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Systematic review for seasonal crop diversity influence on the double burden of malnutrition in rural communities

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This systematic review investigates the influence of seasonal crop diversity on the double burden of malnutrition in rural communities across low-and middle-income countries. The review analyzed *n* = 22 peer-reviewed studies published in the online databases Scopus, PubMed, Google scholar, and the Food and Agriculture Organization's sub-websites, HINARI and AGORA, between January 2017 and April 2024. The review used the preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 set of guidance to explore how variations in seasonal crop production affect dietary diversity and nutritional outcomes among vulnerable populations. Article quality appraisal using the Effective Public Health Practice Project (EPHPP) tool revealed mixed methodological rigor across eight domains in underpowered studies (*n* = 18, weak; *n* = 4, moderate; *n* = 0, strong), emphasizing the need for caution when interpreting the findings. The findings indicate that increased seasonal crop diversity correlates with improved dietary practices and food security. Yet, challenges of resource access and market constraints hindered these benefits. The systematic review further identified critical gaps in current research and emphasized the need for integrated strategies that promote seasonal crop diversity as a tool to combat malnutrition effectively. The insights gained aimed to inform policy decisions and guide future research efforts focused on enhancing nutrition during conditionally lean seasons.

KEYWORDS

double burden of malnutrition, dietary diversity, low-and middle-income countries, rural communities, seasonal crop diversity, systematic review

1 Introduction

The double burden of malnutrition (DBM), defined as the co-existence of both under-and over-nutrition at various dimensions and levels for individuals, households, and communities, is one of the dilemmas faced by mankind (Khare et al., 2018). More than one in three countries is afflicted by high costs for treating non-communicable diseases linked to malnutrition in intergenerational cycles (Vasu et al., 2021). The prevalence of this phenomenon is increasing throughout the world, but the impact is most felt in lower-and middle-income countries (LMICs) (Raman et al., 2023). One major challenge is the insufficient exploration of ecological determinants affecting nutrition-related behaviors and outcomes in these vulnerable populations (Desyibelew et al., 2020). Seasonal crop diversity, defined as the variety of crops grown in different seasons within specific agricultural systems (Deaconu et al., 2021) encompasses several dimensions of species diversity, genetic diversity, and varietal diversity among crops. The phenomenon enhances soil health, agricultural productivity, resilience and

ecological balance through the sustainable reduction of risks of crop failure. However, there is a lack of integrated strategies that effectively utilize seasonal crop diversity to combat malnutrition, despite its potential benefits (Bakhtsiyarava and Grace, 2021). Focusing on low-and middle-income countries (LMICs) stems from the disproportionate burden of under-and overnutrition, which affects approximately 75% of the global population residing in these regions (Anilkumar et al., 2017). This demographic faces unique challenges such as food insecurity, widespread poverty, shifting food systems, dietary transitions, and limited access to resources that exacerbate nutritional issues, making them critical areas for research attention and interventions through seasonal crop diversity (Berra, 2020; Bai et al., 2024). In contrast, developed countries often have more robust food systems and well-established healthcare infrastructures that mitigate these challenges, leading to less urgency in addressing similar nutritional issues within their populations (Hounkpatin et al., 2023). While the level of urgency is debatable for developed countries, the relatively better coping mechanisms of their populations, due to cultural food preferences, reduce the level of urgency.

In LMICs, where food insecurity and malnutrition are disproportionally prevalent, the influence of seasonal crop diversity on the DBM is crucial in the attainment of sustainable development goals, related to hunger eradication, nutrition and good health (Anilkumar et al., 2017). Rural households often experience seasonal fluctuations in food availability, of which nutrient intake is often inadequate during conditionally lean seasons when crop yields dwindle. Woman's dietary diversity scores were found to increase during post-harvest seasons, contrary to the pre-harvest seasons, stressing the importance of timing in food availability (Egata et al., 2013; Bellows et al., 2020). Understanding seasonally diverse cropping systems can mitigate perennial challenges by promoting nutritional interventions, food security, and health outcomes through "double-duty actions" that combat all forms of malnutrition (Pradhan et al., 2021).

Many previous studies have highlighted the importance of seasonal crop diversity on the enhancement of dietary diversity for the improvement of nutritional outcomes (Jones, 2017; Sié et al., 2018; Ayenew et al., 2018; Ojha et al., 2022). Greater crop diversity was further reported by Appiah-Twumasi and Asale (2022) as a contributing factor to higher dietary diversity scores in rural communities, particularly regarding nutrient supply and adequacy. While ensuring nutrient adequacy is crucial in vulnerable populations, seasonality significantly impacts dietary diversity (Bellows et al., 2020). In certain LMICs, such as northern Ghana and Burkina Faso, studies have shown that dietary diversity scores tend to decrease during conditionally lean seasons, and households cope by relying heavily on staple crops of limited nutritive value (Waswa et al., 2021). This lack of variety has been linked to micronutrient deficiencies in women of reproductive age and children, manifesting in short-, intermediate-, and long-term nutritional outcomes (Durga et al., 2017). Seasonal crop diversity allows communities to access a wider range of food sources throughout the year, thus addressing both seasonal food shortages and nutritional requirements. These outcomes have been measured and assessed at the individual, household, and community levels (Fremmpong et al., 2023). Earlier studies by Krause et al. (2021) indicate that increasing dietary diversity is correlated with better health outcomes, making this an increasing focus of agricultural policies.

In essence, the promotion of crop diversity, with proper storage practices, not only improves dietary diversity, but also contributes to economic resilience for the majority of smallholder farmers (Bisheko et al., 2023). When farmers cultivate a variety of crops at any time of the year, they can buffer against fluctuations in markets and climate-linked shocks that threaten their livelihoods (Belayneh et al., 2021). Increased income opportunities arise through access to new markets for more economically valued crops, as reported by Sekabira et al. (2022), enabling households to purchase a wider range of foods. Generated income can be reinvested in community health and nutrition, further addressing malnutrition. This economic aspect is important in rural areas where financial constraints tend to be limiting in accessing nutritious foods. Integrating seasonal crop diversity as a component in agricultural practices, can advance the state of food security and nutritional status across communities (Kinyoki et al., 2021).

1.1 Seasonal crop diversity influence on overnutrition in rural LMICs

While over one-third of LMICs experience overlapping forms of malnutrition (excluding neutral forms), overnutrition, which is often characterized by excessive caloric intake and poor dietary quality, is exacerbated by limited access to diverse food sources (Deaconu et al., 2021). This leads to an increased prevalence of non-communicable diseases such as diabetes and hypertension, which arises when more calorie-dense but nutrient-poor foods are consumed than what the human body needs, resulting in an altered body mass index (Korir et al., 2023). Seasonal crop diversity plays a crucial role in addressing these issues by enhancing dietary variety and nutrient availability throughout the year. By promoting a wider range of crops during different seasons, communities can improve their dietary diversity, which is essential for preventing overnutrition and its associated health risks (Wang et al., 2021). Greater seasonal crop diversity does not only mitigate the risks of food insecurity during conditionally lean seasons, but also fosters healthier eating patterns that can counteract the effects of overnutrition. Therefore, integrating seasonal crop diversity into agricultural practices emerges as a vital strategy for combating the dual challenges of malnutrition in vulnerable rural populations. This has also been central to the interface of agriculture and medicine, as reported by Ojha et al. (2022). Unbiased research can help to identify vulnerable rural populations at risk and inform public health strategies for risk mitigation. This includes the interconnectedness between agriculture, health, and nutrition in rural communities of LMICs.

While existing literature highlights the great potential of seasonal crop diversity to improve dietary diversity and nutritional outcomes in rural LMICs (Belayneh et al., 2021; Deaconu et al., 2021; Barati et al., 2022; Sekabira et al., 2022), significant gaps remain in understanding the nuances of these relationships. Further research is required to explore the specific pathways through which seasonal crop diversity influences the DBM, assess the intermediate and long-term dietary outcomes of such interventions, and further address the discrepancies in the current evidence base regarding the effectiveness of seasonal crop diversity in unique contexts. Therefore, this systematic review was carried out to assess how nutritional outcomes, their pathways, and synthesized discrepancies in the current evidence base

were related to the influence of seasonal crop diversity on the dual burden of malnutrition in rural communities of LMICs. The review contributes to the identification of research gaps relevant to LMICs. Specifically, the review sought to address the following research questions:

- How does the pathways for seasonal crop diversity influence relate to the DBM in vulnerable rural communities?
- What are intermediate and long-term dietary outcomes of seasonal crop diversity influence in rural communities?
- What gaps are in the current evidence base for seasonal crop diversity influence on dual malnutrition in rural communities?

2 Methods

To account for household vulnerability to seasonal changes in dietary diversity, and fluctuations in food access in LMICs (Bonuedi et al., 2022), this systematic review was carried out in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for the 2020 guidance (Haddaway et al., 2022). The protocol was developed to cover the rationale, research questions, eligibility criteria, records to be studied and data synthesis plans (Elsner et al., 2023). Malnutrition-related outcomes considered in this systematic review, included intermediate and long-term nutritional outcomes (Escher et al., 2024; Table 2). Impacts on dietary patterns, economic benefits, resilience against climate variability, community engagement and cultural adaptations are all directly and indirectly linked to seasonal crop diversity scores (Bosha et al., 2019).

