Sustainability in Home Garden Interventions to Improve Food Security: Results, Challenges, and Future Directions

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Food and nutrition security (FNS) is a priority for human development since different facets of malnutrition still prevail in many parts of the world. Home garden interventions (HGI) have been proposed to improve FNS, generally obtaining positive results. This review aimed to evaluate reports of HGI, discussing their characteristics and outcomes in terms of three sustainability dimensions (social, environmental, and economic). A total of 40 papers (n-number of papers) were included, mainly published since 2009. According to literature review, measurement, or discussion of economic (productivity, n=20) and social (diet improvement, n=33) outcomes has taken precedence over environmental ones (agrodiversity, n=15) in HGI's impact assessment (IA). Furthermore, sustainability has not been assessed beyond the continuity of the proposed changes (n=5). Future HGI should apply Systemic-Transdisciplinary approaches with adequate metrics and multidimensional IA methodologies linking FNS and sustainable development. This would allow a contextualisation of the research, establishing the current situation of the study system and identifying precise needs. Also, it would be possible to identify and monitor trade-offs and synergies of the intervention. Such approach would generate a strong body of scientific evidence and awareness of the benefits of a sustainable agricultural system in the prevention and treatment of the double burden of malnutrition (hidden hunger and overweight/obesity).

Keywords: Food security, nutrition, horticulture, systems thinking, transdisciplinary.

1 Introduction

Food and nutrition security (FNS) is a priority for global sustainable development. Substantial progress has been made over the last 50 years to reduce caloric deficiencies and food shortages through increases in agricultural production, particularly in terms of grain staples [1–4]. Thus, the percentage of hungry people decreased by almost 50% from 1990 to 2015 and the famines that afflicted humanity for centuries have been practically eradicated in most parts of the World. However, undernutrition is still a problem growing in numbers since 2015 and over 820 million sufferers worldwide [5].

Ensuring adequate and balanced nutrition in the World's population remains a challenge. On the one hand, the poor intake and/or absorption of high-quality protein and micronutrients such as zinc, iron, vitamin A, and vitamin B12, also called "hidden hunger", is a constant problem for 2 billion people in developing countries (Figure 1) [6–8]. On the other hand, the World faces non-communicable diseases (NCD) related to excessive calorie consumption [9]. According to a report [5], overweight and obesity in adults are growing at an accelerated rate worldwide (almost 40 % in 2018). Likewise, overweight in children show signs of increase in the last decades (Figure 1) [10]. Adding to the complexity, unbalanced diets have caused a situation where hidden hunger and overweight/obesity often coexist in the same territories, in what is known as the "double burden" of malnutrition [11, 12].

In a broader sense, these challenges relate to the sustainability dimensions of food production systems [13]. Although agricultural intensification has improved the availability of food; important changes in the environmental dimension due to, for example, emission of greenhouse gases, loss of biodiversity, and pollution of water have been generated [14–16]. At the social and economic level, agricultural specialization ensued the globalization of nutrient sources to a few crops [17], which in turns may explain the slow progress to meet the protein and micronutrient needs of the population in various countries. In addition, environmental changes such as erosion or climatic variability have affected the livelihoods of individuals; particularly in rural areas, which in turns determines their ability to work and generate resources to access food and improve their nutritional status [2, 18–20]. Humanity faces the need to make food production more sustainable, and this implies promoting agricultural policies as well as agricultural R&D focused on improving the production of diverse and nutritionally dense foods [21, 22], which also guarantee resilient, adaptable, and productive agricultural systems, by implementing practices that conserve natural resources, are culturally acceptable and have reduced ecological impact [23–26]. Therefore, in the Sustainable Development Goals, the nations of the World seek to accomplish food security, hunger reduction, improved nutrition, and sustainable agriculture [27, 28], all of which are especially challenging in the ever-changing conditions created by politics, economics, climate change, globalization, natural resource depletion, population growth [29], and health crises such as the COVID-19 pandemic [27].

There is a need for approaches that consider the complexity of both the food production system and the described FNS situation [30–32]. In this context, horticulture could help addressing the issues described; as it is part of local food production systems in both developed and developing countries, in both urban and rural settings [33–37]. Indeed, horticultural interventions have been proposed to improve the FNS of vulnerable population groups [38–43]. In the case of home garden (HG) interventions, previous reviews have already attempted to evaluate their impact in nutritional and livelihood outcomes [19, 30, 44–47]. These systematic reviews have established valid research needs in terms of design quality, scientific rigor, and nutritional impact assessment. Nevertheless, the outcomes related to the sustainability of the food system have not been examined to the same extent. In this context, the aim of this paper to offer an overview of literature about HG interventions; to review and discuss their impact in terms of reported social, economic, and environmental indicators. As they provide insight into the research needs in sustainability assessment of such nutrition initiatives.

