al., 2012 [12]	* Count of different vegetable species cultivated * Count of different vegetable species collected from wild			
Oyarzun et al., 2013 [17]			* Margalef diversity index (different crop and animal species) * Shannon diversity index (different crop and animal species)	
Walingo and Ekesa, 2013 [18]			* Shannon-Wienner index (different crop and animal species)	
Jones et al., 2014 [38]	* Count of crop species * Count of crop and livestock species		* Simpson Index (different crop species)	
Pellegrini and Tasciotti, 2014 [33]	* Count of crop species * Livestock ownership			
Sraboni et al., 2014 [47]	* Count of crop species * Tropical livestock units			
Dillon et al., 2015 [26]		* Score based on a counts of 5 food groups		
Kumar et al., 2015 [28]	* Count of crop species * Count of crop and livestock species	* Score based on a counts of 7 food groups (same as dietary diversity)		
Malapit et al., 2015 [13]		* Score based on a counts of 9 food groups (same as dietary diversity)		
Sibhatu et al., 2015 [48]	* Count of crop species * Count of crop and livestock species		* Margalef species richness index (different crop species)	
Snapp and Fisher, 2015 [27]	* Tropical livestock units	* Score based on a counts of 10 non-maize crop groups (including two non-food groups)		
Bellon et al., 2016 [22]	* Count of crop species			
Hirvonen and Hoddinott, 2016 [39]		* Score based on a counts of 7 food groups (same as dietary diversity)		
Ng'endo et al., 2016 [31]	* Count of crop species (named "Species richness") * Individual density (number of individuals of a food plant species per 1,000 m^2 farm area) * Count of crop and livestock species		* Shannon diversity index (different crop species) * Simpson index of diversity (different crop species) * Shannon evenness (different crop species)	* Relative nutrient functional diversity (based on 7 nutrients)

Table A1. *Cont.*

Study	Simple Count Indicators	Group Count Indicators	Richness/Evenness Indicators	Nutritional Functional Diversity
Romeo et al., 2016 [49]		* Score based on a counts of 8 food groups		
Vanek et al., 2016 [21]	* Count of crop species (named "crop diversity") * Tropical livestock units			
Jones, 2017 [20]	* Count of crop species (named " crop species richness") * Count of crop varieties (named " crop varietal richness") * Tropical livestock units	* Score based on a counts of 10 food groups (same as dietary diversity)		
Koppmair et al., 2017 [34]	* Count of crop species * Tropical livestock units	* Score based on a counts of 12 food groups (same as dietary diversity)		
M'Kaibi et al., 2017 [35]	* Count of crop and livestock species			
Mulmi et al., 2017 [40]	* Count of crop and livestock species	* Score based on a counts of 7 food groups (same as dietary diversity)		
Rajendran et al., 2017 [43]			* Simpson index (different crop species)	
Saaka et al., 2017 [44]	* Count of crop species (named "crop production diversity") * Count of livestock species (named "livestock production diversity") * Count of crop and livestock species (named "agricultural biodiversity score / production diversity score")			
Ayenew et al., 2018 [50]	* Livestock ownership	* Score based on a counts of 9 to 11 food groups (poorly explained)		
Ecker, 2018 [41]	* Cash crop production * Livestock ownership	* Score based on a counts of 8 groups (including one non-food group)	* Simpson diversity index for (different crop groups)	
Islam et al., 2018 [36]	* Count of crop species including fruits and vegetables (named "farm diversity") * Count of crop species (named "food crop production diversity") * Livestock ownership		* Margalef species richness index (different crop species)	
Jones et al., 2018 [37]	* Count of crop species (named "crop species richness") * Count of crop and livestock species (named "crop and livestock species richness")			
Luna-González and Sørensen, 2018 [32]	* Count of crop species (named "crop species richness") * Count of domestic animals bred			* Nutritional functional diversity (based on 15 nutrients)
Mofya-Mukuka and Hichaambwa, 2018 [45]			* Simpson index of crop diversification (different crop species)	

Table A1. *Cont.*

Study	Simple Count Indicators	Group Count Indicators	Richness/Evenness Indicators	Nutritional Functional Diversity
Murendo et al., 2018 [14]	* Count of crop species (named "crop diversity") * Count of livestock species (named "livestock diversity") * Count of crop and livestock species (named "farm production diversity")			
Sibhatu and Qaim, 2018 [51]	* Count of crop and livestock species	* Score based on a counts of 10 food groups (same as dietary diversity)		
Somé and Jones, 2018 [52]	* Count of crop species (named "household crop diversity")			
Adubra et al., 2019 [42]		* Score based on a counts of 9 food groups		
Lovo and Veronesi, 2019 [46]	* Count of crop species (named "crop diversity")	* Score based on a counts of 9 food groups * Score based on a counts of the previous 9 food groups plus other groups related to animal products (no details)	* Margalef index (different crop species) * Margalef index (different crop groups) * Simpson diversity index (different crop groups) * Shannon-Wiener index (different crop groups)	
Oduor et al., 2019 [24]	* Count of crop species (named "crop species richness") * Count of livestock species (named "livestock species richness") * Count of crop and livestock species (named "household on–farm agrobiodiversity")			
Zanello et al., 2019 [15]	* Count of crop species * Count of livestock species * Count of crop and livestock species (named "aggregate production diversity index")			

* Means that the indicator is only based on plant production; * Means that the indicator is only based on animal production; * Means that the indicator is based on both plant and animal production.