2.1 Data sources and search strategy

In April 2024, 6 key search words: "malnutrition," "crop production," "rural communities/populations," "seasonality," "interventions," "developing countries," along with any of the following 3 terms: "diet(ary) diversity" or "food security" or "food nutrition" were used to search for, identify, and conduct snowball sampling of traceable articles available in full text and open access, meeting the predetermined criteria. Thus snowball sampling was a proxy of backward and forward reference tracing. The search terms were meant to answer all the research questions for this systematic review, covering all dimensions of malnutrition encompassing aspects of under-and overnutrition with a focus on rural LMICs (Escher et al., 2024). The search words and terms accounted for database limitations, search optimization and retrieval efficiency. The lead author of this manuscript developed the search strategy based on the concept and breadth of the search terms, driven by existing gaps in research and the imperative need, using previously conducted systematic reviews in high-ranking journals. The search strategy was designed according to attributes of the electronic databases of Scopus, PubMed, Google Scholar and two of the Food and Agriculture Organization (FAO)'s subwebsites—HINARI and AGORA. This refers to the specific characteristics or properties associated with entities within the electronic databases. In the database management systems (DBMS), attributes served as the defining features that describe various entities such as fields. Previously conducted reviews on nutritional outcomes have helped in the identification of key words for the search strategies for relevant articles to satisfy the requirements of this review's research questions (Asghari et al., 2017; Jones, 2017; Sharma et al., 2021). Relevant and eligible articles in peer-reviewed journals that were ranked by SCImago, as either Q1 (the top 25% of the journals within a specific field) or Q2 (the journals that fall within the 26 to 50% range of rankings) were detected for the preceding 8 years, from January 2017 to April 2024 for the purpose of this review. This was primarily due to methodological considerations, relevance, quality, focus, and reporting standards such as the PRISMA 2020 guidance (Haddaway et al., 2022), including the need to solicit for a current evidence base. Titles, followed by abstracts and then full texts, were used in this order to screen all potentially relevant articles available in open access. The reference management software, Zotero, was used to store, track, and aid in citing referenced articles for this review. Figure 1 illustrates the eligibility of articles for relevance to the research questions in this review, as well as the specific reasons for the "out-of-scope" exclusions.

2.2 The eight-year timeline choice

The decision to focus on the eight-year timeline reflects contemporary practices and is grounded in the need to reflect on existing agricultural practices, nutritional, shifts in food systems and nutritional policy reforms, relevant to rural communities in LMICs. During the eight-year timeline, there has been a significant shifting in crop diversification practices, and indications of intermediate nutritional outcomes, as impacted by the Covid-19 pandemic through disruptions in global food supply chains and dietary diversity (Bai et al., 2024). This ensures that findings are directly applicable to present-day interventions and are tabled for policy reform discussions targeting the anticipated impact of long-term nutritional outcomes. Thus, the eight-year window provides a balanced scope, long enough to observe trends, nutritional outcomes, makes projections from relatively recent agricultural and nutritional interventions, and allows the tracking of policy reform reviews by authorities across LMICs. The period is also short enough to avoid dilution with less relevant historical studies. The preceding 8 years reflect on shocks and innovations during Covid-19 disruptions in which rural inputs and harvested food supply systems, directly influenced seasonal crop diversity (Elsner et al., 2023). Therefore, the review period covered events and remnants of challenges and innovations surrounding dual malnutrition in vulnerable populations. High-impact journals for systematic review protocols increasingly recommend a 5-to 10-year window period for literature searches to maintain relevance. Thus, the eight-year period aligns with these best practices and offers a comprehensive evidence base.

2.3 Article eligibility criteria

Eligible studies were deemed to have met the criteria, if they reported on the influence of seasonal crop diversity related to malnutrition in any dimension at the individual, household, or community level, targeting rural LMICs. To be included in this systematic review, all studies were required to have been published exclusively in Q1 or Q2 peer-reviewed journals, as ranked by SCImago website and indexed in Scopus. They were also required to have been conducted exclusively in rural communities of LMICs, according to

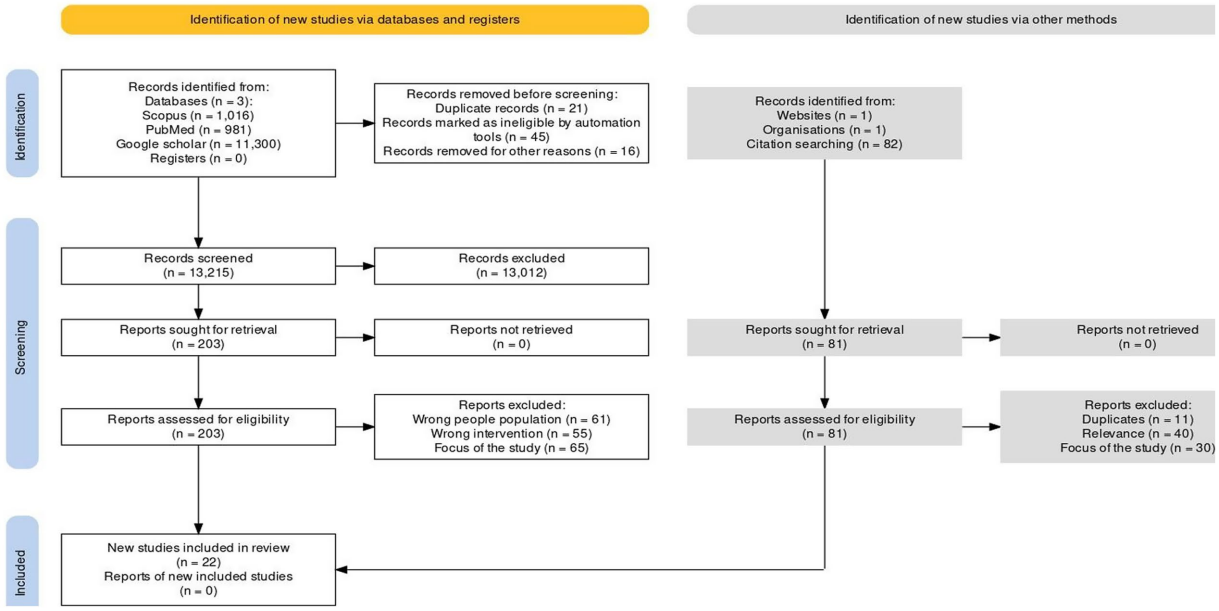

FIGURE 1
PRISMA flow diagram for eligible studies, during the selection processes for this systematic review.

standards set by the World Bank or United Nations (Raman et al., 2023). The rural community standards are centered on sustainable development, poverty reduction, and the empowerment of vulnerable groups. The World Bank standards focus on poverty reduction, community-driven development, and investment in infrastructure. Similarly, the United Nation standards focus on sustainable rural development, resilience building, and access to resources. Both the World Bank and the United Nations focus on empowering vulnerable groups, enhancing infrastructure, promoting sustainable practices, and ensuring that rural communities can actively participate in their development processes (Vasu et al., 2021). These standards aim at fostering inclusive growth that addresses the unique challenges faced by rural populations across the globe.

The studies were also required to have been written exclusively in English, and their duplicates were screened during the search procedure. Papers were also excluded if they did not communicate the intrinsic nature of seasonal crop diversity's influence on malnutrition. The phrase "intrinsic nature of seasonal crop diversity's influence on malnutrition" encapsulates the complex relationship between agricultural practices, specifically crop diversity, and nutritional outcomes, particularly malnutrition and related risk, which varies seasonally. This relationship is crucial in understanding how variations in food availability (low, moderate, high) and dietary diversity (low, moderate, high) may impact nutritional health and malnutrition risk (low, moderate, high), especially in vulnerable rural populations. The key components are seasonal crop diversity, nutritional outcomes, and the mechanism of influence such as dietary diversity score (DDS), weight-for-age and body mass index (BMI) in children during post-harvest seasons when food is plentiful (Roba et al., 2019). Review articles, book chapters, other systematic reviews, meta-analyses and all gray literature sources were further excluded. Peer-reviewed conference papers were included as part of the targeted articles, for the period January 2017 to April 2024. Regarding this review's research questions, all searches found made a valuable contribution (Asghari et al., 2017). All relevant articles were included and fairly assessed; thus, poor reporting within any included article did not affect the article's eligibility. Yet, it constitutes a limitation to this systematic review. For the overall direction effect of the DBM research and hypotheses, a narrative synthesis was used to extract information and data from eligible articles, standardize and relate their content for this review (n = 22, cf. Tables 1, 2).

3 Results

3.1 Study designs for seasonal crop diversity

This systematic review, (n = 22), included quantitative (n = 12) and mixed-methods (n = 10) studies, which constituted the evidence base, and their aggregated findings were synthesized accordingly. All relevant articles constituting the evidence base, regardless of study design type, were included. The study designs reported in the reviewed articles were: survey with longitudinal component (n = 2, 9%), longitudinal (survey or cohort) study (n = 3, 14%), face-to-face interviews (n = 1, 5%), repeated (cross-sectional) (n = 5, 23%), and household surveys with a follow-up component (n = 2, 9%). A non-random selection study (n = 1, 5%), a balanced panel study (n = 1, 5%), a prospective cohort study (n = 1, 5%), and a mixed methods design (exploratory ethnography, cross-sectional survey, and focus group discussions) (n = 1, 5%) were also reported. In addition, panel surveys (n = 3, 14%), a cluster randomized trial (n = 1, 5%), an investigation approach (n = 1, 5%), and quantitative surveys (n = 1, 5%) were also part of the reviewed articles (Table 1).

TABLE 1 Characteristics of eligible studies (n = 22).

