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Can agroecology improve food security and nutrition? A review

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ABSTRACT

Agroecology increasingly has gained scientific and policy recognition as having potential to address environmental and social issues within food production, but concerns have been raised about its implications for food security and nutrition, particularly in low-income countries. This review paper examines recent evidence (1998–2019) for whether agroecological practices can improve human food security and nutrition. A total of 11,771 articles were screened by abstract and title, 275 articles included for full review, with 56 articles (55 cases) selected. A majority of studies (78%) found evidence of positive outcomes in the use of agroecological practices on food security and nutrition of households in low and middle-income countries. Agroecological practices included crop diversification, intercropping, agroforestry, integrating crop and livestock, and soil management measures. More complex agroecological systems, that included multiple components (e.g., crop diversification, mixed crop-livestock systems and farmer-to-farmer networks) were more likely to have positive food security and nutrition outcomes.

1. Introduction

Agroecology is a holistic approach that incorporates ecological, health, social, and economic considerations into agricultural and food systems design and implementation. Agroecology can be applied at the field, farm and whole food system scale (Wezel et al., 2009; Wezel and Soldat 2009). As a scientific and policy approach to transform the food system, agroecology has gained greater recognition, including as one of four flagship eco-schemes of the European Common Agricultural Policy (European Union, 2020), as a means to address environmental and social issues within food systems by the United Nations (HLPE, 2019) and the Intergovernmental Panel on Climate Change (Mbow et al., 2019). Social movements such as the international peasant organization La Vía Campesina advocate agroecology as a means to ensure food sovereignty (Pimbert 2018). Agroforestry, organic agriculture and permaculture can all fall under the category of farm-scale agroecological approaches (HLPE 2019). Some critics have raised concerns, however, about the implications of using agroecology to improve food security and nutrition (FSN). This review examines the evidence for whether agroecological practices can improve FSN. Previous reviews examined evidence for diversified farming systems and organic agriculture's impacts on yield and other ecosystem service outcomes (Ponisio et al., 2015; Reganold and Wachter 2016; Müller et al., 2017) as well as whether diversified systems influence FSN (Jones 2017; Pellegrini and Tasciotti 2014; Powell et al., 2015; Sibhatu and Qaim 2018). No review so far uses the holistic concept of agroecology and the evidence of agroecological practices' impact on FSN. This review contributes to this knowledge gap.

1.1. *Agroecological practices*

Agroecological practices aim to optimize ecological processes, environmental and public health and well-being, and minimize social-ecological costs from agriculture such as soil degradation, water contamination, greenhouse gas emissions, exhaustion of nonrenewable resources, and inequitable social structures (HLPE 2019; Wezel 2017; Wezel et al., 2014; Dumont et al., 2013). Relying on principles rather than standardized practices, agroecological farming systems vary based on agroecosystem and socio-cultural context. A non-exhaustive list of the agroecological principles includes co-creation of knowledge, economic diversification, soil and animal health, input reduction,

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biodiversity, recycling, fairness and connectivity (Wezel et al., 2020). In agroecological food and farming systems, these principles translate into certain agricultural practices, marketing approaches, and food system governance.

Since agroecology encompasses a range of principles that vary in both scale and timeframe, transitions to agroecology have been depicted as a series of levels, from adoption of farming practices and cropping systems to more complex and comprehensive food system redesign (Gliessman 2014). Field-level changes based on principles of soil management and animal health can move incrementally towards an agroecological approach by enhancing efficiency of non-renewable inputs and through substitution, such as replacing synthetic fertilizers with organic soil amendments (Hill and MacRae 1995). Agroecological transitions involve more substantial farm-scale re-design centered around principles of diversity, nutrient recycling and animal health (HLPE 2019). Farm- and community-level changes are supported when social values are incorporated into food system design; for example, when culturally important foods are reintroduced or gender equity improves at the household level. Food-system transformation may occur when principles of fairness and participation are implemented through reconnecting producers and consumers and supporting food justice. Notably, this process is nonlinear and systems do not necessarily transition in sequential steps.

Most literature related to agroecology assumes farm-level pathways will lead to improved FSN, primarily for smallholder farm households. Recent estimates suggest that smallholder farms (often defined as < 2 ha) make up 80% of all farms globally (Samberg et al., 2016). Globally, small and medium farms provide significant proportions of diverse food groups (e.g., vegetables, fruits, pulses), thereby contributing to human nutrition (Herrero et al., 2017). At the same time, smallholder farming households make up a significant proportion of the world's chronically food insecure population (HLPE, 2013). Direct consumption, agricultural income, and changes in gender relations are recognized as the primary household-level pathways most immediately responsible for FSN improvements (Carletto et al., 2013; Herforth and Harris 2014).

Complex adoption of agroecology can potentially lead to FSN improvements by changing outputs (what is produced) and generating mechanisms (processes and actions) that influence FSN pathways, when adhering to principles that increase agroecosystem health and resilience and transform food system governance to be based on cultural and social values, (Carletto et al., 2013; Herforth and Harris 2014). There is considerable variation in the extent to which food and farming systems implement agroecological principles, with the ecological, socio-economic, and political context in which a farm operates shaping whether more incremental or transformative approaches to agroecology are practiced.

Fig. 1 depicts how diverse forms of agroecology could present different possibilities for FSN impact, generating a variety of outcomes and mechanisms. Depending on the scale at which agroecological principles are applied (denoted in Fig. 1 by the inner and outer rings), certain mechanisms and outputs (the spokes of the rings) will be more relevant. While agroecological principles and related mechanisms applied at the household scale can reinforce those at the community-level, the extent of the FSN impact may depend on the extent of adoption. For example, farm-level agroecological practices could provide in- and around-field habitat for wild flora and fauna, linking household-level agroecological adoption to landscape-level biodiversity; however, the impact on biodiversity and the ecosystem services this diversity provides, such as pollination, will be minimal if surrounding households practice conventional monocropping (Ramos et al., 2018).