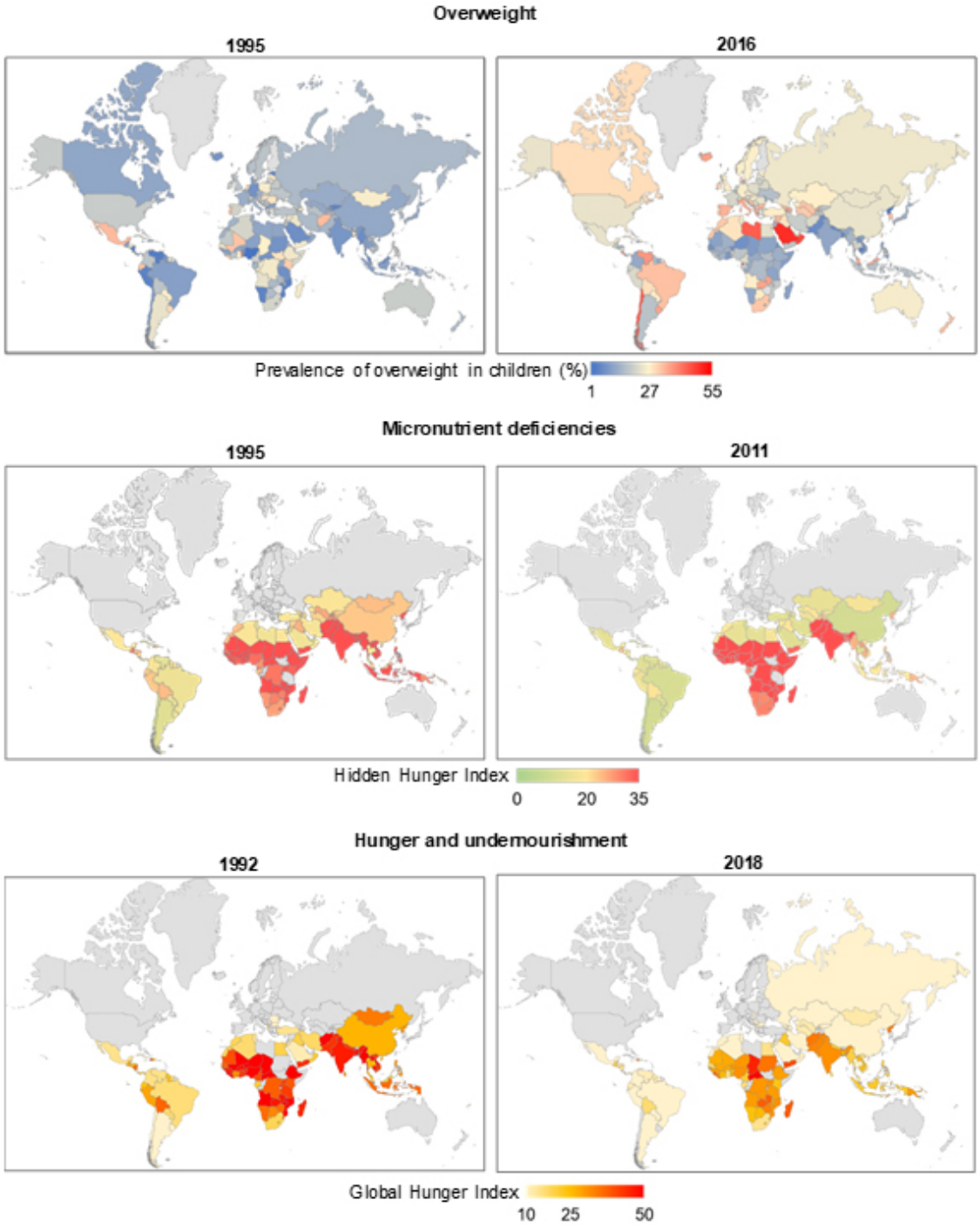

Figure 1: *Configuration considered for analysis: Challenges for food and nutrition security a) Overweight, b) Micronutrient deficiencies and c) Hunger and undernourishment. Based on data from [8, 48, 49].*

2 Methodology

Papers were obtained from searches in online databases (Scopus, Web of Science and PubMed), using a combination of keywords [(garden*) AND ("intervention" OR project OR program OR "horticultural intervention" OR "intervention trial") AND (nutrition OR "food security")]. Resulting articles were screened using, first, their titles and abstract (written in English), and then a read and re-read process. The projects included in the review consisted of interventions, experimental projects, or case studies. In these gardens were used, established, improved, or promoted; to produce a nutritional effect on a target group (also known as participants, actors, or beneficiaries).

The type of garden settings included were backyard/home/house/homestead, in both urban and rural locations. Preference was given to papers reporting results of interventions, which were published in peer reviewed academic journals over 20 years (1999-2019). Reports from non-government organizations, books, and book chapters, as well as reviews, comment, legal and conference papers were not considered. We do not attempt to evaluate the design quality and strengths/weaknesses of the studies, as this has been addressed in several reviews over the years. By using peer-reviewed research we expected that the evidence has already been evaluated and deemed suitable within the discipline of interest. Both in methodologies and results, and thus, was able to reach publication stage.

3 Results

A total of 40 academic papers were selected as relevant and therefore included in this review. Most of them were published between 2009 and 2019, and detailed research projects done in 16 countries, most of which consisted in low-income countries in Asia and Africa (Figure 2a and c). Twenty-seven journals published the selected reports on gardening interventions (Figure 2b), however, only four of them published three or more of the reviewed papers. The journals were categorized under a variety of subject areas: Medicine, health, nutrition, and nursing (48.2%), Agricultural and Biological sciences (22.2%), and social sciences (21%). This shows the diverse interests in these types of interventions and, to some extent, the disciplinary scope of the reports. The studies were published in the journal compatible with the objective of the research or the characteristics of the intervention.

Selected HG interventions generally consisted in the establishment, improvement, or diversification of small-scale family-managed production units, implemented along with educational components in nutrition, agriculture, hygiene, and health (Table 1). In a few cases, HG were promoted via training in farmer groups or organizations, at home via mentors or at school, occasionally using participants as agents of change (Table 1). Intervention participants usually received practical agricultural/horticultural training to plan, plant, and maintain the gardens (Table 1). This training was necessary for new gardeners, but also for experienced ones since several interventions introduced new garden models, crops, add-on livestock components and improved or organic practices [50–52].

This review examined, the characteristics and results of the selected papers according to the dimension (social, economic, or environmental) to which they belong, to understand how sustainable gardening interventions are. The classification carried out is by no means definitive since there is always overlap between the different dimensions and their outcomes. This will be detailed and discussed in the following sections.

3.1 Social Dimension

In a large part of the studies, social elements were the main outcomes measured to assess the impact of HG interventions. According to the requirements of this review, all interventions sought to improve FNS aspects in the beneficiaries. However, the aims seemed to be related to the nutrition challenges the different countries face (Figure 1). Papers from Africa or Asia mostly referred to food insecurity and undernutrition alleviation. Meanwhile, in higher income countries, it was more common to find gardening interventions to aid in the fight against overnutrition and its burden of disease. Although some addressed food insecurity