Interventions in LMICs								
Author(s), year	Continent and country	Study design and method	Targeted population size	Study Level	Interventions deployed	Duration	Outcomes measured	Key study findings
Rousseau et al. (2023)	Africa, south-eastern Madagascar.	Household survey with a longitudinal component. (Quantitative)	Around 3,900 households in 102 rural villages. 492 households (13%) were included in the full sample.	Regional level	No interventions were deployed. 102 villages were purposively selected because of their comparatively weak humanitarian presence in their locations.	One year. Data was collected at 3 moments of minor lean period, major lean period and post-harvest period.	Household food insecurity, based on household food insecurity experience scale (FIES). Child malnutrition indicators of: Wasting and Stunting. Weight-for-age z-score (underweight), and mid-upper arm circumference (MUAC).	Diets showed strong seasonality, with lowest dietary diversity during the major lean period. 90% of the households experienced moderate to severe food insecurity. Child malnutrition rates were very high, with 27% children being wasted, 48% stunted, and 44% underweight during the major lean period.
Waswa et al. (2021)	Africa, Kenya.	Longitudinal study. (Quantitative)	426 mother–child pairs.	Rural communities, in western Kenya.	None, this was an observational study.	During harvest and post-harvesting seasons in 2012.	Women dietary diversity score (WDDS). Women's nutritional status, and children aged between 6 to 23 months.	Dietary diversity (>4 of the 9 food groups) increased from 36 to 52% between the two seasons. Seasonality had a minor, but significant influence on WDDS, including nutrient intakes, which differed significantly with season.
Shiratori et al. (2023)	West Africa, Burkina Faso.	Face-to-face interviews. (Mixed)	230 sample of rural households were surveyed.	Household level.	No specific interventions were deployed.	6 different times in 2 months intervals.	Household demographic backgrounds. Dietary habits and agricultural production. Agricultural field size and intake of energy (macronutrients and micronutrients).	Descriptive statistics of the households by commune. Examination of food consumption. Nutrient intake among surveyed households.
Wondafrash et al. (2017)	Africa, rural Ethiopia	Repeated cross-sectional survey, with a follow-up component. (Quantitative)	6–12 months old children (n = 587). 12–18 months old children (n = 266).	Household level.	None, as it was an observational study.	Harvesting season from, October to December 2009. Pre-harvesting season from, June to August 2010.	Nutritional status (Wasting, Stunting and Underweight). Dietary diversity score (DDS). Infant and child feeding index (ICFI). Morbidity (Diarrhea, Fever, Cough).	Dietary diversity during the harvest season (HS) was an independent predictor of linear growth during the 6-month follow-up period. Very poor dietary diversity score (DDS $\leq$ 2) was associated with stunting in the pooled data. There was no association found between infant to child feeding index (ICFI) and child growth.

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TABLE 1 (Continued)

Interventions in LMICs								
Author(s), year	Continent and country	Study design and method	Targeted population size	Study Level	Interventions deployed	Duration	Outcomes measured	Key study findings
Roba et al. (2019)	Africa, Rural Ethiopia.	Longitudinal study design (Quantitative)	Rural households and children.	Household level.	None.	Two seasons of post-harvest (plenty) and pre-harvest (conditionally lean).	Dietary diversity score (DDS) at household level. Infant dietary diversity score (IDDS). Dietary diversity score for women (WDDS). Maternal hemoglobin.	Nutritional indicators changed significantly between the post-harvest and pre-harvest seasons. There was a decrease in dietary diversity scores, (<3 food groups) and an increase in household food insecurity. Nutritional status worsened among women and children in the pre-harvest (lean) season.
Esaryk et al. (2021)	Africa, Ethiopia. and Asia, Vietnam.	Non-random selection of 20 sentinel sites in each country. Oversampling in poor areas to ensure regional diversity. Random selection of 100 households, with a child born in 2001 to 2002, from sentinel sites. (Quantitative).	Final sample size for analysis was 1,012 households for Ethiopia and 1,083 households for Vietnam.	Children born in 2001 to 2002 from different households in poor areas of Ethiopia and Vietnam.	Crop diversity and dietary diversity for children, considering factors like household wealth and proportion of harvested food.	Two follow-up rounds of data collection.	Child diet diversity, assessed through a qualitative 24-h recall for each follow-up round.	Agricultural diversification improve market engagement and farmer incomes. Crop diversity enhance child dietary diversity in low-income rural households in Ethiopia and Vietnam.
Ayenew et al. (2018)	Africa, Nigeria.	Panel data analysis using two rounds of survey data for 2010 and 2012. (Mixed)	6,089 observations with 3,063 in the year 2010 and 3,026 in the year 2012.	Household level.	None, it was an observational study.	Post-planting season (September to November). Post-harvesting season (February to April).	Relationship between farm production diversification and dietary diversity across season. Relationship across different income quartiles.	In the post-harvest season, increased farm diversification is associated with increased dietary diversity. Production diversification does not significantly influence dietary diversity during post-planting periods. Poorest households remain malnourished regardless of season, suggesting the need for targeted continuous nutrition interventions.
Alam et al. (2023)	South Asia, Bangladesh	Balanced panel study for dataset from the Bangladesh integrated household survey in 2012, 2015 and 2018. (Quantitative).	12,279 individuals in each round from 4,093 households.	Farm households in rural areas.	Agricultural diversification. Influence on dietary diversity of individuals in households.	2012, 2015 and 2018.	Dietary diversity scores of adult men, women and children in rural farm households.	Positive relationship exist between agricultural diversification and dietary diversity in farm households. The positive relationship impact was greater on women and children when compared to men.

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TABLE 1 (Continued)

Interventions in LMICs								
Author(s), year	Continent and country	Study design and method	Targeted population size	Study Level	Interventions deployed	Duration	Outcomes measured	Key study findings
Guizzo-Dri et al. (2022)	Asia, Timor-Leste	Longitudinal study. (Mixed)	377 children. 98 households, and 24 variables.	Community-level based.	None	Early April to mid-May 2018, and again in October 2018.	Dietary diversity score (DDS). Child anthropometric measurements. Child growth indicators.	Children in high dietary diversity score households had comparatively better growth outcomes, unlike those in medium and lower ranked households. Dietary diversity significantly influenced weight gain in children across seasons.
Jordan et al. (2022)	Africa, Uganda	Prospective cohort study (Mixed).	445 women with under-five-year old children from smallholder farm households.	Household level study in smallholder rural farming settings.	Women's dietary diversity score (WDDS) across three agricultural seasons.	Between May 2016 and January 2017. Three agricultural seasons (covering the lean, harvest and post-harvest seasons).	Dietary diversity score for women (WDDS) across three different seasons. Socio-demographic characteristics. Dietary practices. Differences in dietary diversity between urban and rural regions.	Rural women consumed more dark green leafy vegetables during the conditionally lean season. Poorer households in rural areas were more vulnerable to food insecurity and malnutrition. Seasonal variations of dietary diversity affected the nutrition of women in agricultural settings.
Deaconu et al. (2021)	South America, Ecuador.	Mixed methods designs (Exploratory ethnography, Cross-sectional survey and Focus group discussions) (Mixed).	91 farmers (61 agro-ecological farmers, and 30 reference farmers).	Empirical assessment.	Participation in agro-ecological associations.	Multiple phases, including Ethnography and surveys.	Nutrient adequacy. Dietary moderation. Production diversity. Dietary health.	Agro-ecological farmers showed better nutrient adequacy and dietary moderation than their reference neighbors. Higher production diversity and local food consumption, contributed to healthier diets at lower costs. Agro-ecological networks can effectively integrate nutritional health into sustainable food systems.
Bakhtsiyarava and Grace (2021)	Africa, Ethiopia	Longitudinal study using data from the Ethiopia's socio-economic survey (ESS) conducted by World Bank living standards measurements study (LSMS). (Mixed)	4,000 households tracked between 2011 and 2016.	Household level.	Relationship between farm production diversity and child nutrition outcomes.	Three rounds of survey data collected 2011/2012, 2013/2014 and 2015/2016.	Height-for-age (HAZ). Weight-for-height (WHZ) scores for child nutrition indicators.	Farm production diversity plays a crucial role in child nutrition outcomes. The diversity of food groups produced by households influenced child nutritional status.

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TABLE 1 (Continued)

Interventions in LMICs								
Author(s), year	Continent and country	Study design and method	Targeted population size	Study Level	Interventions deployed	Duration	Outcomes measured	Key study findings
Tesfaye (2022)	Africa, Ethiopia	Panel survey data. Historical weather instrumental data. (Quantitative)	Rural households with children who are below 5 years of age.	Household level.	Crop diversification.	Five years (2011–2016).	Household nutrient production gaps. Diet quality. Food intake. Child growth (height-for-age or weight-for-height z-scores). Stunting and wasting.	Crop diversification is positively associated with child growth outcomes, by improving nutrition, under repeated shocks and limited market access. Drought shocks negatively affects child growth by gender, but crop diversification can mitigate this effect.
Ghosh-Jerath et al. (2022)	Asia, India	Cross-sectional study. (Mixed)	268 rural women	Individual level. Household level.	None	Two seasons, with data collections done in the monsoon and winter season.	Usual intake of macro- and micronutrients (nutrient inadequacy). Women anthropometric status (body mass index).	Women who consumed indigenous foods had a higher dietary iron intake than those who did not. Indigenous foods help to address malnutrition. Dietary diversity was positively associated with iron intake.
Madzorera et al. (2021)	Eastern Africa, Tanzania	Cluster randomized trials. (Quantitative)	880 women from Rufiji rural with maternal and child health, including nutrition in rural Tanzania.	Homestead level	Food crop diversity, and distance to markets. Women's participation in nonfarm economic activities	August to October, 2017.	Women's diet quality, assessed using the prime diet quality score (PDQS) based on self-reported dietary intake.	Positive association exist between food crop diversity and maternal dietary quality. Increase in prime diet quality score (PDQS) was correlated with a larger food crop diversity.
Korir et al. (2023)	Africa, Kenya	The year, 2014 cross-sectional household survey. (Quantitative)	36,430 rural households. 13,048 women aged 15–49.	Household level. Individual level.	Diet diversity (DD). Body-mass index (BMI).	Snapshot of the 2014 Kenya demographic and health survey.	Diet diversity using various indices. Individual body-mass index (BMI).	Diet diversity has a beneficial effect on both underweight and overweight or obese individuals. Doubling diet diversity was correlated to a 15% increase in body-mass index (BMI) for underweight women, and a 7.0% reduction in BMI for obese women.
Ojha et al. (2022)	Asia, India	Investigation approach. (Mixed)	A total of 445 respondents were interviewed in rural areas of Bageshwar district.	Community level.	Traditional agricultural practices, crops and foods. Food-medicine interface of traditional crops and plants.	2017 to 2019 summer, monsoon and winter seasons.	Dietary diversity indices (DDIs). Nutrient adequacy. Food consumption score or patterns. Traditional food and medicinal usage.	Highlights of the nutritional role of local crops and plants in treating ailments. Importance of traditional food systems for adequate nourishment.