Principles applied at the community/landscape level will generally strengthen and reinforce household-level ones. In a community with established farmers' networks, for example, individual households could benefit from exchanging knowledge about food preparation and preservation (Bezner Kerr et al., 2019a), effective pest management strategies, or techniques to improve soil quality. Principles more relevant to agroecosystem health and resilience can work synergistically with those pertaining to values-based food system governance, and vice versa. Increasing productivity at a household-level through improved soil, crop, and animal health may bolster food sharing networks, with social-practices of reciprocity redistributing resources within the community. Some principles, if applied at the community or farm-level, can themselves act as mechanisms of food security improvement: equitable land and resource governance, and input reduction directly influence FSN pathways.

This review summarizes available evidence on how agroecological approaches, characterized by considerable variation in the scale and extent to which principles are applied, influence FSN. The objectives of the study are to: 1) summarize all research between 1998 and 2019 that demonstrates a relationship between agroecology and FSN; 2) qualitatively describe the strength of the evidence (+, +/− and -), and 3) identify research gaps. The review considered direct (improved quality, quantity and distribution of agricultural products) and indirect effects of agroecological practices including, for example, how more equitable social relations may influence child feeding practices, labor distribution within households, and seed sharing networks. Other indirect effects are environmental improvements such as soil organic matter content or water quality. These capacities may either be direct (household consumption) or indirect (greater market access) — each impacting variety and quantity of food.

2. Methods

2.1. Inclusion criteria and search methodology

In this review we examined the evidence for whether agroecological practices have positive outcomes on FSN. Agroecological practices were drawn from a compiled set of practices (Table 1), including field-level practices such as crop diversification, intercropping or polycultures, agroforestry; farm-level practices such as integration of livestock and crops, riparian buffers; and community or regional practices such as farmer-to-farmer networks and increasing local markets that connect consumers to producers (HLPE, 2019; Wezel 2017; Wezel et al., 2014). The FSN indicators included came from a range of published papers (see

Food security and nutrition (text box).

The United Nations has defined global food security as a scenario in which "all people have physical and economic access to sufficient, safe and nutritious food that meets their food preferences and dietary needs for an active and healthy life" (FAO 1996). Nutrition is an integral, multi-dimensional aspect of food security that includes adequate diet, health services, sanitation, proper childcare and feeding practices (HLPE 2017). FSN are broad concepts that can be applied at the global, national, regional, household and individual level. National or global indicators such as per capita dietary food energy supply derived from aggregated data, however, often fail to capture the determinants of food insecurity below the national level (Jones et al., 2013). National and global indicators do not effectively capture the food security dimensions of utilization (Leroy et al., 2015) or power dynamics that affect control over food at the community, household and individual levels (Rocha 2009). As such, a global or national level of analysis would not be fine-grained enough to assess the impact of specific approaches such as agroecology on FSN. In this study we focus on evidence of improved FSN at a regional, household and individual scale.

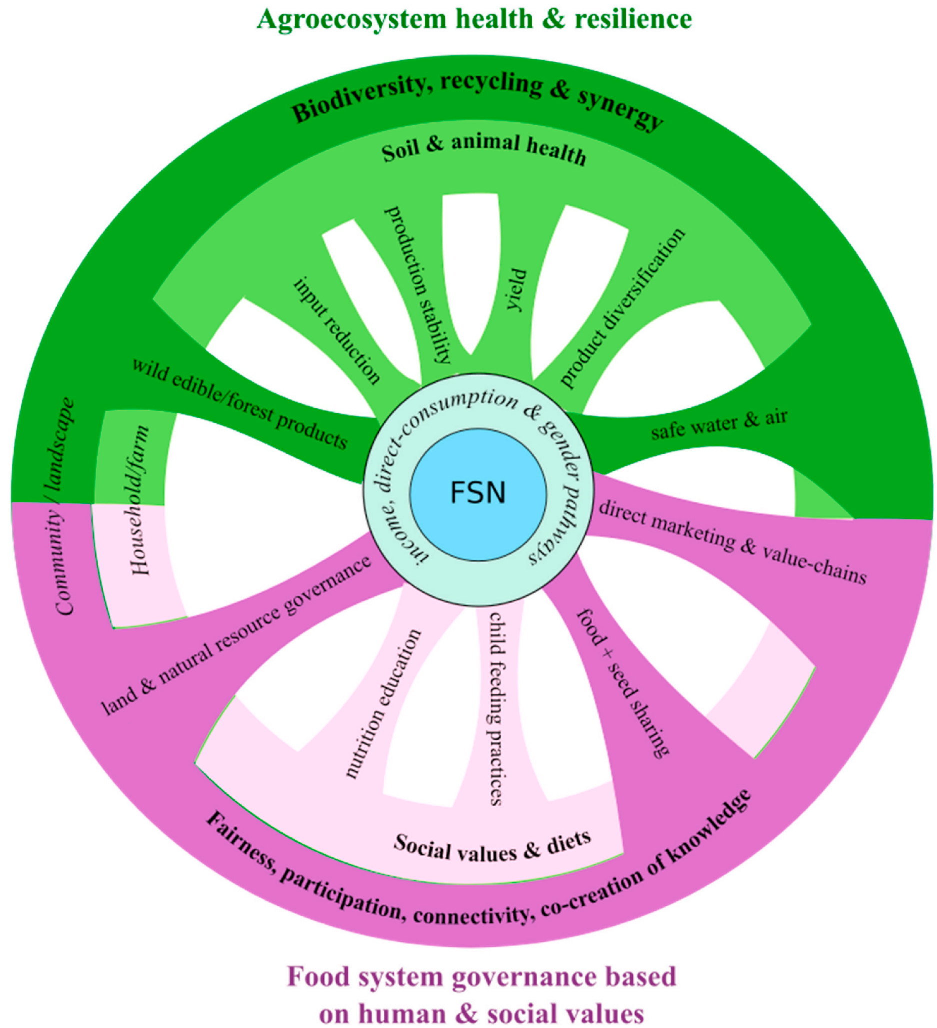

Fig. 1. Conceptual framework – how agroecology can lead to improved FSN. Agroecological principles applied at different scales (inner and outer rings) may influence food security and nutrition pathways through multiple mechanisms and outputs (spokes of the rings).