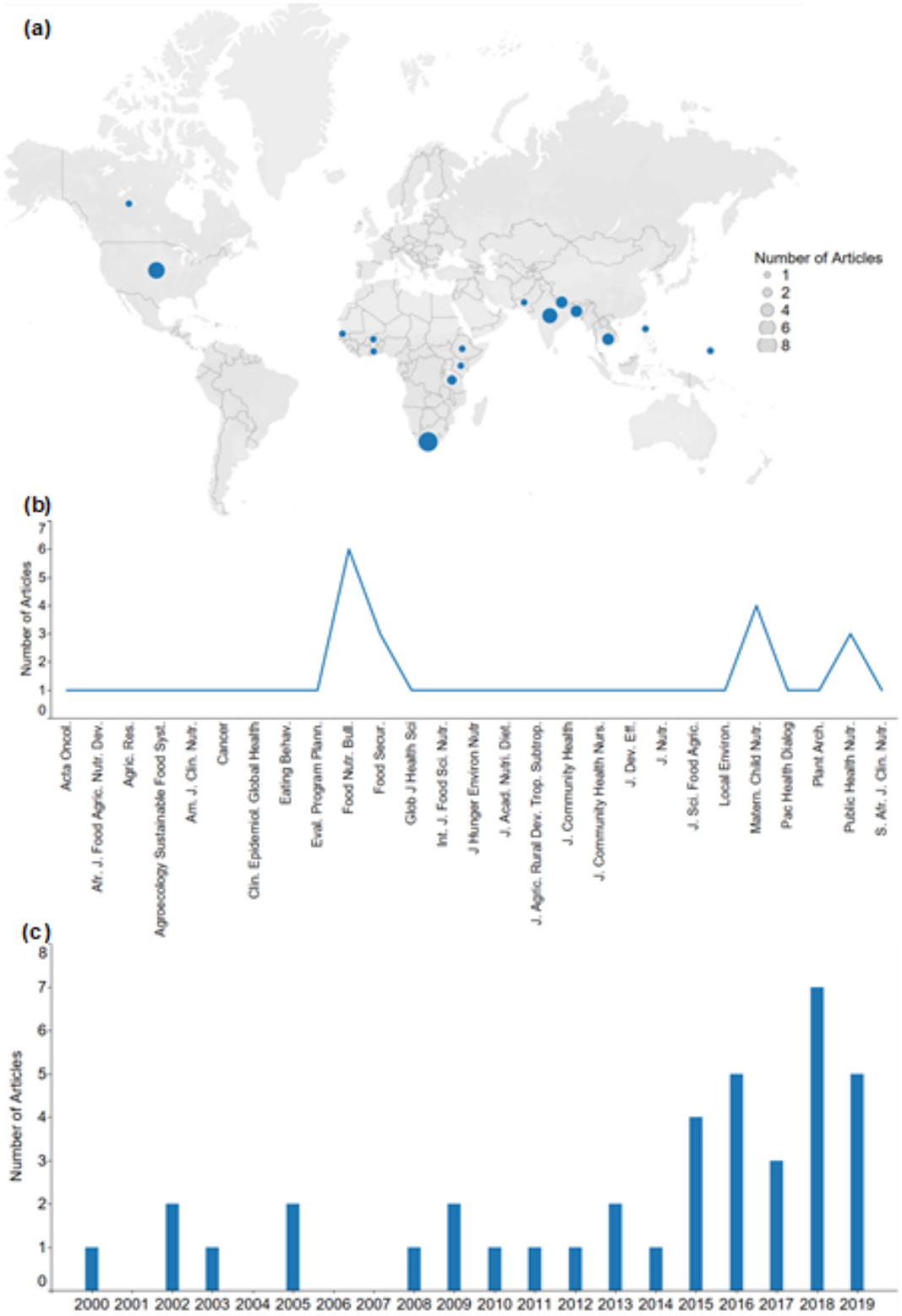

Figure 2: *Overview of the selected home gardening intervention studies. Number of studies per (a) intervention country, (b) journal and (c) year.*

issues in underprivileged populations. Other directly measured social outcomes were related to household (HH) wellbeing, both in developed and developing countries. This speaks to the diversity of problems that have been addressed using horticulture-based interventions.

3.1.1 Food and Nutrition Security

In terms of effectivity, 70% of reviewed HG papers reported positive FNS results for participants in terms of increased availability, access and/or consumption of nutrient rich food, often related with increased diet diversity (Table 1). Spill-over benefits were also noted in non-participants, as surplus garden produced foods could be shared or made available in local markets [53–55], but also because gardening could be adopted by neighbours themselves due to the participatory nature of many programmes [32, 56].

Studies that measured nutritional and health status; however, were often unable to prove impacts in nutritional or health status measures, such as anthropometry, morbidity, and biochemical markers due to previously noted limitations in their design (e.g., sample selection, lack of power, study length or deficient randomization) [19, 44, 49]. Despite these shortcomings, previous reviews on HG still regard HG interventions as valid options to address food insecurity, micronutrient deficiencies, and undernutrition via intermediate pathways (Figure 3). It is recommended integrating other strategies, such as supplementation and continuous food and nutrition education and sensitization campaigns at a community level to improve nutritional status outcomes [50, 51, 57].

At the other extreme of malnutrition, only five reports related to interventions for the prevention of obesity and NCD in vulnerable populations by promoting healthy eating [mainly increase fruit and vegetable (FV) intake]. They mainly consisted in short-term evaluations (feasibility and pilot studies) with limited numbers of participants, so the evidence cannot be generalized, however, some increases in FV consumption measures were recorded in populations like cancer survivors [58–60] and seniors [61]; other positive outcomes were trends towards improvements in weight status and blood pressure, or blood lipids (in South African studies [62]). These results concur with other studies, relating to community and school gardening: the which have showed promise in addressing overnutrition problems and reducing consumption of unhealthy food [63–66].

Further efforts should be devoted to assessing the suitability of HG interventions to target nutrition related NCD and the double burden of malnutrition in middle- and low-income countries. Even if the evidence for improvement in nutritional status is not strong, in the long-term; diversified gardens have shown to be an important part of a food and nutrition system that addresses some of the underlying causes of different FNS issues (both from under and overnutrition), such as ignorance, inadequate feeding practices, reliance on staple/energy-dense cheap foods and limited access to nutrient rich food, for example [21, 39]. These causes correspond to the pathways in Figure 3, and future studies should focus on measuring them as outcomes of these interventions since they are more attainable and easier to monitor than following nutritional status changes. Also, additional evidence is needed to support the possible benefits of home gardens for the prevention of nutrition related NCD.

3.1.2 Nutrition Education and Knowledge Preservation

The attainment of knowledge and skills in nutrition, health and agriculture were a common goal of gardening interventions. Hands-on horticultural practice is often implemented along with nutritional education, both present synergistic effect in the FNS benefits of the participants, constituting an important pathway shown in Figure 3c [44]. HG studies have reported improvements of health awareness and nutrition knowledge scores in maternal and young participants after an intervention. These results were associated with improvement in dietary diversity, dietary and feeding practices, and child health outcomes in developing countries [67–71].

Reviewed literature indicates that education and sensitization can help addressing cultural or personal barriers and prejudices against healthy foods, adoption of adequate dietary practices and equitable intra-household food allocation [72, 73]. For example, interventions improved infant feeding practices by teaching

the importance of exclusive breastfeeding [72, 73]; other times, education was aimed to correct food taboos and beliefs which limit access to food in the pregnancy [51].

Previous interventions with school children and youth have shown that garden exposure promoted acceptance of healthy eating behaviours and attitudes towards fruits and/or vegetables, which may lead to changes in their diet [74–76]. In the present review, a couple of studies from North America also reported more positive attitudes and beliefs towards garden produced healthy foods, and activities like cooking or eating them [61]. Similarly, participants tended to recognize the importance of FV as part of a healthy diet and were motivated to adopt one [58–60].

It has been observed that changes in behaviours and/or attitudes were frequently related to nutrition lessons/workshops during the school or community garden interventions [75, 77–80]. Furthermore, gardens can be used to preserve, reconnect with, and transfer traditional practices, spiritual views, food values, and other aspects of the knowledge base of aboriginal [81, 82] and migrant communities [55, 83–86]. This could be an interesting topic for future research during the home garden interventions. it is relating to the development of culturally acceptable practices, community integration and ownership, which could contribute to increasing the success of the programs.