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TABLE 1 (Continued)

Interventions in LMICs								
Author(s), year	Continent and country	Study design and method	Targeted population size	Study Level	Interventions deployed	Duration	Outcomes measured	Key study findings
Mehraban and Ickowitz (2021)	Asia, Indonesia	Longitudinal survey, for a 7-day distant past food consumption recall. (Quantitative)	3,214 rural farmers in the year 2000. 2,785 households in the balanced panel.	Community level. Household level.	Dietary diversity. Production diversity. Market access.	Three waves of: The Indonesian family and life survey (IFLS) during: 2000, 2007/8 and 2014/15.	Dietary diversity score. Crop production diversity. Accessible markets.	Between 2000 and 2015, production diversity and dietary diversity declined, while income increased in rural Indonesia. The panel-fixed effects regressions show statistically significant associations between own production and consumption of all food groups. Community market reliance showed strong correlation with the consumption of all food groups
Albert et al. (2020)	Oceania, Solomon Islands	Quantitative surveys, for anthropometric assessments. (Mixed)	Women aged 15 to 49 years in eligible households. Children under 5 years.	Community-based study	Dietary diversity of women and minimum dietary diversity for infants. Household food consumption scores	May–June 2016.	Comparative number of women who were overweight or obese. Stunting rate in children. Anthropometric measurements in children under 5 years. Dietary quality for women.	High consumption of table sugar and the need for policy considerations in the food sector. Nutrition-sensitive interventions and education should improve nutritional outcomes.
Bonuedi et al. (2022)	Africa, Sierra Leone	Cross-sectional study. (Quantitative)	13,256 households	Household level	None	12 months (January to December) 2011 and 2018, respectively.	Household dietary diversity index (HDDI), own food, and purchased HDDI.	Households closer to food markets had relatively better dietary diversity, during conditionally lean seasons. The post-harvest period had a relatively better HDDI.
Wang et al. (2021)	Asia, China	Cross-sectional study. (Quantitative)	499 small holder farmers	Individual level	None, this was an observational study	June to July, 2020	Individual dietary diversity score (IDDS). Nutritional status and nutrient adequacy ratios (NAR) on 14 micronutrients. Mean adequacy ratios (MAR) for the 14 micronutrients. Associations between DDS, NAR, MAR, and socio-demographic factors.	Mean dietary diversity score was relatively low. Grain consumption was excessive, in contrast to the consumption of vegetables, fruits, beans, eggs, meat, fish and dairy products. Higher DDS was associated with higher NAR for most nutrients. Low dietary diversity and poor intake of essential micronutrients negatively affected public health within the studied population.
Lourme-Ruiz et al. (2022)	Africa, Burkina Faso	Longitudinal Cohort study. (Mixed)	300 rural women	Individual level	None, this was an observational study	1 year (October 2017 to September 2018).	Dietary diversity score for women (WDDS-10) from the 24-h dietary recalls and their associations with farm characteristics. Food sources of production, purchase and foraging.	Dietary diversity scores and food sources were seasonally influenced at WDDS-10, and was relatively stable from August to January. Diet diversity required initiatives to diversify production, promote foraging and increase income for food purchasing.

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TABLE 2 Intermediate and long-term nutritional outcomes in LMICs.

Author(s) and year, (*n* = 22)	Reported intermediate outcomes	Reported long-term outcomes	EPHPP Global rating score	Overall effect direction on DBM	Implications on the DBM
Rousseau et al. (2023)	FIL, Child malnutrition indicators, DD	Chronic malnutrition, Food security resilience	Weak	◆	DBM-neutral
Waswa et al. (2021)	Increased DD, Nutrient intake variability	Sustained dietary improvements, Health outcomes	Weak	▲	Potentially DBM-harmful
Shiratori et al. (2023)	Food security, Nutrient intake	Nutritional deficiencies, Rising overweight rates	Weak	▲	DBM-harmful
Wondafrash et al. (2017)	DDS, Linear growth	Stunting, No association of child growth with ICFI	Weak	◆	DBM-neutral
Roba et al. (2019)	DDS for infant and households, Nutritional status	Increased food insecurity, Worsening nutritional status	Weak	▲	DBM-harmful
Esaryk et al. (2021)	DDS for children, Agricultural earnings	Sustainable agricultural practices, Reduction in malnutrition	Weak	▼	DBM-beneficial
Ayenew et al. (2018)	Farm diversification associated with increased DD	Chronic malnutrition regardless of season	Weak	▼	Potentially DBM-beneficial
Alam et al. (2023)	DD, Gender-specific benefits, Socio-economic factors	Sustained dietary improvements, Reduction in malnutrition risks	Weak	▼	DBM-beneficial
Guizzo-Dri et al. (2022)	DDS for children and households	Low and medium-DDS households and improved child growth	Weak	◆	DBM-neutral
Jordan et al. (2022)	WDDS, Urban versus RDP, Socio-demographic influences	Nutritional security, Impact on child nutrition	Weak	◆	DBM-neutral
Deaconu et al. (2021)	Nutrient adequacy, DM, PD, Local food consumption	Sustained health benefits	Weak	▼	DBM-beneficial
Bakhtsiyarava and Grace (2021)	Nutritional status, Policy implications	Health benefits, Behavior change, Food security	Moderate	▼	Potentially DBM-beneficial
Tesfaye (2022)	Nutritional improvement, Diet quality	Child growth, Resilience to shocks	Weak	▼	DBM-beneficial
Ghosh-Jerath et al. (2022)	DII, DD, Anthropometric status	Nutritional status of rural women	Weak	▼	Potentially DBM-beneficial
Madzorera et al. (2021)	DQI, Women's participation in economic activity	SDI, Child health and nutrition	Moderate	▼	DBM-beneficial
Korir et al. (2023)	Increase in BMI, Reduction in BMI	Lesser underweight and overweight risks and rates	Weak	◆	DBM-neutral
Ojha et al. (2022)	Nutrient adequacy, Food consumption patterns	Sustainable nutrition, Health outcomes	Moderate	▼	Potentially DBM-beneficial
Mehraban and Ickowitz (2021)	Decreased DD, Production diversity, Market access	Nutritional status, Socio-economic changes	Weak	▲	DBM-harmful
Albert et al. (2020)	DD, Nutritional status, HFCS	Health implications, Food system changes	Moderate	◆	DBM-neutral
Bonuedi et al. (2022)	HDDI, Market access	Nutritional improvements, Education, Interventions	Weak	◆	DBM-neutral
Wang et al. (2021)	DDS, NAR, MAR	Chronic health issues	Weak	▼	Potentially DBM-beneficial
Lourme-Ruiz et al. (2022)	DDS, Seasonal variations	Sustainability of DD, Economic implications	Weak	▲	Potentially DBM-harmful

▲ Overall increase. ▼ Overall decrease. ◆ DBM-neutral.

Acronyms for reported intermediate and long-term nutritional outcomes: DBM, double burden of malnutrition; FIL, food insecurity level; DD, dietary diversity; DDS, dietary diversity score; WDDS, women dietary diversity score; RDP, rural dietary pattern; DM, dietary moderation; DII, dietary iron intake; DQI, dietary quality improvement; SDI, sustained dietary improvement; PD, production diversity; NAR, nutrient adequacy ratio; MAR, mean adequacy ratio; HDDI, household dietary diversity index; HFCS, household food consumption score; BMI, body mass index; ICFI, individual child feeding index.

3.2 Participants

Participants in the reviewed articles included individuals, households, communities, smallholder farmers, children, and women from rural agrarian communities in low-and middle-income countries (LMICs), as defined by the United Nations and World Bank (Raman et al., 2023).

3.3 Categories of research articles, *n* = 22, based on their reported findings

3.3.1 DBM-beneficial

Articles that provide evidence supporting intervention practices leading to improved nutritional outcomes. Their reported findings demonstrate how increased crop diversity enhances dietary diversity, thereby reducing both under-and overnutrition in populations. Studies showing that diverse agricultural practices lead to better access to nutrient-rich foods fall into this category. For example, the article by Esaryk et al. (2021) was categorized as *DBM-beneficial* (diversity-based management beneficial) for several reasons: (a) Positive association with child diet diversity: The study reported a significant positive association between crop diversity per household and the dietary diversity of children in the Ethiopian context. This was more evident in low-income households facing a higher risk of dual malnutrition, further suggesting that increased crop diversity directly enhance dietary options for vulnerable children. (b) Mechanisms of impact: The article highlighted two major pathways through which crop diversity influences dietary diversity (the subsistence pathway, where households grow food crops for their own consumption) and (the market pathway, where increased agricultural production enables greater income for purchasing diverse foods). (c) Contextual relevance: The study presented contrasting findings, in which crop diversity positively influenced child diet diversity in Ethiopia, but not in Vietnam, due to differences in agricultural practices and market dynamics. This highlighted that practices have to be tailored. (d) The study further advocates for policies that support seasonal crop diversity to combat malnutrition.

3.3.2 Potentially DBM-beneficial

Research articles suggest that certain practices or interventions might have positive effects on nutrition, but lack definitive evidence. Articles belonging to this category may include studies indicating a correlation between crop diversity and improved nutrition, without establishing a clear causal link. For example, studies showing that communities with diverse crops have better health outcomes, but other influencing factors are uncontrolled.