Table A2. Indicators Used to Measure Market Access and/or Market Participation (n = 25).

Study	Physical Access	Market Participation	Availability
Keding et al., 2012 [12]		- Share of women selling vegetables	- Count of different vegetable species purchased
Oyarzun et al., 2013 [17]			- Proportion of food consumed coming from purchases
Jones et al., 2014 [38]		- Production orientation of farm (share of food from own production) - -Production orientation of farm (share of cropped land area devoted to market crops)	
Dillon et al., 2015 [26]	- Market prices and local input prices (not tested in final model)		
Kumar et al., 2015 [28]	- Owning a mode of transport	- Total agricultural income	
Sibhatu et al., 2015 [48]	- Distance to the nearest market (in km)		- Food group diversity of purchased foods
Snapp and Fisher, 2015 [27]	- Distance to the nearest major road (km) - Presence of a bus stop in the community - Owning a bicycle - Presence of food market in the community		
Bellon et al., 2016 [22]	- Presence of an urban food market - Presence of an semi-urban food market - Distance to the nearest market (in minute)	- Total agricultural income (expressed in terms of whether agricultural sources of income were rated as very important)	- Number of different purchased food items
Hirvonen and Hoddinott, 2016 [39]	- Presence of food market in the village (within a 3 km range)	- Total agricultural income	
Ng'endo et al., 2016 [31]		- Production orientation of farm (main on-farm food uses with percentages dedicated for home consumption or sale in formal and informal markets)	

Table A2. *Cont.*

Study	Physical Access	Market Participation	Availability
Romeo et al., 2016 [49]	- Presence of food market in the village		- Relative concentration or spread of food expenditure (Shannon and Simpson indexes)
Vanek et al., 2016 [21]	- Distance to the nearest market (in km)		
Jones, 2017 [20]	- Distance to the nearest urban center (in km) - Distance to the nearest major road (in km)	- Production orientation of farm (share of crops sold for each household and as earnings from sold)	- Proportion of food consumed coming from purchases
Koppmair et al., 2017 [34]	- Presence of food market in the village - Distance to the nearest market (in hour)	- Production orientation of farm (share of maize sold, share of other food crops sold, and farm area share grown with non-food cash crops)	
Rajendran et al., 2017 [43]	- Distance to the nearest market (in km) - Distance to the nearest market (in hour)	- Total agricultural income	- Household food expenditures
Ayenew et al., 2018 [50]	- Distance to the nearest market (in km)		
Ecker, 2018 [41]		- Production orientation of farm (level of food self-sufficiency: share of consumed food from own-production measured in monetary value terms)	
Islam et al., 2018 [36]	- Distance to the nearest market (in km)	- Production orientation of farm (share of produce sold to the market)	- Food group diversity of purchased foods

Table A2. *Cont.*

Study	Physical Access	Market Participation	Availability
Jones et al., 2018 [37]		- Production orientation of farm (share of harvest destined for sale and earnings from sold crops)	
Luna-González and Sørensen, 2018 [32]	- Distance to the nearest market (in km) - Frequency of visits to market		- Number of edible crop specie found in food systems (includes market) - Nutritional functional diversity of the food systems (includes market)
Mofya-Mukuka and Hichaambwa, 2018 [45]	- Distance to the nearest urban center (in hours) - Distance to the nearest major road (in km)		
Murendo et al., 2018 [14]		- Production orientation of farm (incidence of household selling crop and or livestock to the market) - Intensity of market participation (share of crop output sold to the market)	
Sibhatu and Qaim, 2018 [51]	- Distance to the nearest market (in km)		
Somé and Jones, 2018 [52]	- Distance to the nearest market (self-reported travel time)	- Production orientation of farm (share of harvested crops sold or planned to be sold) - Total agricultural income	- Household food expenditures
Lovo and Veronesi, 2019 [46]	- Distance to the nearest market (in km)		
Zanello et al., 2019 [15]	- Cost of transporting a 50 kg of wheat to the nearest market		- Market Food Availability Index - Food group diversity (FCS) of purchased foods - Varying availability of specific foods in the market across the year

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