Table 1 below).

This paper is classified as a rapid review (Tricco et al., 2015), a tool used by policy-makers for evidence-based decision-making (Dobbins 2017). The review was initially used to inform the United Nations Committee for World Food Security High Level Panel of Experts (HLPE 2019) report. We used the four-phase PRISMA-RR protocol (Stevens 2018) for identifying records, de-duplicating and screening abstracts, assessing full-text, and final quality evaluations (Fig. 2). We developed a search protocol with inclusion criteria and search terms for use in literature databases (Tables 2 and 3).

Search terms were developed through abstract review of relevant papers, assessment of relevant systematic reviews (e.g., Santoso et al., 2019) and testing in databases. Using these search terms, articles were identified in six bibliographic databases (Table 2). Wildcards, such as an asterisk (*) used at the end of the root word (i.e., truncation), were used to retrieve variations of the listed search terms (Table 2). Two searches of these databases, using identical search terms and protocol, were conducted: first in October 2018 and then as an update in June 2019. Together, these searches retrieved articles published between 1998 and 2019. Topical websites were also searched by hand in 2019 to identify pertinent literature. Additional articles were included based on the expert consultation by the author team, searching individual relevant journals that did not appear in searched databases, and hand-screening references of selected articles (Table 2). Expert consultation has been used in other systematic reviews (e.g., Harris-Fry et al., 2020) and is recommended in topical areas where there is a limited number of research groups (Lefebvre et al., 2021), as is the case in this study.

All of the identified articles (n = 12,955) were imported into EndNote (version X8.2) for de-duplication, and then imported into the Rayyan QCRI (Ouzzani et al., 2016) software platform for collaborative, online screening. After the elimination of duplicates (n = 1184), the remaining abstracts (n = 11,771) were screened by two reviewers separately and concurrently. In cases where there was disagreement between the two reviewers, a third reviewer (the first and last author) made the final decision. The screening team was trained using a shared protocol that included descriptions of agroecological practices, food security and nutrition outcomes and other inclusion criteria (Tables 1 and 3). Following this screening procedure, 275 abstracts were selected for full-text review (Fig. 2).

A full-text quality evaluation of 78 papers was processed in a synoptic table with the following information: author, title, journal, publication year, study country, study type, years of study, number of observations, agroecological practices, impact on FSN, limitations, and suitability. Papers were rejected at this stage for several reasons: 1) the study did not measure agroecological practices and/or food security and nutrition outcomes (using criteria and indicators in Table 1); 2) the study design and research methods were not clearly described; 3) the study design was too weak, for example if there was only one farm as a case study in the study; or 4) cross-sectional studies that did not adequately control for other factors that may influence food security and

Table 1
Agroecological practices, components and FSN indicators included in review.

Agroecology components	Practice or indicator		
	Individual or field scale	Household or farm-scale	Community or regional scale
Crop diversification	Diversified crop rotations; crop diversification (inter- or intra-specific); homegardens	Organic production[b] Agroforestry	Farmer-to-farmer networks; community seed banks
Soil management	Cover crops; intercropping; mulching; green manure; compost; animal manure; reduced/no tillage;	Riparian buffers; soil and water conservation (terracing, ridging, swales or contour bunds/depressions to capture rainwater)	
Pest management[a]	Botanical/natural pesticides; insectary plantings (i.e., strategic planting of particular species to attract beneficial insects, such as pollinators or natural enemies).	Border plantings/flower strips	
Livestock integration		Mixed crop-livestock	
Socio-economic approaches		Gender equity in household division of labor, decision-making, control and access to agricultural products Gender equity in food processing, production and childcare	Gender equity; social equity; local marketing; cooperatives;
Food security	Food consumption score (Wiesmann et al., 2009; Leroy et al., 2015)	Household Food Insecurity Access Scale, (HFIAS) Household Food Security Scale Module, (HFSSM), Latin American Food Security Scale or Household Hunger Scale (HHS) (Coates et al., 2007; Deitchler et al., 2010; Swindale and Bilinsky 2006; Leroy et al., 2015; Melgar-Quinonez et al., 2006; Knueppel et al. 2010).	
	Coping Strategy Index (CSI): weighted aggregation of location-specific coping strategies used when food insecure (e.g., skipping meals) (Christiaensen et al., 2000).	Household Dietary Diversity Score (HDDS), Household Consumption and Expenditure Survey (HCES), or Months of inadequate household food supplies (Leroy et al., 2015; Carletto et al., 2013; Jones et al., 2014).	
	Reported food security (qualitative) (Pradhan and Ravallion 2000; Carletto et al., 2013).	Reported food security (qualitative) (Pradhan and Ravallion 2000; Carletto et al., 2013)	Reported community food security changes (qualitative) (Pradhan and Ravallion 2000; Carletto et al., 2013)
Nutrition	Individual dietary diversity e.g., FAO Minimum Dietary Diversity Score for Women; WHO Minimum Dietary Diversity for children (Arimond and Ruel 2004; Jones et al., 2013b) Standardized child growth measures/anthropometry, e.g., height for weight (WHZ), height for age (HAZ), and weight for age (WAZ), Allen 1994; Jones et al., 2014). Changes in micronutrient status e.g., vitamin A, iron or zinc (Brown et al., 2004; Fishman et al., 2000). Reported changes in nutritional status, e.g., children with healthier appetites		

[a] Pest management in agroecological systems is supported by practices categorized within crop diversification and soil management components.
[b] Organic production cannot be classified according to one of the five components as it overlaps with several of them.

nutritional outcomes, such as a cross-sectional study looking at the relationship between agrobiodiversity and anemia outcomes.