The overall effectiveness of gardening interventions might reflect their ability to engage target populations as active participants in an experiential learning process [87]. Authors often recommended strengthening (or adding) continuous education and training components to the intervention and promoting knowledge communication and sharing to address limitations, broaden the impact and enhance the benefits of them [50–52, 88–90].

3.1.3 Psychosocial Aspects, Equity, Community Participation

Horticulture offers a series of intangible benefits for those who take part in the activity and spend time in food producing landscapes. Most evidence of this has been obtained from community gardening studies and very vulnerable populations [42, 60, 84, 85, 91–93]. However, at least 50% of the presently included papers reported non-physical wellbeing and quality of life accounts from the participants, mostly showing positive results.

It was seen that HG beneficiaries not only enjoyed gardening; but also formed emotional and spiritual connections with the process of growing their own food, which in turn can influence their food values and dietary choices [61, 94]. Also, gardening interventions often encourage or strengthen community and family integration and a sense of belonging or unity in the participants [86, 95]. Interactions occur as people work together, share the harvest, or spend time with others in and around gardens, or participate in group activities like nutrition workshops and cooking lessons. Social integration/cohesion improvements were associated with better cognition measures in senior gardeners [94] and well-being in people adapting to a new country [83, 86]. Sharing the harvest has been also a way to improve social standing of participating HH, whose neighbours see as “giving” and “well-to-do” [96].

Gardening activities can be challenging, but by taking part in them, and learning about different intervention topics, participants took pride and became more confident in their own skills [89, 94]. Interventions were often targeted to women, so the aspects of education and capacity building have been related to empowerment. Women’s empowerment has been measured using composite indexes and mixed methods to quantify their changes in HH influence. Reported results showed women participants gained control over HH food production and means of income generation, thus lifting their status in society, self-esteem, and their decision-making ability, even in male headed homes [53, 89, 97]. Women’s participation in gardening often comes with a higher workload, which has been previously associated with negative impact in care provision [19, 98], however, measures of time spent in the garden indicated no conflict between the two activities [50, 99]. Further studies should examine this possible trade-off of women’s empowerment to avoid worsening child and HH nutrition outcomes.

The results presented in this section show that FNS centred HG interventions can be enriched. It could be by evaluating their effect on emotional, affective, and social integration outcomes as they could be important for maintaining the changes [91]. Indeed, study participants have stated that engaging in

hands-on horticultural practice was a satisfying part of the intervention and a motivation for continuous participation [58, 59, 100, 101].

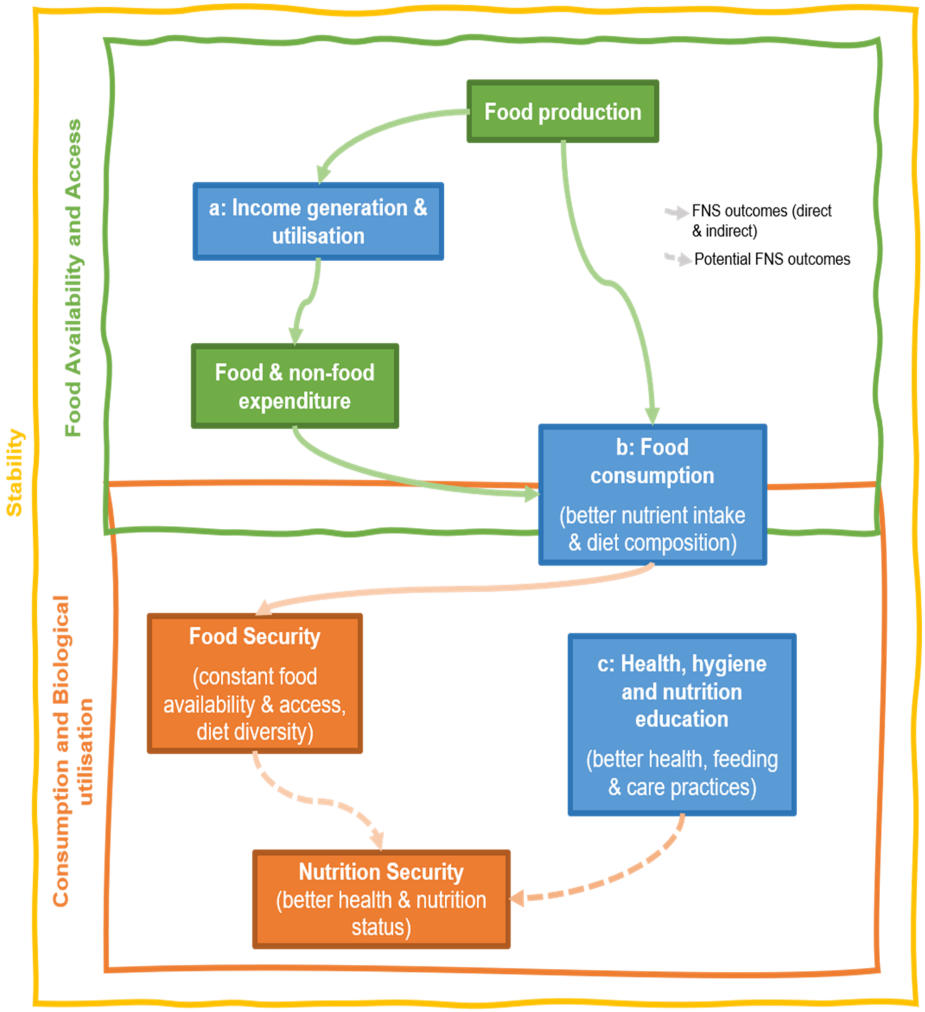

Figure 3: *Linkages between horticultural production and nutrition. Main pathways (a, b, c) to improve nutrition during home garden interventions, and the dimensions of Food and Nutrition Security to which they belong.*

3.2 Economic Dimension

In developing countries, financial impact has been widely mentioned, as part of the objectives of the interventions is to promote income generation or cost savings (Table 1), generally reporting positive results. However, it's worth saying that these specific benefits were not directly reported in most documents, rather discussed, or used to explain changes in FNS outcomes (impact pathways), which suggests a gap between, what is mentioned, and is demonstrated in the studies.

3.2.1 Productivity, Income, and Savings

The improvements made to agricultural practices during the interventions often led to increases in horticultural productivity among the beneficiaries, which were used as a proxy of intervention success. For example, studies in Bangladesh, India and Cambodia reported increases in the number of plots dedicated to horticulture [50, 52, 102]. Other studies in Africa reported increases in production and yield of the promoted FV [103, 104]; these increases in plant productivity can translate into higher nutrient availability for the HH [50, 105]. The literature also indicates greater economic returns in HH that have diversified and mixed gardens [52, 67, 73, 106]. In some instances, a productive perennial diversified gardening eventually allowed beneficiaries to acquire chickens and ducks at the time of evaluation, thus increasing HH assets [39, 52, 73].