3.3.3 Potentially DBM-harmful

Articles indicate that certain agricultural practices or food systems might negatively impact nutritional status, though evidence is not conclusive. This involve findings suggesting that while crop diversity is beneficial, specific practices associated with it, such as heavy reliance on cash crops may lead to decreased availability of nutrient-dense foods, and potentially exacerbate the dual burden of malnutrition. For example, Waswa et al. (2021) was categorized as *Potentially DBM-harmful*, for several reasons: The findings indicate that seasonality significantly affects dietary diversity scores (DDS) and nutrient intakes, which could be classified as potentially harmful to dietary behavior management (DBM) for several reasons; (a) Inadequate nutrient availability due to seasonal fluctuations in food availability, particularly during conditionally lean seasons. This is detrimental to women of reproductive age and young children, due to their developmental stages and growth needs. (b) Variability in dietary diversity scores, as the proportion of women consuming a diet with high DDS increased from 36.4% during the conditionally lean season to 52.4% during the harvest season. However, this variability indicates that during certain times of the year, dietary diversity is significantly constrained and compromised, which can lead to deficiencies in essential nutrients such as iron, calcium and vitamins. (c) The study suggests that socio-economic disparities exacerbate the effects of seasonality on nutrition. Thus, inconsistent access to diverse food undermines effective dietary behavior management.

3.3.4 DBM-neutral

Researched articles present findings that do not significantly influence nutritional outcomes concerning the double burden of malnutrition. The studies show no linear relationship between seasonal crop diversity and nutritional outcomes, indicating that other factors are more critical in determining the dual burden of malnutrition and level of risk within studied populations. Another example is a study by Jordan et al. (2022), which was classified as *DBM-neutral* for several reasons; the study focuses on dietary diversity and does not directly address the DBM. Specifically, there was no examination of the overlapping and coexistence of undernutrition and overnutrition within the studied populations, which characterizes the DBM in the Kapchorwa district of Uganda. This study was also limited in scope across the three agricultural seasons regarding nutritional outcomes.

3.4 Mechanisms through which seasonal crop diversity influence nutritional outcomes

The relationships depicted between seasonal crop diversity and nutritional outcomes are complex and involve several mechanisms (Tables 1, 2). Enhanced dietary diversity, when crop diversity increases, provides a wider range of nutrients. This ultimately addresses micronutrient deficiencies that are prevalent among vulnerable populations relying on staple crops alone during conditionally lean seasons (Bosha et al., 2019). Different crops contribute unique nutrients essential for human health and medicine, as reported by Ojha et al. (2022). The cultivation of a variety of crops ensures a balanced intake of vitamins and minerals required by vulnerable groups, particularly pregnant women and children (Bellows et al., 2020). This is important in communities with high rates of malnutrition. In addition, the resilience against food insecurity helps to mitigate seasonal food shortages and reduce the risk of hunger and malnutrition during conditionally lean seasons, when some food sources remain accessible (Albert et al., 2020). Moreover, economic stability arises from diverse cropping systems, which can foster reinvestment in community health initiatives and nutrition programs. The allocation of income resources toward healthcare and nutrition education further enhances the overall health outcomes in rural communities.

3.5 Significant insights

There was a diversity of study designs and methodologies employed among the reviewed studies (Table 1). The geographical representation of the studies spanned LMICs, depicting regional differences in crop diversity and nutritional outcomes at different scales (Figure 2; Tables 1, 2). Studies focused largely on vulnerable groups, particularly women and children in rural communities, emphasizing the need for targeted interventions focusing on these demographics (Albert et al., 2020; Korir et al., 2023). Identifiable research gaps included the lack of longitudinal data to track long-term sustained impacts of seasonal crop diversity on nutritional outcomes. Table 2 highlighted a positive correlation between seasonal crop diversity, dietary diversity, and nutritional outcomes. Studies have demonstrated that rural communities with a higher crop diversity have lower rates of both under-and over-nutrition (Wondafrash et al., 2017; Rousseau et al., 2023; Korir et al., 2023). The implementation of seasonal crop diversity by rural smallholder farmers faced barriers related to resource access and market constraints. The main nutritional outcomes highlighted in rural LMICs included reduction of anemia among women of reproductive age, improvement in micronutrient intake, low rates of stunting and wasting, low childbirth weight, instances of overnutrition even in children, and long-term health benefits (Table 2). Using the EPHPP tool to assess the impact of seasonal crop diversity on nutritional outcomes, specific domains of quality assessment, such as blinding, withdrawals and drop-outs, and intervention integrity were identified as key areas in underpowered studies that require attention in future research to strengthen the evidence base (Figure 3).

4 Methodology for quality assessment

A three-member expert inter-rater panel was employed, consisting of the lead author and two other anonymous senior local cohorts (as acknowledged in this manuscript). This panel reached consensus in the appraisal of $n = 22$ eligible articles for this systematic review, using the EPHPP (Effective Public Health Practice Project) tool, with reference to the tool's user manual, to assess risk of bias and achieve unanimous scoring across eight domains. Specifically, the quality assessment tool was applied across the eight domains of: study design, selection bias on participants, blinding, confounders, intervention integrity, data collection methods, withdrawals and drop-outs, and selective reporting. The global risk of bias rating was: (a) weak, if two or more of the domains were weak; (b) moderate, if only one of the domains was weak; and (c) strong, if none of the domains was weak (cf. Figure 3). Most of the reviewed studies were rated as weak ($n = 18$, 82%), moderate ($n = 4$, 18%) and none were rated as strong. Among the underpowered studies, issues included under-reporting of intervention integrity and blinding, followed by withdrawals and drop-outs. There was also one instance of selective reporting and another of selection bias on participants (Figure 3). Only two studies ($n = 2$, 9%) had initiatives addressing intervention integrity regarding seasonal crop diversity integration for improved nutritional outcomes. This contributed to the weak global ratings for most of the reviewed studies, as the majority were observational in nature (Doustmohammadian et al., 2022, p. 15). There were issues concerning the reliability and validity of data collection tools across most domains, in the majority of the reviewed studies during the quality assessments. A narrative synthesis was conducted on the same studies, and they were all categorized as DBM-beneficial, potentially

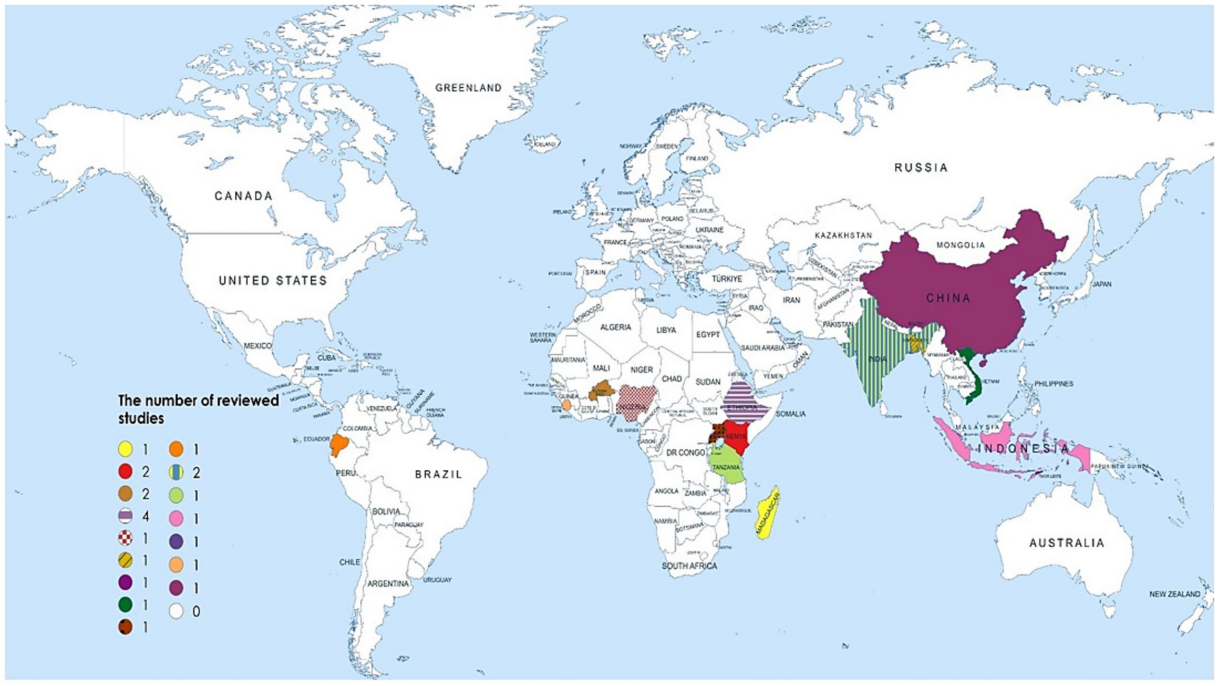

FIGURE 2
Distribution of reviewed studies across LMICs, regarding seasonal crop diversity influence on malnutrition dimensioning ($n = 22$).

DBM-beneficial, potentially DBM-harmful, or DBM-neutral (cf. Table 2).

5 Discussion

As global efforts to combat malnutrition intensify, promoting seasonal crop diversity could serve as an effective strategy for improving nutritional outcomes in vulnerable populations (Connors et al., 2021). This systematic review addresses critical questions regarding the influence of seasonal crop diversity on the DBM in rural communities of LMICs. The study's findings indicate a complex relationship between crop diversity and dietary outcomes, suggesting DBM-beneficial and potentially DBM-beneficial, DBM-neutral and potentially DBM-harmful effects on nutritional status (Table 2). This review also sought to investigate pathways through which seasonal crop diversity influences dietary outcomes related to the DBM in vulnerable rural communities. The systematic review analyzed $n = 22$ peer-reviewed studies, revealing a correlation between increased seasonal crop diversity and improved dietary practices (Tables 1, 2). Specifically, studies indicated that households with greater crop diversity reported higher dietary diversity scores, which are crucial for nutritional adequacy. For instance, dietary diversity scores increased during the post-harvest and conditionally lean seasons (Bonuedi et al., 2022). Earlier studies conducted by Lourme-Ruiz et al. (2022) and Jordan et al. (2022), highlighted that women's dietary diversity scores increased during the post-harvest season, suggesting a direct relationship between crop availability and nutritional outcomes. The review also noted that greater crop diversity was associated with better health outcomes, emphasizing its role in mitigating the DBM (Tables 1, 2). A study conducted by Korir et al. (2023) quantified the benefits of diverse cropping systems, showing that households practicing seasonal crop diversity had access to a wider range of food sources, which helped to alleviate food shortages during their lean seasons. Findings suggest that increased income opportunities from diverse crops allowed households to invest in nutrition, further enhancing dietary diversity.