2.2. Final study set and data processing

A total of 56 articles, describing 55 cases, were included in the final study set, of which 52 were peer-reviewed scientific publications, two were Masters' theses/PhD dissertations, and two were monographs. The included studies were characterized by performing descriptive statistical analysis. The results were then summarized based on the different agroecological practices that were addressed (Supplementary Material 1), and sorted by reported FSN outcome: positive, negative or mixed. Positive results in quantitative studies were those that were statistically significant, using a rigorous research design and methods, while positive qualitative results were those studies with a consistent reported finding from study participants. Mixed results were those that reported both positive and negative FSN outcomes, and negative results were those that had statistically significant negative impacts on FSN (quantitative studies), and overall negative impact on FSN as reported by study participants in qualitative studies.

We also assessed the strength of the relationship between agroecology and FSN outcomes, for the quantitative studies. 'Weak outcome' studies had non-significant relationships and were cross-sectional studies with bivariate statistical tests done, not controlling for other factors influencing FSN outcomes. 'Moderate outcome' studies had primarily positive, but some mixed or non-significant, relationships between agroecology and FSN outcomes. 'Strong outcome' studies were those in which all relationships between agroecology and FSN tested were positive, statistically significant, and multivariate analyses were used to control for other variables that influence FSN. 'Very strong outcome' studies also had case-controlled, intervention and longitudinal design which were assessed as more robust than cross-sectional or observational studies. There was a wide range of study design type. One-quarter of selected studies were case-control studies, comparing agroecological farming households to 'control households' not using agroecological practices.

We captured the degree to which an agroecological approach was used or evaluated in a study by considering the number of different categories of practices used (based on the literature (e.g., Wezel et al., 2014), using the following categories: crop diversification, mixed crop-livestock systems, soil management, pest management and socio-economic elements (Table 1). Rather than rely on the authors using the term 'agroecological' to describe the practices, we used the system transition concept of agroecology to assess the level of complexity of the system and the number of a range of practices used (Gliessman 2014). We used these categories after reviewing and synthesizing the 55 cases, since they captured the core components of agroecological practices that were most commonly studied in the included literature.

Empirical data regarding the impact of agroecological practices on FSN originated from a number of different epistemological traditions and a range of disciplines from ethnobotany to public health (Table 1). The study set was categorized using causality and/or outcome indicators derived from both qualitative and quantitative methodologies. Causality