The sale of surplus horticultural production can improve the financial status and welfare of beneficiaries by generating supplementary income when it is sold in local markets [39, 52, 53, 107]. Another widely mentioned benefit of HG interventions is a lower expenditure in garden produced foods of animal and plant origin [54, 107, 108]. In fact, a study from the USA reported that the cost saving benefits of gardening exceeded 300 USD during the summer season (high productivity, 5.9 m2) thanks to the high market value of organic produce [55]. These monetary benefits can translate into greater purchasing power. It has been observed that the income generated is generally invested in, for example, food items that are not produced in the garden, education (paying school fees and/or materials), as well as covering gardening production costs [39, 52, 53, 69, 99, 100]. This seems to indicate that the extra income is allocated to cover basic needs that improve HH wellbeing in the long run, contributing to poverty alleviation. Also, economic, or financial benefits are often cited as the reason for continued participation in the activities promoted during the intervention [53, 96, 100].

3.2.2 Economic efficiency

Cost-effectiveness of the intervention was mentioned in five reviewed papers of recent publication (2014-2018), but only quantified in 2 instances. Including these economic efficiency measures help validating food-based approaches as solutions for problems that could be solved with alternative health interventions, but it is uncommon in reports from developing countries. This parameter was related to maximizing the economic and nutrition benefits of an intervention for a given investment, reduction of costs and eventual expansion or continuity of the programmes [109]. The results from the 2 papers indicated that gardening interventions can be as effective as supplementation or medication to prevent micronutrient deficiencies or morbidities. However, in the long-term as they also generate positive effects in areas of HH wellbeing that may not be of economic nature; it has been advised to not use as the sole criterion for effectivity [50, 62].

3.3 Environmental dimension

In the case of gardening interventions, the evaluation of economic and social aspects has taken precedence. Few indicators or outcome measures relating to natural resource management (NRM) or ecological aspects of production have been used to evaluate the impact of gardening interventions. A review on community gardens also emphasized the lack of evidence pertaining to environmental benefits, environmental equity, and environmental sustainability as a need for future research in the topic [110].

3.3.1 Agrodiversity and Ecosystem Services

Although there is not much information in the studies reviewed; the most relevant principle is the promotion of agrodiversity in the gardens, whose main objective was increasing productivity, and reduce seasonality. Indeed, dietary improvements, vegetable consumption and utilization have been positively associated with garden diversity [50, 54, 56, 111]. Twenty-five papers mentioned the number of crops planted or the integration with livestock production or conservation of diversity, stating increases or conservation.

In addition to productivity, diverse gardens and perennial production could generate other ecological benefits. Establishing intercropping and polycultures can help control pests, reduce weed competition and climate shocks, thus lowering the risk of crop loss [112–114], which could explain a reduction in the incidence of said problems after training and adoption of sustainable practices in Bangladesh [50]. A vegetation covers can reduce water loss, soil erosion, and maintain fertility (mentioned in [68]). Finally, by increasing the number of flowering plants, pollination, pollinator diversity and plant genetic material dispersion are promoted [115, 116], in this context, the conservation of traditional and culturally important plants could be an important benefit (as mentioned in [55, 83]). Together, these ecosystem functions and services make it possible to increase the stability of the garden agroecosystem and HH's livelihood and FNS [117–119] and have been mentioned as potential benefits of HG [120]. According to our review, no recent paper has directly examined these kinds of services in the context of the outcomes of a FNS intervention. This lack of information is unfortunate, and it shows the relationship between food production and the NRM base has been overlooked in practice.

3.3.2 Agricultural practices

Even if ecological impact has not been explicitly evaluated, successes and challenges mentioned in previous sections have been associated with degrees of adoption of environmentally sound and low input practices. For example, studies in South Africa stated that gardening HH reported problems related to improper fencing, water use and availability, and insufficient access to pest/disease chemical control agents [54, 103], which kept appearing in subsequent evaluations [96]. These problems occurred in a large percentage of beneficiaries (41-72%) even when the intervention included training in water conservation and integrated pest management.

Other problems related to agricultural practices have been associated with inadequate design, e.g., introducing plants or garden models that are not adapted to local conditions, are difficult to maintain or include time-consuming practices; this could cause disadoption [88] or even adaptation if the participants are sufficiently motivated to continue gardening and overcome the limitations [100]. Unfortunately, the promotion of gardening and continuity based only on productivity motivations (economic or to maintain social standing) can also signify the continued use of agricultural methods that may not be environmentally friendly, e.g., using chemical pesticides and fertilizers [50, 103, 121]. Even if the benefits are preserved for decades, inadequate NRM practices have been shown cause environmental degradation (loss of soil fertility, loss of biodiversity) as well as negative health effects (reduction in water quality, agrochemical exposure), which will eventually compromise the livelihoods and nutrition outcomes of the beneficiaries [122–124].

In contrast, projects undertaken in developed countries often highlighted; that an important motivation for beneficiaries to adopt home gardens was precisely to learn how to produce FV in a clean and organic way, and to increase their access to healthy foods [55, 83, 94]. To create a similar view in developing countries, it is necessary to build an environmental conscience and strengthen the links between safe agriculture and FNS, and the long-term consequences of unsound practices, using transdisciplinary approaches. This could be done by, for example, consulting with the target population and integrating the local/traditional views of agriculture, food, nature and health to the design and evaluation of the intervention [41, 81]. Also, it is necessary to offer continuous support or extension services to overcome limitations and prevent returning to conventional practices by providing advice on low-cost agroecological/organic solutions. An encouraging example of this approach was found in a Pakistani project. It was largely focused on promoting organic practices and disaster recovery gardens, and devoted large efforts to create awareness in the dangers of pesticides [89]. This led to an overwhelming adoption of biopesticide use and integrated pest/weed management, as well as perceived improvements in some nutrition and economic outcomes, as well as psychosocial measures.

In summary, it is possible to observe in Table 1 (see Appendix), a list of selected home gardening interventions where their characteristics and results found by the various authors are observed.

4 Discussion

4.1 Sustainability of the Interventions

"Sustainability" has been addressed or discussed in gardening interventions, but it has been understood as the "continuity" or "longevity" of the promoted changes and obtained benefits after completion of the projects [53, 96, 100, 104, 125]. This definition of sustainability, although incomplete has been useful, since this type of articles have identified some of the determinants for disadoption, continuance or adaptation of practices. Thus, providing useful recommendations for the design of future interventions. In this way, the design of HG interventions now includes more comprehensive approaches to address malnutrition, including both human and environmentally friendly approaches in their design and implementation. Previous reviews have highlighted as a pre-requisite of a HG intervention success and a sign of their "holistic nature" (mentioned as natural capital investments [19, 44]. In some cases, interventions use participatory research approaches to solve nutrition issues. Thus, creating partnerships with the target population so that their priorities and needs are considered for the intervention design [126–129]. This type of research allows for dissemination of the interventions, even if beneficiary groups are small [56], and is generally considered to produce lasting benefits due to community engagement [41, 83, 89, 130]. However, as seen in the previous sections, the evidence base of these interventions is fairly limited to social and economic indicators.