Reviewed studies exhibited limitations regarding ecological determinants. Studies exhibited a significant lack of exploration of ecological determinants affecting nutrition-related behaviors and outcomes in vulnerable populations (Alam et al., 2023). This gap limited the understanding of how environmental factors influence the effectiveness of seasonal crop diversity in combating malnutrition. The reviewed articles often failed to propose integrated strategies that effectively utilize seasonal crop diversity as a tool against malnutrition. The need for comprehensive approaches that combine agricultural practices with nutrition interventions remains largely unaddressed. The reviewed studies primarily focused on certain demographics, particularly pregnant women and children across rural LMICs (Madzorera et al., 2021; Guizzo-Dri et al., 2022). The range of socio-economic groups studied can be expanded to include disabled and sick individuals to understand the full impact of seasonal crop diversity on malnutrition across different vulnerable populations. While many studies have assessed immediate dietary changes due to seasonal crop diversity, there are insufficient data on the long-term nutritional outcomes and health impacts associated with sustained crop diversification practices over time. Studies did not adequately explore the intricacies related to market access and resource availability that hinder potential benefits from seasonal crop diversity. Understanding these barriers is crucial in developing effective interventions that can enhance food security and nutrition.

The reviewed studies reveal conflicting evidence regarding the relationships between seasonal crop diversity and dietary outcomes, influenced by local dietary habits and economic conditions (Wang et al., 2021; Bonuedi et al., 2022). While Kinyoki et al. (2021) found a positive correlation between increased crop diversity and improved dietary diversity, other studies indicated that seasonal crop diversity could lead to higher malnutrition rates, especially among children during seasonally lean periods (Roba et al., 2019; Waswa et al., 2021; Shiratori et al., 2023). Despite these mixed findings, a consensus emerged on the importance of promoting seasonal crop diversity to enhance food security and nutritional outcomes for vulnerable populations. This was demonstrated by reports of improved dietary practices and anthropometric measurements among women and children (Deaconu et al., 2021; Esaryk et al., 2021; Madzorera et al., 2021). Therefore, policymakers are urged to integrate agricultural policies with nutrition initiatives to effectively address food security and health outcomes in rural LMICs.

Previous literature has often focused on short-and intermediate-term dietary benefits from increased crop diversity (Bellows et al., 2020; Bai et al., 2024), whereas this review emphasized both intermediate and long-term dietary outcomes. The emphasis on the seasonal timing of food availability and access in relation to seasonal crop diversity is a unique aspect of this systematic review. It highlights how different seasons can significantly affect dietary practices, which has been less emphasized in many earlier studies in literature (Tables 1, 2). The variability in findings may stem from differences in study designs or specific local contexts affecting food access (Table 2). This complexity suggests that simply increasing crop diversity may not be sufficient to combat malnutrition, without addressing other underlying factors such as food access and socio-economic conditions. Therefore, the effectiveness of seasonal crop diversity appears to be moderated by external factors of resource access and market constraints (Figure 4).

5.1 Challenges that influence nutritional outcomes

In this review, several challenges appear to influence nutritional outcomes, as reflected in Table 2. These challenges are critical because they can hinder the effectiveness of interventions aimed at improving nutrition through the integration of seasonal crop diversity. Firstly, limited access to diverse crops due to resource constraints may result in lower dietary diversity scores among vulnerable populations (Anilkumar et al., 2017). Secondly, market access issues could lead to reduced consumption of available nutritious foods, thus failing to improve the overall nutritional status for rural households (Abay and Hirvonen, 2017). Thirdly, cultural preferences might prevent the adoption of beneficial dietary practices that could arise from increased crop diversity (Bai et al., 2024). Reviewed studies also suggest that despite potential benefits of increased crop diversity, challenges of poor infrastructure and limited access to seasonal agricultural inputs hinder these benefits. Addressing these challenges is essential for enhancing the positive impact of seasonal crop diversity on nutrition in rural LMICs. Therefore, integrated strategies that consider these barriers will be crucial for the effective combatting of malnutrition, as

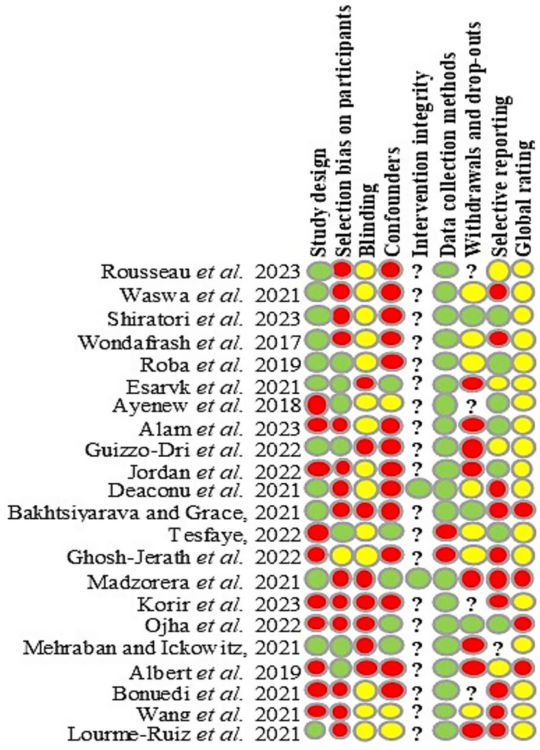

FIGURE 3
Assessment of quality using the EPHPP of included studies (n = 22). W, week; M, moderate; S, strong.

highlighted in the findings of this systematic review (Figure 5; Tables 1, 2).

5.2 Observed nutritional outcomes

Intermediate and long-term nutritional outcomes (Table 2) reveals both consistencies, inconsistences and discrepancies regarding their linkage with seasonal crop diversity across rural LMICs (Table 1). This suggests that the dual burden of malnutrition, both under and overnutrition is crucial in rural settings, although the latter is often overlooked in many underpowered studies. Notably, earlier studies, including those by Jones (2017) and Sié et al. (2018), have similarly reported that increased seasonal crop diversity is linked to improved dietary diversity scores among vulnerable rural populations. This aligns with some of the findings in this systematic review (Table 2), which indicate that diverse cropping systems contribute positively to nutrient intake, for better nutritional outcomes. The emphasis on pregnant women and children in assessing nutritional outcomes has been highlighted across many studies (Bosha et al., 2019; Bellows et al., 2020; Hasan et al., 2022; Jordan et al., 2022). The focus on women and children in assessing nutritional outcomes aligns with global health priorities, as these groups are often most affected by malnutrition (Hayes et al., 2023). For instance, studies reported by Bellows et al. (2020) also highlight that interventions targeting these groups often yield significant improvements in dietary practices and nutritional status, as shown in Table 1 and reflected in Table 2. This systematic review supports the notion that seasonal crop diversity can enhance food security, a conclusion echoed by Fremmpong et al. (2023). While seasonal crop diversity can enhance food security and build resilience against climate shocks, there are notable discrepancies in how these benefits manifest at individual versus community levels (Tables 1, 2). Therefore, improved seasonal crop diversity is a crucial component for addressing malnutrition during conditionally lean seasons.

5.3 Existing research gaps

This systematic review addresses several critical research gaps regarding the influence of seasonal crop diversity on the double burden of malnutrition in rural communities of LMICs: (a) The ecological determinants of nutrition: Previous studies have insufficiently explored the ecological factors affecting nutrition-related behaviors and outcomes in vulnerable populations (Esaryk et al., 2021). This review emphasizes the need for a deeper understanding of how seasonal crop diversity can serve as a tool for ecological determinants with a profound influence on dietary practices. (b) Integrated strategies for malnutrition: Despite the recognized potential benefits of seasonal crop diversity, there is a lack of studies on integrated strategies that effectively leverage this diversity to combat malnutrition (Tables 1, 2). This review highlights the necessity for policies and interventions that incorporate agricultural diversity into nutritional programs. (c) Impact of seasonality on nutritional outcomes: The reviewed studies often overlook how seasonal variations in crop production affect dietary diversity and nutritional outcomes in the mid-to long term. This review seeks to fill this gap by analyzing intermediate and long-term effects of seasonal crop diversity on dietary practices in rural communities of LMICs. (d) Resource access and market constraints: Challenges faced in resource access and market constraints have been inadequately addressed in past research (Bonuedi et al., 2022). The review identifies these barriers and suggests that understanding them is crucial for developing effective interventions. (e) Vulnerable populations: There is an apparent need for more focused research on specific vulnerable groups within rural communities, such as women and children, who are disproportionately affected by malnutrition. This review aims to illuminate these disparities and inform targeted interventions. (f) Policy implications: This review underscores the lack of comprehensive policy frameworks that integrate agricultural practices with health and nutrition objectives, particularly in rural LMICs. The review calls for research that informs policy decisions to enhance food security and nutritional outcomes via seasonal crop diversity, with focus on intermediate and long-term benefits.