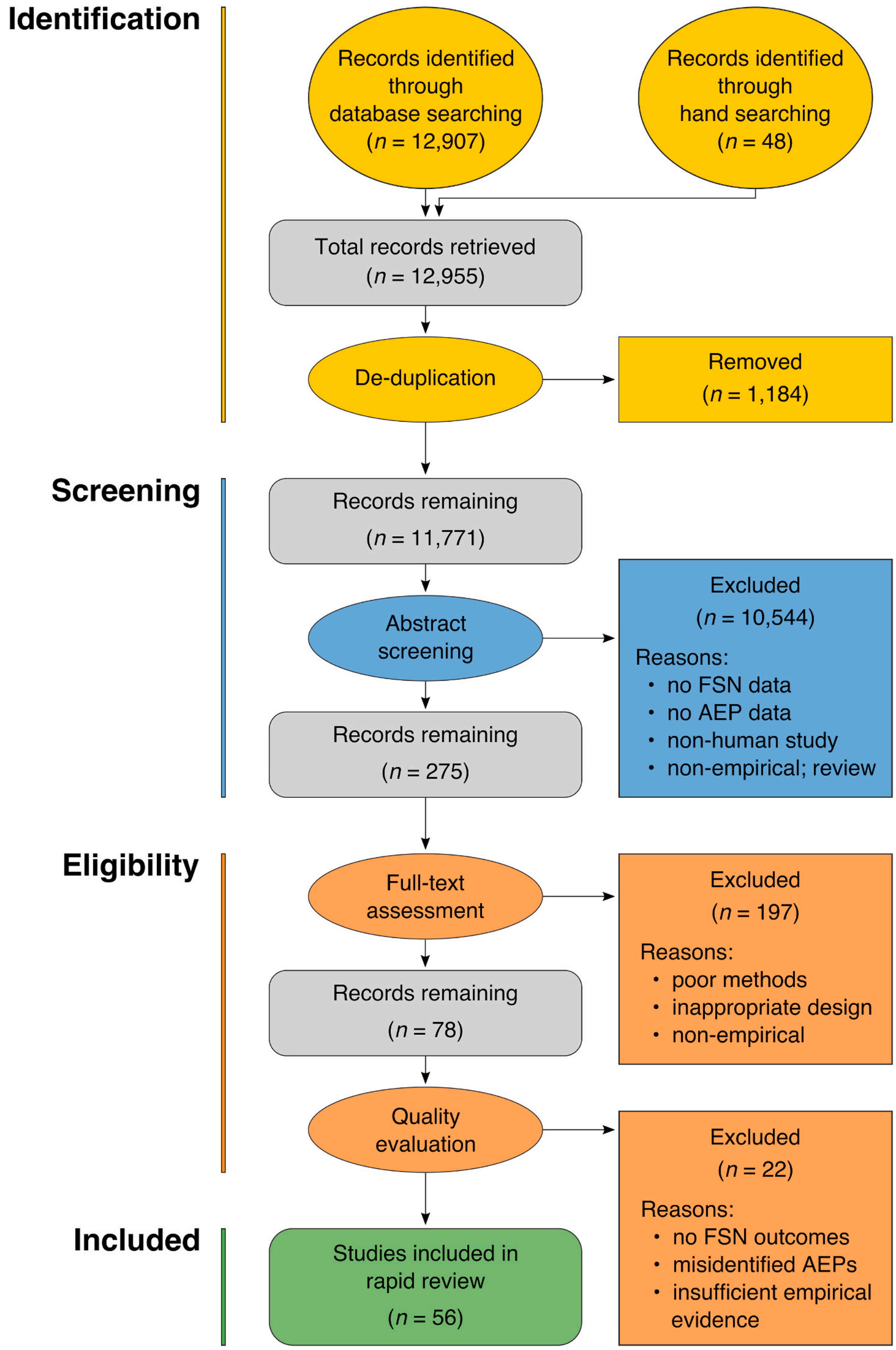

Fig. 2. PRISMA-RR flow diagram, representing the stepwise process of record identification, de-duplication and abstract screening, full-text assessment, and an additional quality evaluation phase for the rapid review. The database search included Web of Science Core Collection, CABI: CAB Abstracts, SciELO Citation Index, AGRICOLA, Academic Search Premier, and PubMed.

indicators assess the diet of study subjects; outcome indicators look at the impact of agroecological practices on human nutrition capturing food utilization.

3. Results

The majority of studies (78%) found positive relationships between a range of agroecological practices as described in the literature and FSN; only one study found a negative relationship, while the remaining cases found mixed linkages-either no relationship, or both positive and negative results (Fig. 3). Fig. 4 illustrates the distribution of cases that examined simple vs. more complex adoption of agroecological practices, components and their links to food security outcomes.

Agroecology studies that measured one or two agroecological components accounted for 69% of the cases respectively. Many studies focused on agrobiodiversity, reflecting a surge of research on the relationship between agrobiodiversity on FSN outcomes in recent years (Jones 2017). Complex agroecological studies (30% of total) examined three or four agroecological components in relation to household FSN. Although there were fewer studies of complex agroecological systems,

Table 2
Database search terms; systematically and hand-searched databases, journals, and websites; and initial references identified with the inclusion criteria.

Search terms[a]	Databases, journals and websites searched	Records identified
English: ((agroecolog* OR agro-ecolog* OR "diversified farming system" OR "diversified farming systems" OR "ecological agriculture" OR agrobiodivers* OR agro-biodivers*) AND ((food suppl* OR food secur* OR food insecur* OR food access* OR food sufficien* OR food insufficien* OR food stability OR food agency) OR (nutrition* OR nutrition status OR nutritional status OR nutrition outcome* OR nutritional outcome* OR anthropometry OR diet OR diets))) *Spanish:* ((agroecolog* OR agro-ecolog* OR agrobiodiversidad OR agro-biodiversidad) AND ((suministro de alimento* OR suministro alimentario OR seguridad alimentaria OR inseguridad alimentaria OR acesso de alimento* OR alimentación suficiente OR alimentación insuficiente OR estabilidad alimentaria) OR (nutricion* OR estado nutrición OR estado nutricional OR resultado nutrición OR resultado nutricional OR antropometría OR alimentación OR dieta OR dietas))) *French:* ((agroécologie* OR agroécologique OR agro-écologie* OR agro-écologique OR agrobiodiversité OR agro-biodiversité) AND ((approvisionnement aliment* OR sécurité alimentaire OR insécurité alimentaire OR alimentation insécure OR accès alimentation* OR alimentation suffican* OR alimentation insuffican* OR stabilité alimentation) OR (nutrition* OR statut nutrition* OR effet nutrition* OR effets* nutrition* OR anthropométrie OR diététique OR diète OR diètes OR régime alimentaire))) *Portuguese:* ((agroecolog* OR agro-ecolog* OR agrobiodiversidade OR agro-biodiversidade) AND ((fornecimento de aliment* OR segurança alimentar OR insegurança alimentar OR acesso aos alimentos OR acesso ao alimento OR suficiência alimentar OR alimentação insuficiente OR estabilidade de alimentos) OR (nutric* OR estado nutricional OR resultado nutriciona* OR antropometria OR alimentação OR dieta OR dietas)))	*Databases:* • Web of Science Core Collection • CABI: CAB Abstracts • SciELO Citation Index • AGRICOLA • Academic Search Premier • PubMed	7118 5530 259
	Journals hand-searched: • Agriculture and Food Security • Agroecology and Sustainable Food Systems • Agronomy and Sustainable Development • Journal of Peasant Studies	46
	Websites hand-searched: • FAO • SOCLA • Agroecology Europe, Agroecology Fund • McKnight Foundation	2

[a] Search terms varied slightly according to database specifications for truncation symbols and the use of brackets or parentheses.

Table 3
Inclusion and exclusion criteria for the review protocol.

Inclusion criteria	Exclusion criteria
1. Published between 1998 and 2019 2. Reports empirical data. 3. Involves human subjects. 4. Includes agroecological practices (see Table 1). 5. Reports food security or nutrition outcomes (can be qualitative or quantitative, see Table 1). 6. Full text accessible and in either English, French, Spanish or Portuguese. 7 Peer reviewed article OR dissertation/thesis OR academic book OR if grey literature from a reputable institution a. Institution has track record of reputable research b. Institution has expertise in subject area c. Institution has no track record of falsified or dishonest research.	1. Not published between 1998 and 2019. 2. Does not report empirical data, e.g., review or modeling paper (does not report original data). 3. No human subjects, e.g., animal feed study 4 Does not include agroecological practice (see Table 1). a. Papers that use agroecology to refer to agroecosystem or agroecozone. 5 Does not report food security or nutrition outcomes (can be qualitative or quantitative). a. Reports only indirect effect on human FSN, e.g., pollinator habitat, soil health. 7. Full text not accessible or not in English, Spanish, French or Portuguese. 8 Study is not peer reviewed (e.g., conference proceedings) OR 9. If book or book chapter/dissertation/OR if grey literature NOT from a reputable institution a. Institution has no track record of reputable research b. Institution has no expertise in subject area c. Institution has track record of falsified or dishonest research

FSN outcomes in these categories were tested with more empirical rigor, with a greater proportion of studies using longitudinal, case-control, mixed methods design and multivariate analysis. A higher proportion of studies on more complex agroecological approaches found positive FSN outcomes, albeit with a smaller number of studies for comparison (Fig. 4).