As mentioned earlier, sustainable systems should be based in three pillars: profit, people, and planet, which means supporting economic and socially just development in an environmentally compatible way [131]. Increasing yields and productivity of gardens is the first step towards improving FNS. Adopting environmentally sustainable approaches during an intervention is a necessity in terms of achieving stability in the dimensions of food availability, access, and utilization [132]. Thus, HG interventions should not be considered sustainable just because the end-line state is preserved over time and without understanding the impact in the natural resource base that may be occurring upon adoption of certain practices.

The lack of evidence regarding the environmental outcomes of an intervention is, therefore, unfortunate and it also indicates how environmental and NRM aspects are mainly seen as "inputs" and not so much as outcomes of a FNS intervention (se models presented in [131] and [132]). More efforts should be devoted to rectifying this situation, however, a survey of current agriculture-nutrition interventions showed that impact assessment priorities remain skewed towards socioeconomic factors, as only 7% of the projects contained one indicator (water quality) related to the how an intervention can influence NRM and the environment [135].

4.2 Future directions

Systemic-transdisciplinary approaches have the potential to increase the sustainability of HG interventions. By using indicators or outcome measures from all three dimensions it would be possible to identify trade-offs and synergies between the different dimensions before, during and after the intervention is established [136, 137]. It would allow a holistic view of the complex interactions that exist between FNS and the food production system. Thus, furthering our understanding of the pathways by which interventions influence nutrition in the beneficiaries [138].

Systemic approaches have been used for ex ante and ex post impact assessment in agriculture-nutrition projects showing promising results linking sustainability (or sustainable development) and FNS [41, 139, 140]. These studies used participatory processes to evaluate and compare intervention outcomes. Systemic approaches become Transdisciplinary by integrating stakeholder knowledge (a.k.a. non-disciplinary knowledge) to an expert/academic/disciplinary FNS improvement strategy. Although there are other characteristic features that should be considered, such as the self-investigation of the stakeholders or some of them, in such a way that the union for a solution to the problem is achieved, mutual learning, etc [144, 145]. Of this manner, knowledge of academics and stakeholders is shared between each other at all research stages, generating innovative solutions for real-world problems [141–145]. This would also intensify participant involvement during a horticultural intervention from information and consulting to

empowerment and ownership [146].

A Systemic-Transdisciplinary approach also requires interdisciplinary academic collaboration. With rigorous research and expertise sharing across disciplines, the quality of the studies could be increased [144], and all aspects of sustainability considered. In the context of an intervention, cooperation between agricultural and nutrition scientists would allow the generation of adequate outcome/indicator metrics to explore its proximal benefits. Also, these scientists could encourage the realization of field experiments to validate the agricultural/horticultural practices promoted and adapt them to different geographical contexts [89, 147, 148]. Social, political, and economic scientists should also be consulted by agricultural/biological experts to account for factors such as markets, laws and regulations that influence sustainability, FNS and household decision-making processes.

We acknowledge that changing from a reductionist (single outcome) research methodology towards a Systemic-Transdisciplinary one is not simple, and it is one of the great challenges of truly holistic approaches. Measuring outcomes from all three dimension in FNS interventions leveraging agriculture is work intensive; as it requires a higher number of variables to be quantified and recorded, as has been found by our own research group in Mexico [143, 149]. Additionally, for HG interventions, multidimensional sustainability evaluations would require the development or adaptation of indicators and sustainability assessment frameworks [148, 150]. Regarding indicator selection, it has been recommended that interventions focus on results they may affect in a more direct way than nutrition status [135], such as diet diversity or variety, food consumption, income, and food supply and access. Inclusion of measures for energy or water use efficiency, soil fertility, weed/pest incidence and even some ecosystem services was also needed to address stakeholder concerns and specific challenges of local food production. In the long-term their monitoring would help maintaining resources and biodiversity, as well as building HH resilience [41, 119].

Finally, rigorous inter and transdisciplinary research across regions would be necessary [145]. This would mean the time required for developing, implementing, and assessing the multidimensional impacts of an intervention may be higher. Perhaps more importantly, it would be crucial to eliminate institutional and disciplinary barriers, as well as personal prejudices and group research preferences to ensure cooperation between scientists and actors [151]. However, we believe all this is justified in terms of gaining a better understanding of the elements and processes that contribute to improving FNS and sustainability at a local and even global level. Cooperation would also allow for expertise sharing across regions [145]. Thus, expanding the research landscape towards low- and middle-income countries and addressing both over and undernutrition issues.

5 Conclusions

The literature review supports the validity of HG interventions to improve food security by integrating agricultural aspects and nutritional considerations. Home gardening interventions mainly improve the diet of the households benefited directly and indirectly by them. However, the evidence base has tended to consider mainly undernutrition and micronutrient deficiencies; with few studies treating nutrition related NCD and the double burden of malnutrition, a rising issue in recent times.

Very few studies have used holistic research approaches that simultaneously considered the effects in the social, economic, and environmental dimensions of the intervention. Additionally, even if the interventions stated or discussed positive or negative effects in all three dimensions; they were often not demonstrated within the study, or their report was not considered relevant.

Further efforts should be devoted to developing adequate metrics and assessing the environmental outcomes of HG interventions, as well as multidimensional methodologies that offer a complete view of the sustainability of an intervention. This also implies using Systemic and Transdisciplinary research processes that address the complexity of the systems involved (FNS and productive) and foster cooperation between researchers and stakeholders in all stages of the intervention.

Transdisciplinary methodologies could be a support to carry out with rigor and in a broader sense the home garden interventions to improve food security, presenting their application in their various

characteristic features as one of the challenges in current research in some countries, mainly developing countries.

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Martha E. Domínguez-Hernández is a professor and researcher in the Department of Agronomic Sciences of the National Autonomous University of Mexico, as well as a member of the National System of Researchers. She is interested in the agricultural application of multidimensional sustainability impact assessment, participatory research, systems thinking and geographic information systems. Using these tools, her research focuses on the understanding of Mexican Agroecosystems and sustainable intensification of production to meet the food needs of a growing population while reducing environmental impact.

APPENDIX

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions.