5.4 Crop species for the management of dual malnutrition in rural LMICs

To enhance the diversity of rural agricultural systems while improving nutritional outcomes, several crops can be strategically integrated. Studies suggest that smallholder farmers should cultivate drought-resistant, tolerant, and nutrient-dense crops, with medicinal properties for the prevention and treatment of

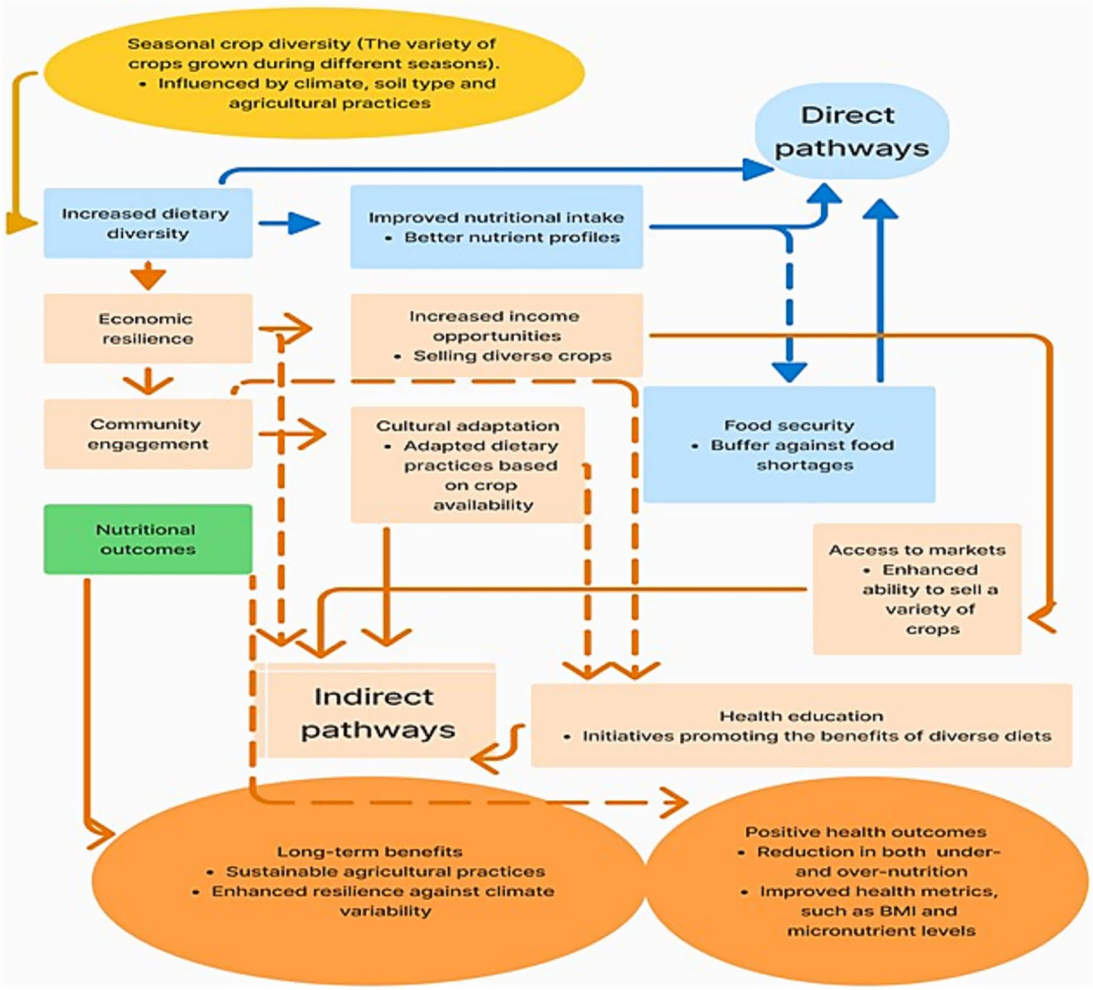

FIGURE 4
Pathways through which seasonal crop diversity influences nutritional outcomes.

ailments (Ojha et al., 2022). These crops should also be climate-smart (Durga et al., 2017). This indicates the need for cultivating small grains such as finger millet, sorghum, aerobic rice, and watermelons at household level. Legumes such as lentils, chickpeas, round nuts, groundnuts, hazelnuts, cowpeas, and beans are excellent candidates due to their ability to sustainably enrich the soil with nitrogen and their high protein content (Bai et al., 2024). These should constitute 40% of the diet for people living with diabetes and hypertension. Root vegetables, including sweet potatoes and yams, provide essential vitamins and minerals while exhibiting resilience to adverse weather conditions. Moreover, leafy greens such as pumpkins, spinach, and amaranth are vital for their micronutrient density, especially iron and calcium. Along with rapeseed and carrots, these crops can be cultivated in consolidated community nutritional gardens to minimize nutritional risk in children under the age of five (Desyibelew et al., 2020; Belayneh et al., 2021). Incorporating fruits such as bananas and guavas can also provide essential vitamins and diversify rural diets (Wang et al., 2021). The promotion and cultivation of these crops within localized agricultural systems, can help rural communities achieve greater dietary diversity, improve food security and household income, and effectively combat the double burden of malnutrition (DBM).

5.5 Findings of the study

The findings from this systematic review suggests a positive association between increased seasonal crop diversity, improved dietary diversity and nutritional outcomes in combating the DBM in rural communities of low-and middle-income countries (LMICs). In addition, the systematic review of $n = 22$ articles reveals several impactful findings: (a) Improvements in dietary practices and food security: The analysis demonstrates a correlation between increased crop diversity and improved dietary practices, as well as enhanced food security among vulnerable populations. This aligns with the study's intention to explore how variations in crop diversity affect dietary diversity and nutritional outcomes. (b) Resource access and market constraints: Limited access to resources and market constraints hinder the full realization of the potential benefits of seasonal crop diversity. This highlights the complexity of implementing crop diversification strategies and the need for supportive interventions. (c)

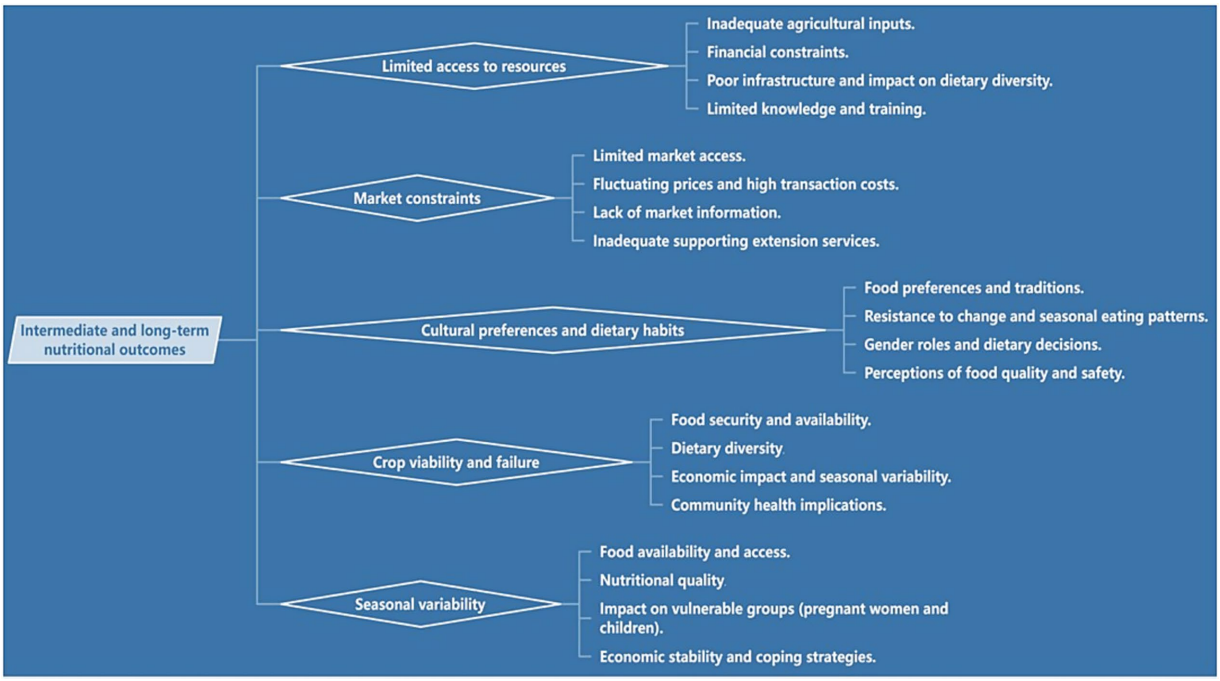

FIGURE 5
Reviewed challenges that influence nutritional outcomes.

Micronutrient deficiencies: The review emphasizes that a lack of crop variety, particularly during conditionally lean seasons, is linked to micronutrient deficiencies in women of reproductive age and children. The majority of the studies reported that greater crop diversity is linked to enhanced food security and better nutritional intake, particularly during periods of seasonal scarcity. Seasonal crop diversity can address food shortages and diverse nutritional requirements. (d) Economic resilience: The study underscores the benefits of crop diversification, which enable farmers to buffer against market fluctuations and climate-linked shocks. (e) Overnutrition; Seasonal crop diversity also plays a crucial role in addressing issues related to under-and over-nutrition by enhancing dietary variety and nutrient availability throughout the year.