Twenty-four studies were categorized as exclusively quantitative, 9 as exclusively qualitative, and 23 were characterized as mixed-method (Table 2). Both observational ($n = 39$) and intervention ($n = 17$) studies were included in the study set. Observational designs recorded the experiences, practices and FSN of participants who used agroecological practices. Intervention designs tracked the impact of an agroecological project or program initiated by a research team, state agencies, NGOs, farmer organization or the study respondents themselves. Seventy-one percent of studies looked at cross-sectional data at a given point in time, while 29% collected research two or more times during the study period (longitudinal studies). A total of 30% were designed as intervention studies, the remaining were observational (also called natural experiments). One quarter of the studies had a case-control design.

3.1. Studies with one agroecological component

Publications focusing on crop diversification alone comprised 31% of all cases included in the review. Most commonly, diversification was measured by the number of field crop species and cultivars, although two studies assessed the relationship between homegarden diversity and FSN. Nearly two-thirds of these studies found a positive relationship between crop diversification and FSN, most often measuring dietary diversity or food security indices, with one study including intake of micronutrients (de Haan 2009) and child growth (Luna-González and Sorensen, 2018). Three studies examined an agroecological approach to soil management, most commonly as soil organic amendments, such as compost (Silva et al., 2018; Kaufman 2015; Sarker and Itohara 2010).

Most studies implied a direct consumption pathway to FSN. An ethnographic study of traditional agroforestry systems in Mexico found that families consumed an average of 60 foods, most sourced from their own production. Homegardens provided the bulk of dietary diversity, while *milpa*, an intercropping of maize, legumes, and squash, provided the bulk of staple foods, complementing each other in terms of temporality by providing food throughout the year (Hernández et al., 2017). Household or community transition toward a diet that includes more processed and purchased foods coincided with less crop diversified farms and diets as well as loss of traditional knowledge (Hernández et al., 2017; Van Rensburg et al., 2015). One study using econometric analysis found that on-farm and market diversity were positively associated with mothers' dietary diversity (Bellon et al., 2016).

Five studies found no significant relationship between crop diversity

Agroecological component		Cases with positive outcomes (%)	Cases with negative outcomes (%)	Cases with mixed outcomes (%)	Cases describing category (%)	Evidence strength
1 component						
Crop diversification		22	0	9	31	
Soil management		4	0	2	6	
2 components						
Crop diversification +	Mixed crop-livestock	13	2	4	19	
	Socio-economic	9	0	2	11	
	Soil management	4	0	0	4	
3 components						
Socio-economic +	Crop diversification + mixed crop-livestock	2	0	0	2	
	Crop diversification + soil management	11	0	2	13	
4 components						
Crop diversification + mixed crop-livestock + soil management + socio-economic		13	0	2	15	

Fig. 3. Frequency of food security outcomes per number of agroecological components studied. Bars represent the row-wise proportion of the total.

Agroecology	No. of agroecological components	Cases with positive outcomes	Cases with negative outcomes	Cases with mixed outcomes	Cases describing category (n = 55)
Simple	1	14	0	6	20
	2	14	1	3	18
	3	8	0	1	9
Complex	4	7	0	1	8

Fig. 4. Distribution of agroecological components assessed in relation to evidence of household FSN outcomes (table format adapted from Rasmussen et al., 2018).

and FSN. Two studies compared FSN outcomes of organic farmers, most non-certified, but who self-reported reducing synthetic inputs and using organic soil amendments instead (Kaufman 2015; Sarker and Itohara 2010). In one study in Thailand, there were no significant increases in FSN for farmers who used organic inputs compared with those who used synthetic inputs (Kaufman 2015). For farmers trained in organic production in Bangladesh, conversion to organic production alone was not significantly correlated with FSN, but the duration of organic farming was a significant determinant of household food security (Sarker and Itohara 2010).

3.2. Studies with two agroecological components

Of 46 quantitative and mixed methods studies, 18 examined two agroecological components. All studies assessed crop diversification in addition to a second agroecological component, which was most commonly mixed-crop livestock systems (56% of the 18 studies), followed by social elements of agroecology (33% of total), and soil management (11% of total). Crop diversification was studied at the field level, except for two studies that assessed homegarden diversification (Bushamuka et al., 2005; Whitney et al., 2018). Compared to cases that assessed only one agroecological component practiced in a farming system, a slightly higher proportion of studies provided evidence for positive FSN outcomes.

3.2.1. Mixed crop-livestock systems

Cases provided mixed evidence of the food security impact of integrating crop and livestock systems and FSN, with 7 of the 10 cases finding positive relationships (Azupogo et al., 2019; Bisht et al., 2018; Fernandez and Méndez, 2019; Jones et al., 2018; Walingo and Ekesa, 2013; Whitney et al., 2018), while those remaining found mixed or negative evidence. Farm-level agrobiodiversity in Peru was associated with more micronutrient-rich and diverse diets for women (Jones et al., 2018). In Ethiopia, Ambikapathi et al., 2019 found a significant positive relationship between women's dietary diversity and mixed crop-livestock systems. Three studies assessed the food security in mixed crop-livestock systems in Kenya: two found a non-significant relationship (Gitagia et al., 2019; Ng'endo et al., 2015), while another found a strong positive relationship between dietary diversity of preschool children and crop and livestock diversity (Walingo and Ekesa, 2013). One study in East Timor found an association between livestock ownership and poorer child growth (Thu and Judge 2017).