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Bangladesh	HH, women (active vs former participants)	Examines continuity of all-year HG & NE programme designed to improve vitamin A status, evaluation of FNS, continuity, as well as economic & social benefits.	↑Productivity ↑Income ↑Purchasing power	↑Women Empowerment ↑Consumption (FV) ↑Agricultural knowledge	↑Agrodiversity		Quantitative	[53]
	Women	HG programme, including training in organic gardening, cooking & NE to ↑ availability & consumption of NR vegetables.	↑Productivity (all-year, harvest/yield, garden size) ↑Commercialisation	↑Variety (vegetable) ↑Nutrient yields ↑Female workload ↑Food utilisation (↓waste) ↑Agricultural knowledge ↑Women Empowerment	↑Agrodiversity (new crops) ↑Management practices (Planting, irrigation, seed, org. fertiliser etc.)		Quantitative	[97, 99]
	Women		↑Productivity (all-year, harvest/yield, garden size) ✓Cost-effective intervention	↑Consumption ↑Nutrient yields ↑Female workload ↑Food utilisation ↑Social integration (sharing) ↑Women Empowerment ↑Agricultural knowledge	↑Agrodiversity (new crops) ↑Management practices (×seed, water availability)		Quantitative	[50]
Burkina Faso	Women	All-year HG & NE programme w/ community monitoring (older women, health promotors) designed to improve production & consumption of NR foods (FV, animal-source), as well as child health outcomes.	↑Productivity	↑DD ↑Nutrition knowledge/Care practices ↓Child morbidity ↑Women empowerment ↑Community participation	↑Agrodiversity (promoted crops)		Quantitative	[67]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	**Participants/ beneficiaries**	**Characteristics**	**Economic**	**Social**	**Environmental**	**Pilot study**	**Type of measurements**	**Reference**
Cambodia	Women and children (<18 months)	All-year enhanced homestead food production (diversified gardening & w/ or w/o fishpond) paired w/ NE/hygiene/BCC/gender training programme designed to improve micronutrient & weight status.	N.D.	↑/=Nutritional status (children's anaemia, women's vit. A)/weight	↑Agrodiversity (crops, fish)		Quantitative	[151]
	HH w/Children	All-year HG & NE programme w/ community monitoring (older women, health promotors) designed to improve production & consumption of NR foods (FV, animal-source), as well as child health outcomes.	↑Productivity (all-year) ↑Income (moderate)	↑Consumption (Nutrient rich plant foods) ↑Nutrition knowledge/Care practices =Child morbidity/Nutritional status ×Nutrition knowledge/Care practices	↑Agrodiversity (improved &diversified gardens)		Quantitative	[52]
	Women and children	Enhanced homestead food production (diversified gardening w/ or w/o fishpond) paired w/ NE/hygiene/BCC/gender training designed to improve diets, micronutrient status.	×Productivity (low season)	↑Women nutrient intakes/*adequacy =Children's nutrient intakes/*adequacy ×Dietary habits (snack foods)	↑Agrodiversity (crops, fish)		Quantitative	[152]
Canada	Seniors	HG partnerships for health as alternative to community gardens.	↑Savings ↑Land access	↑Psychosocial measures ↑Dietary attitudes/Food values ↑PA ↑Social interaction	N.D.	Yes	Qualitative	[94]
Ethiopia	Adolescents	School based NE + home gardening &community participation programme to ↑ attitudes, knowledge & DD. Explores predictors of DD.	↑Productivity (#gardens)	↑DD ↑Nutritional knowledge ×Nutrition & food prejudices	↑/= Soil fertility	Yes	Quantitative	[68]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Ghana	Children	Mixed gardening (container) & livestock (poultry, egg, honeybees) intervention including input supply, organic agricultural training, NE (group & community) to improve health, consumption of NR foods, income generation (egg sales	↑Productivity ↑Income	↑Consumption (likelihood, eggs) ↑DD (Likelihood) ↑Nutritional status (child growth) ↑Care practices ↑Nutrition knowledge/Women empowerment/Community participation	↑Agrodiversity (Intercropping, livestock) ↑Management practices		Quantitative	[69]
India	HH w/children (<6years)	A perennial kitchen garden model (training, plant distribution according to season & demand) & NE to ↑ DD.	↑Productivity (#, size of gardens)	↑DD =Consumption (FV, Leg., Cer.) ↑Participation interest ×Food utilisation knowledge ×Agricultural knowledge	↑Agrodiversity (# crops) ↑Practices for RUE		Quantitative/ Qualitative	[102]
	Rural HH	Community based project- Provision of micro-credits, inputs & capacity building to improve FNS & income via diversification of HH activities (nutrition gardening w/ cash & food crops, mushroom production, livestock integration, food processing/cooking & recycling of crop waste).	↑Productivity/Diversification of activities ↑Income (↓poverty)	↑Consumption (FV, animal foods) ↑DD ↑Nutrition awareness ↑Food utilisation	↑Agrodiversity (Intercropping, livestock) ↑Organic fertiliser use		Quantitative	[106]
	Adolescent girls (10-19 years)	Community based interventions w/ kitchen gardening, supplementation & health promotion to improve availability of NR vegetables, ↓ anaemia & morbidity.	N.D.	↓Morbidity ↑Health, sanitation & nutrition knowledge ↑Nutritional status (anaemia)	N.D.		Quantitative	[70]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
India	Women and children (<60 months)	Mixed gardening & livestock (foraging laying hens) intervention including input supply, farm technology adoption training, BCC, HNE, to improve health, consumption of NR FV & eggs.	↑Productivity (# gardens, eggs produced) ↑Income (sales)	↑Consumption (eggs) ↑DD (Likelihood) ↑Nutritional status (child growth) ↑Hygiene/Care practices/Nutrition knowledge	↑Agrodiversity (crops, poultry) ×Management practices		Quantitative	[51]
	Rural HH	Kitchen gardening intervention to improve FNS, including organic production training & scientific advice, NE (utilisation & consumption of NR vegetables).	↑Productivity (all-year, yield) ↑Savings	↑Consumption ↑Women empowerment	↑Agrodiversity (types of veg.)		Quantitative	[108]
Kenya	HH w/children, neighbours (indirect beneficiaries)	Community-based participatory approach to address micronutrient deficiencies via horticulture & NE.	↑Productivity ↑Income	Children (direct/indirect: ↑Consumption ↑DD/Nutrient adequacy) Women: =Consumption/DD/Nutrient adequacy ↑Nutrition knowledge ↑Community participation	N.D.		Quantitative	[56]