While the review identified a general trend supporting the beneficial role of seasonal crop diversity, the overall certainty of the evidence is limited by several factors related to the quality of the studies included in this review in underpowered studies ($n = 18$, weak), ($n = 4$, moderate) and ($n = 0$, strong). This heterogeneity in reviewed study quality was also considered in the synthesis of outcomes to suppress vote counting (Table 2). Indeed, the review adhered to the PRISMA 2020 guidelines and focused on peer-reviewed articles, in high-ranked sources, but the absence of consistence in high-quality standards among the articles reviewed, means that the strength of the conclusions is somewhat constrained, perhaps due to the rigor of the EPHPP appraisal tool, applied across eight domains of study design, selection bias on participants, blinding, confounders, intervention integrity, data collection methods, withdrawals and drop-outs, and selective reporting (Figure 3). Notably, synthesized findings of this systematic review indicate the following: (a) A positive link between crop diversity and nutrition, but findings should be interpreted with caution, including emphasized geographical confinement to LMICs. As such, the evidence-based reviewed does not allow a definitive conclusion. Therefore, policymakers and practitioners should be aware of these limitations, and consider current findings as indicative rather than conclusive, pending further high-quality research. (b) The quality and consistence of included studies were also variable, thus limiting the uncertainty of conclusions. There is noticeable heterogeneity in study designs, outcome measures, and reporting standards across reviewed articles. Many studies reviewed did not provide comprehensive details on their methodologies, or did not match the standardized tool for assessing nutritional outcomes. Moreover, the lack of uniform quality appraisal criteria across reviewed articles, indicate further uncertainty regarding the robustness of the evidence base. (c) While insights are tailored to guide policy decisions focused on the enhancement of nutrition, there is a need for a more rigorous, standardized research to clarify the relationship and inform policy. This is questionable in the majority of the reviewed articles.

Future research should prioritize rigorous study designs, standardized outcome measures, and transparent reporting to strengthen the evidence base. Thus, future research should focus on addressing identified gaps, especially on ecological determinants, vulnerable rural populations especially women and children, and the development of comprehensive policies that align agriculture with health outcomes. Ultimately, seasonal crop diversity can serve as a "double-duty action," enhancing both dietary quality and economic resilience during conditionally lean seasons, while accounting for the impact of seasonality. A priority on these strategies, is an important step toward the attainment of sustainable development goals related to the eradication of hunger, nutrition, and good health, thereby improving the well-being of millions affected and populations at high risk of both under-and overnutrition, globally.

5.6 Relationships with existing theories and frameworks

The findings of this systematic review contribute significantly to the socio-ecological model of health, which emphasizes the interplay between individual, social, and environmental factors affecting dietary behaviors. The review evidence suggests that increased seasonal crop diversity, not only enhances dietary diversity but also addresses food security, thus aligning with the food systems framework that advocates for integrated approaches to nutrition and agriculture. The review findings resonates with the sustainable livelihoods framework, indicating that diverse cropping systems can boost economic resilience among rural households by providing varied sources of income. The one health approach, which recognizes the interconnectedness between human and environmental health, is also supported (Durga et al., 2017).

5.7 Potential challenges in implementing the study findings

Resource constraints remain, as many rural communities in LMICs operate under financial limitations. This curtails investment in diverse cropping systems. Barriers to market access, such as poor infrastructure, lack of transport, and outdated market information can hinder the profits of smallholder farmers from crop diversity (Abay and Hirvonen, 2017). Deficiencies in policy support may not be sufficient to adequately support the integration of seasonal crop diversity in farming practices. Unpredictable weather patterns are a hurdle as part of climate variability, which may affect crop yields, making it challenging for farmers to sustainably rely on diversified cropping systems (Barati et al., 2022). Interconnected challenges and the intertwined nature of food security, health, and economic stability mean that readdresses in one area will require improvements in others. Therefore, several research questions emerge for the future: (a) How can seasonal crop diversity be optimized to enhance nutritional outcomes in vulnerable populations at risk? (b) What are the long-term impacts of seasonal crop diversity on health outcomes across generations in rural communities? (c) How can policy frameworks be designed to support sustainable practices for seasonal crop diversity to enhance dietary diversity?

5.8 Actionable policy strategies in LMICs

Given the potential benefit of seasonal crop diversity to vulnerable populations under rain-fed agriculture, implementing subsidies and incentives to smallholder farmers who diversify their crops, will enhance food security and nutritional outcomes (Walls et al., 2023). Investment in the training of smallholder farmers and extension personnel, emphasizing sustainable agricultural practices such as intercropping and crop rotation, which promote crop diversity, will be crucial in the mitigation of malnutrition during conditionally lean seasons. Developing initiatives that enhance market access for diverse crops, such as collective marketing, will ensure farmers have products to sell year-round, thus increasing household income and food sources (Abay and Hirvonen, 2017). Collaborations between government agencies, development partners, and grassroots communities in key decision-making processes on pro-poor policies can leverage seasonal crop diversity for improved nutritional outcomes. Cross-sector partnerships between agricultural and health practitioners can align efforts in combating the double burden of malnutrition (DBM) through tailored, diversified farming practices. Support for storage and preservation techniques by promoting proper storage practices can help to maintain the nutritional quality of harvested crops, allowing communities to access diverse foods throughout the year, even during off-seasons. Robust monitoring and evaluation frameworks will be useful in assessing the effectiveness of implemented policies. Periodic data collection on dietary diversity and nutritional outcomes will motivate communities to participate in policy feedback loops (Dulal et al., 2017). This will help to shed light as to why and how certain policies should be amended to create an enabling environment.

6 Strengths and limitations of the study

This systematic review included $n = 22$ peer-reviewed studies on the influence of seasonal crop diversity on malnutrition, utilizing a wide array of reputable and open-access electronic databases, including Scopus, PubMed, Google Scholar, and FAO's two sub-websites—HINARI and AGORA for diverse evidence base. The studies underwent rigorous quality assessments across eight domains, evaluated by a team of three independent participants to ensure reliability. The review focused on peer-reviewed articles from high-ranking journals (Q1 and Q2) as ranked by Scimago to ensure a high standard of methodological rigor, credibility, and scientific impact for articles published within the preceding 8 years, capturing a diverse range of methodologies including qualitative, quantitative, and mixed methods. This diversity enriched the review's findings regarding how seasonal crop diversity impacts the DBM. Adhering to the PRISMA 2020 guidelines enhanced the transparency, replicability, and rigor of the review process. The review covered both intermediate and long-term nutritional outcomes, providing a comprehensive assessment of the impact of seasonal crop diversity in rural communities.

The review faced limitations related to the choice of search terms used, which could affect the breadth of literature included. The reliance on open-access articles, exclusion of non-English and non-peer-reviewed articles may have omitted valuable insights, introducing researcher and language biases. The geographic focus on LMICs means that findings may be less applicable to countries in high income settings. The heterogeneity of study designs and outcome measures across covered studies ($n = 22$) could limit the comparability and synthesis of study results. The eight-year window for this review may exclude older studies that could provide longitudinal insights. While qualitative assessments were integral to understand the findings, the lack of quantitative data on dietary diversity scores limited the ability to measure impacts rigorously. Another additional limitation of this systematic review is the exclusive inclusion of peer-reviewed articles from Q1 and Q2 journals. This may have introduced publication bias, because studies published in lower-ranked journals, other informative organizational websites and gray literature, which may report null, negative, or positive findings, were not considered. Gray literature such as government sources, paywalled studies that were subscription-based, and theses which were hard to access and

appraise systematically, was out of the scope of this study. This potentially, overestimate the effect sizes observed. The absence of triangulation, exhibited methodological weaknesses in reviewed studies raised concerns about establishing causal relationships between seasonal crop diversity and nutritional outcomes, highlighting the need for robust longitudinal designs in future research.

7 Suggestions for future research

Future research on the DBM should prioritize longitudinal studies to understand and track the relationships between seasonal crop diversity and dietary changes, especially during conditionally lean seasons. If data are available, reporting changes in dietary diversity scores over multiple seasons can illustrate trends and provide evidence for the impact of seasonal crop diversity on nutritional outcomes over time. The mixed results regarding nutritional outcomes highlight the necessity for deeper investigations into how seasonal crop diversity influence nutritional outcomes over time. Researchers should aim to standardize methodologies and examine contextual factors that affect dietary behaviors and nutritional outcomes, which will help to inform more effective agricultural inventions. Exploring socio-economic barriers to accessing diverse crops can provide insights into improvements in nutrition in rural communities. Understanding local cultural practices that shape dietary choices is also critical for promoting nutritional improvements through seasonal crop diversity strategies.

Integrating agricultural practices with nutrition-focused interventions is essential for maximizing health benefits. Research should evaluate the effectiveness of combined strategies, such as nutrition education alongside seasonal crop diversity, to inform policymakers. Investigating specific nutritional interventions that complement seasonal crop diversity can enhance understanding of their health impacts. Given the challenges posed by climate variability, future studies should explore how seasonal crop diversity can build resilience against climate shocks, thereby informing strategies to mitigate climate change's adverse effects on food security and nutrition. Community-based approaches that engage local populations in participatory research will yield practical insights into effective interventions and guide policymakers in refining strategies to combat malnutrition among vulnerable populations in rural LMICs.

8 Conclusion

This systematic review comprehensively examines the influence of seasonal crop diversity on the DBM in rural communities within LMICs, revealing a complex interplay of factors affecting nutritional outcomes. The evidence suggests that promoting seasonal crop diversity can significantly enhance dietary diversity, food security and economic resilience, thereby mitigating both under-and overnutrition. However, the effectiveness of these strategies is contingent upon addressing critical challenges such as resource access, market constraints, and climate-related shocks. The review successfully identified key research gaps, emphasizing the need for further investigation into the specific pathways through which seasonal crop diversity impacts malnutrition, intermediate and long-term dietary outcomes of interventions. This include the discrepancies in current evidence across diverse contexts. Integrated, context-specific approaches are essential for leveraging seasonal crop diversity as a sustainable solution to combat malnutrition. These strategies should consider the interconnectedness of agriculture, health, and nutrition, and prioritize community engagement and cultural adaptations. By addressing these gaps and implementing evidence-based policies, stakeholders can effectively harness the potential of seasonal crop diversity to improve the nutritional outcomes and overall well-being of vulnerable populations in LMICs. This will contribute to the achievement of sustainable development goals related to hunger eradication, nutrition, and good health.

Author contributions

VM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Funding acquisition. TS: Resources, Supervision, Validation, Writing – review & editing, Project administration. MK: Resources, Supervision, Validation, Writing – review & editing, Project administration. SM: Resources, Supervision, Validation, Writing – review & editing, Project administration.

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Conflict of interest

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

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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