3.2.2. Crop diversification and social elements

Crop diversification was examined in combination with organic and fair-trade certification (Bacon et al., 2017; Bandanaa et al., 2016), market development and farmer-to-farmer networks (Lucantoni et al., 2018; Bacon et al., 2017; Gotor et al., 2017) and efforts to address social inequalities faced by women (Gondwe et al., 2017) and poorer community members (Bushamuka et al., 2005). When combined with initiatives addressing these socio-economic components of agroecology, crop diversification was positively associated with FSN in all but one study. Interventions promoting diverse homegardens (Bushamuka et al., 2005) and on-farm agrobiodiversity conservation (Gotor et al., 2017) led to increased incomes and vegetable consumption. A case-controlled study of coffee farmers trained by a farmer-to-farmer organization in Nicaragua found that FSN was enhanced in households who cultivated and sold beans, grew more fruit trees, and were more food self-sufficient (Bacon et al., 2017). Interestingly, in all studies that included certification schemes, certification alone was not associated with improved FSN. However, Bandanaa et al. (2016) found that as a result of their management practices, organic coffee producers sustained more floral diversity in their farming systems, which led to greater consumption of edible wild plants and income from flora sales than their conventional counterparts.

3.2.3. Crop diversification and soil management

One study that examined the association between crop diversification in combination with soil management practices found positive relationships with FSN (Nunes et al., 2018).

3.3. Studies with three agroecological components

Nine studies focused on three agroecological components. Four of these studies used a qualitative research approach. Longitudinal multivariate analysis showed that in Kenya children in households included in participatory farm diversification and nutrition education had higher dietary diversity after the two-year intervention (Boedecker et al., 2019). Eight studies examined crop diversification, soil management, and a social component of agroecology, such as addressing gender inequity in household work. Both quantitative (Calderón et al., 2018; Miyashita 2015; Carney et al., 2012) and qualitative analyses (Deaconu et al., 2019; Bliss 2017; Nyantakyi Frimpong et al. 2016; Blixen Magariños et al., 2006) found this combination of agroecological components was associated with better FSN. Farmers reported that they intentionally maintained production systems with high spatial and temporal diversity to ensure diverse diets throughout the year (Deaconu et al., 2019; Bliss 2017; Blixen Magariños et al., 2006). In addition to dietary improvement through direct consumption of diversified production, farmers found further benefit from transitioning to agroecological soil management practices, including better crop resilience to climate shocks (Bliss 2017), reduced workloads, and increased farm productivity (Nyantakyi Frimpong et al., 2016). One study of a farmers' network promoting agroecology found that farm-level adoption of agroecological practices led to higher incomes and similar crop yields as conventional management with synthetic fertilizer (Calderón et al., 2018). Reduced fertilizer expenditures were linked to improved FSN; in three qualitative studies where farms diversified production and applied agroecological soil management practices, respondents reported that by spending less on inputs they improved FSN (Deaconu et al., 2019; Nyantakyi-Frimpong et al., 2016; Blixen Magariños et al., 2006). Agroecological and diversified systems also provided farmers an opportunity to exchange food and other products within their communities, building and strengthening social ties that are often integral to FSN (Deaconu et al., 2019; Blixen Magariños et al., 2006).

3.4. Studies with four agroecological components

Nine studies, but eight cases, covered four components of agroecology (Bezner Kerr et al., 2019b; Valencia et al., 2019; Kamau et al., 2018; Kangmennaang et al., 2017; Nyantakyi-Frimpong et al., 2017; Darrouzet-Nardi et al., 2016; Fedyna da Silveira Furtado et al. 2014; Bacon et al., 2014; Bachmann et al., 2009). In all studies, farmer-to-farmer teaching methods and farmer organizations facilitated uptake of agroecological practices, leading to positive FSN outcomes in all but one case. These studies were also characterized by more robust methodological and statistical approaches. Linear regression models in three longitudinal intervention studies all demonstrated evidence of a positive relationship between use of agroecological practices and food security. Notably, all three used participatory approaches to design interventions and address gender inequality (Bezner Kerr et al., 2019b; Kangmennaang et al., 2017; Darrouzet-Nardi et al., 2016). A community-level intervention in Nepal, involving weekly gatherings of women groups to learn about agroecological practices, animal health and community building, significantly improved children's diet quality, with a stronger effect observed during the hungry season (Darrouzet-Nardi et al., 2016). Children of families who had participated in the intervention for two years were 1.5 times more likely to have consumed an additional food group, 1.2 times more likely to have achieved the minimum dietary score, and 1.2 times more likely to have consumed animal source foods. Farmer-to-farmer training in Malawi in legume intercropping, composting, mulching, crop diversification and botanical pesticide use within a sample of 1000 households led to a significant improvement in household food security (Kangmennaang et al., 2017). Another study in Kenya found that, of five farm household typologies, the one with the highest dietary diversity was characterized by those farmers who had most comprehensively adopted soil management practices, such as mulching, legume intercropping, and use of organic soil amendments (Kamau et al., 2018); these farmers earned the highest livestock income and were strongly involved in social networks.

Two cross-sectional studies used a case-control design to assess effectiveness of farm-level agroecological approaches combined with market development for improving food security. Valencia et al. (2019) found that Brazil's national school feeding program (PNAE), which encouraged agrobiodiversity, cover cropping, intercropping, and synthetic chemical input reduction by providing a price premium for certified organic and agroecological production, collectively supported farmer autonomy. Total species richness on-farm was a significant but weak predictor of dietary diversity for households across all farms (Valencia et al., 2019). In the Philippines, organic farmers reported better food security compared to the period before they converted their farms to organic production, conserved rice genetic diversity, practiced agroforestry and intercropping, and organized for farmers' rights (Bachmann et al., 2009).