Micronesia	Urban HH	Container gardening & improved cooking workshops & NE to improve health & nutrition through access to traditional foods (FV, staples).	N.D.	↑Consumption (↑promoted local foods, ↓processed foods) ↑Psychosocial ×Nutrition/Agricultural knowledge	×Management practices		Quantitative/ Qualitative	[88]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Nepal	Mothers and children (<2 years)	Enhanced homestead food production programme (gardening+poultry), training, NE, BCC, cooking classes, health promotion, input distribution & community monitoring to improve nutrition status of participants.	↑Productivity (food availability)	↑Women's DD (low season, remote zone) ↑/=Children's DD ↑Extension/support ↑Community participation ↑Nutrition/Health knowledge	↑/=Agrodiversity (poultry)		Quantitative	[153]
	Rural HH	↑ income via production of high-value horticultural crops w/ extension & improve nutrition via education.	↑Productivity	↑Consumption (FV) ↑Nutrition knowledge (unacceptable levels) ↑Hygiene/nutrition practices/Food utilisation	↑Agrodiversity (# crops planted & eaten)		Quantitative	[72]
	Women and children (12-48 months)	Enhanced homestead food production programme (gardening+poultry), training, NE, BCC, cooking classes, health promotion, input distribution & community monitoring to improve nutrition status of participants.	↑Productivity (# Enhanced gardens)	↑Food Security ↑Children DD ↑*Nutrition knowledge/Care practices ↑*Child &women nutritional status	↑Agrodiversity (types of FV)		Quantitative	[73]
Pakistan	Women	Participatory programme to provide training & capacity building in nutrition, rehabilitation of agricultural practices (sustainable horticulture, ↓ in pesticide use/risk, livestock raising) in the aftermath of a devastating earthquake. No comparison.	✓ Commercialisation/livelihood rebuilding/Diversification of activities	✓Consumption (veg.) ↑Psychosocial ↑Social integration/Community participation/Organisation ↑Women empowerment (capacity building/knowledge)	↑Agrodiversity (crop, livestock) ↑Management practices (↓Agrochemical use)		Quantitative/ Qualitative	[89]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Pakistan	Children (1-5 years)	Community based HG training, HNE programme w/ growth monitoring to ↑ production & consumption/utilisation of vitamin A rich produce (esp. orange-fleshed sweet potato).	↑Income/savings (potential)	↑Consumption (vit. A rich FV) ↑Psychosocial ↑Nutrition knowledge/Care practices ↓Child morbidity ↑Community participation	↑Agrodiversity (promoted crops) ×Management practices (pest control, irrigation)		Quantitative/ Qualitative	[103]
	Women	Integrated intervention, including HG (soy & vegetables), NE & cooking to improve FNS and DD.	↑Productivity	↑ Consumption (soy containing) ↑Psychosocial (attitudes) Community participation (req. for continuity)	N.D.		Quantitative/ Qualitative	[154]
	HH	Examines factors contributing to continuity of an integrated intervention, including HG (soy & vegetables), NE & cooking to improve FNS and DD.	↑Productivity/Diversification of activities ↑Income (↓poverty)	↑Consumption (FV, animal foods) ↑DD (×variety) ↑Nutrition awareness ↑Nutritional status (lipid status)	↑Agrodiversity (Intercropping, livestock) ↑Management practices (Organic fertiliser use)		Quantitative	[125]
	Gardening vs non gardening HH (women)	Examines continuity of practices. HG training & NE programme w/ community monitoring to ↑ production & consumption/utilisation (incl. cooking classes) of vitamin A rich produce.	✓ Income/commercialisation (not main objective)	↑Consumption (vit. A rich FV) ↑Psychosocial =Nutrition knowledge/Care practices ↑Social integration (sharing)	↑Agrodiversity (promoted crops) ×Management practices (pest control, irrigation, seasonality)		Quantitative/ Qualitative	[96]
Tanzania	Women (18-49 years, indirect beneficiaries)	Examine the broader nutritional effects of a HG intervention in non-participants.	↑Productivity (spillover, garden)	↑DD (Likelihood) ↑Social integration/Community participation	N.D.		Quantitative	[32]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Tanzania	Mothers & children	Examines continuity of a horticulture & nutrition education intervention to↑ knowledge & care practices &nutritional status of children.	↑Productivity (# gardens)	↑Consumption (vit. A rich FV) ↑Food utilisation (solar dryer) ↑Nutrition knowledge ↓Nutritional status (retinol, parasites)	↑Agrodiversity (promoted crops)		Quantitative	[104]
USA	Low-income families	Citizen scientist evaluation of gardening project (raised bed, provision of seeds & organic agriculture training).	↑Productivity (yield) ↑Savings (food) ? Costs (✓ water/? inputs)	↑Consumption (recommended cups) ↑Agricultural knowledge ↑Social integration (sharing)	=Agrodiversity (cultural foods) ×Practices for RUE (drip irrigation)		Quantitative	[55]
	Breast cancer survivors	Mentored gardening to improve health & dietary outcomes (↓obesity & comorbidities) in a high-risk population.	? Cost-effectiveness	↑Psychosocial measures ↑Dietary attitudes ↑Consumption (FV) ↑PA ↑*Nutritional status (BMI)	N.D.	Yes	Qualitative	[58]
	Adult and child cancer survivors		N.D.	↑Psychosocial measures ↑Dietary attitudes ↑Consumption (FV) ↑PA	N.D.	Yes	Quantitative/ Qualitative	[59]
	Latino migrant worker families	Community based participatory gardening and agricultural training program to produce FV in a pesticide-free & organic way.	✓Savings	↑Consumption (FV) ↑Psychosocial ↑PA ↑Food Security ↑Knowledge (preservation) ↑Social integration/Community participation ↑Agricultural knowledge (+interest)	↓Agrochemical use		Quantitative/ Qualitative	[83]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	**Participants/ beneficiaries**	**Characteristics**	**Economic**	**Social**	**Environmental**	**Pilot study**	**Type of measurements**	**Reference**
USA	Cancer survivors (≥60years)	Mentored gardening to improve health & dietary outcomes (↓obesity & comorbidities) in a high-risk population.	? Cost-effectiveness	↑Psychosocial measures/Psycho-biomarker (telomerase) ↑Dietary attitudes ↑Consumption (FV) ↑Phys. performance ↑Nutritional status (Waist circumference)	N.D.	Yes	Quantitative/ Qualitative	[60]
	Seniors	Feasibility study to explore the health & nutrition benefits of a gardening project (raised bed, provision of tools, recipes & training) in a low-income senior community.	N.D.	↑Psychosocial ↑Consumption/view of health ↑Workload (manageable) ↑Social integration (sharing, engagement) ↑Agricultural knowledge	N.D.	Yes	Quantitative/ Qualitative	[61]

↑ Improvement or higher. ↓ Decrease or lower. = No change, maintenance.? Unknown or inconclusive effect. * Trends. ✓Positive outcome. × Negative outcome. *Italics imply the outcomes were measured.* Regular font style implies the outcomes were mentioned or discussed. FV: Fruits and vegetables. PA: Physical activity. BMI: Body mass index. RUE: Resource use efficiency. N.D.: Not determined or detailed.