State-level recognition of the ecological contribution of traditional agro-silvopastoral systems in Paraná, Brazil, provided municipal resources to support these diversified systems. Farmers emphasized that these agricultural systems ensured a healthy diet that was not only diversified and secure, but devoid of synthetic pesticides (Fedyna da Silvestri et al., 2015). Farmers in this and another study highly valued self-sufficiency, explaining that they grew their own food or exchanged it with neighbors to avoid the need to purchase food from markets, which may have been grown with synthetic pesticides (Deaconu et al., 2019; Blixen Magariños et al., 2006).

4. Discussion

This review provides insight into how farming and food system approaches along a spectrum of agroecological transition contribute to FSN outcomes. The majority of studies were carried out with farming households, and 78% of all studies found evidence of improved household food security and dietary diversity. Most studies focused on food security or diet quality indicators, rather than direct human nutrition measures; while changing diets is not always enough to address nutritional status, due to other factors such as disease prevalence or water access, it is an important outcome strongly associated with human nutrition outcomes (Arimond and Ruel 2004; Leroy and Frongillo 2019).

The trends observed in this review support the hypothesis that more comprehensive adoption of agroecological approaches to food and farming systems increases the likelihood that FSN will improve. This change might occur because more agroecological components work synergistically to strengthen FSN improvements along one pathway or increase the number of possible pathways through which a household might improve FSN. In farming households where crop diversification was the principal agroecological practice implemented, for example, diets primarily improved through direct consumption of a greater variety of foods. When diversification included livestock integration, the direct-consumption pathway might be even more effective for FSN outcomes, with more nutrient rich animal products available. Both instances might also include crop and livestock product sales. When applied in combination with agroecological soil management, livestock integration, and farmer organizations, more opportunities for crop and livestock sales and more diverse food options likely increased FSN outcomes. Agroecological practices such as organic soil amendments, intercropping and botanical pesticides may also reduce expenditures on inputs, leading to more income available for purchasing a diversity of food types.

Three of the four most commonly studied agroecological components—crop diversification, livestock integration, and soil management—were most relevant to principles supporting agroecosystem health and resilience, and all farm-level outputs/mechanisms theorized as linked to FSN were observed in at least one included study, with input reduction, product diversity, increased yield, and production stability influencing income and direct-consumption pathways (Fig. 1). Household and community-level impacts of agroecology were documented in those studies that included a social component of agroecology. The two most common approaches were gender equity-sensitive interventions at the household-level, often focused on child-feeding practices and nutrition education, while farmer organizations, representing principles of co-creation of knowledge and food system participation, were active in many study communities and played a role in strengthening social support practices such as food and seed sharing. Notably, no study examined the impact of more equitable land and resource governance on FSN.

Looking at the differential impact of simple versus complex adoption of agroecology helped to capture variation between the studies, to identify components of agroecology and agroecological practices that are understudied. There is ample research on the relationship between crop diversification and FSN; less studied are linkages between FSN and farms applying agroecological approaches to livestock integration, soil management or landscape-level practices. A large number of studies assessed the impact of agroecology in the context of strong farmer-to-farmer networks and associations, but there was a dearth of studies that address food system change, such as fostering direct producer-consumer markets. There were also few studies examining the impact of agroecological practices on other human nutrition outcomes such as micronutrient status or child growth. One study excluded from full review showed direct impacts on child growth from the agroecological intervention, but only measured indirect evidence of legume intercropping practice (Bezner Kerr et al., 2010). Another study in Tanzania, published after the review was completed, found increased children's dietary diversity in households using agroecological practices (Santoso et al., 2021). Overall, the review shows increased diversity and complexity in crops and livestock management is feasible, and that positive outcomes on FSN were even more significant within more complex systems. While income was not a focus of the review, positive outcomes for yield and farm profitability can be expected in most cases. D'Annolfo et al. (2017) show in their review that adopting agroecological practices increased yield for 61% of the 74 studies and farm profitability increased in 66% of the 73 cases studied, whereas a decrease was only found in 20% and 23%, respectively.

5. Conclusions

This review searched for evidence of improving FSN through the use of agroecological practices. Overall, we conclude that a larger majority of studies (78%) found such evidence, with positive outcomes linked to the use of agroecological practices on FSN in households in low- and middle-income countries. Some studies found mixed FSN outcomes and a few studies reported negative FSN. The most common agroecological practices included crop diversification, agroforestry, mixed crop and livestock systems, and practices improving soil quality, with positive outcomes on FSN indicators such as dietary diversity and HFIAS. There was also a slightly positive trend between the number of agroecological practices applied and the strength of the positive relationship with FSN outcomes, showing that complexity in farm management can lead to benefits for FSN.

Although the present study provides a clear indication on mainly positive outcomes of agroecological practices on FSN, more studies are needed that use rigorous research designs (such as case-control, longitudinal studies) and statistical tools that control for other variables that influence FSN outcomes. Socio-economic dimensions of agroecology, such as direct marketing, addressing social inequities, and land and natural resource governance, also have received limited attention.

As far as the authors are aware, this is the first review over the last 20 years to assess whether agroecological practices have positive impacts on FSN outcomes. The 56 studies identified provide considerable evidence for an overall positive impact of agroecological practices on FSN, regardless of the indicator selected or the agroecological practice that was evaluated. This review adds weight to recent global calls for further research investment in agroecological approaches (Herrero et al., 2017; HLPE, 2019). In addition, the review supports the rationale for agroecological approaches, alongside the benefits identified for biodiversity conservation (Wanger et al., 2020; Kremen and Merenlender 2018), ecosystem services (Santos et al., 2019) and increased resilience (Mbow et al., 2019).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2021.100540.

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