Homegarden agroforestry systems in achievement of Sustainable Development Goals. A review

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Abstract
Homegarden, a type of agroforestry system, is one of the earliest thriving traditional food systems reported. Studying the contribution of homegardens in the context of Sustainable Development Goals (SDGs) is crucial when the COVID-19 pandemic has hindered the achievement of many of the crucial SDGs. In this review, we focused on 94 peer-reviewed papers on homegardens from 2010 to 2021 to interrelate them with the corresponding targets and indicators of each SDG. The SDGs were classified into five categories, each focusing on a specific aspect: Category 1 (SDGs 1–5, poverty dimension), Category 2 (SDGs 6–9, development infrastructures), Category 3 (SDGs 10–12, sustainable production and consumption), Category 4 (SDGs 13–15, green infrastructures), and Category 5 (SDGs 16–17, green institutions). The distribution of the 94 papers analyzed was 92%, 23%, 33%, 51%, and 50% in each of the SDG categories, respectively. Category 1 and SDG 2 were found to be most realized in the homegarden literature. Important observations were found that highlight homegardens’ probable use in providing food security, nutritional needs, health and wellness, preservation of agrobiodiversity, and enduring sustainability. Homegardens appear to be an important strategy for attaining the SDGs and can be accomplished with proper planning, in addition to taking into consideration how the traditional societies have sustained it for long.

Keywords Agroforestry systems · Homegardens · Sustainable Development Goal · Traditional systems · Food security · Agrobiodiversity

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1 Introduction
The Sustainable Development Goals (SDGs) are a set of 17 actionable areas and 169 targets adopted by the United Nations General Assembly in 2015, aspiring to be fulfilled by the year 2030. It complements the eight Millennium Development Goals (MDGs) to achieve sustainability in social, environmental, and economic growth (Sachs 2015; Salvia et al. 2019). Land-use, particularly food systems, has been mentioned as a single point of convergence for these
goals (Agroforestry Network 2018; van Noordwijk et al. 2018). All the participating nations have reported annual progress on these goals (Allen et al. 2020). However, the COVID-19 pandemic has hampered progress on several fronts to achieve some of these goals (in particular, SDGs 2 and 3) (Shupler et al. 2021), which is evident from the rising levels of malnourishment and hunger around the world. As per the latest UN report on food security and nutrition (FAO, IFAD, UNICEF, WFP and WHO, 2020), 720 to 811 million people are undernourished globally. Both developed and developing countries are being affected, although South Asia, Sub-Saharan Africa, Latin America, the Caribbean, and the Pacific area will be the hotspots of food insecurity (Lal 2020). COVID-19 has exacerbated the already chronic problems of hunger and hidden hunger in Asia and Africa, the two continents with the highest rates of under-nourishment and malnutrition. Therefore, strengthening local food production at the family and community levels is critical. Clearly, more robust food production techniques must be adopted to reduce food waste along the supply chain. There is also a need to strengthen local agricultural capacities (Lal 2020; Minan and Kumar 2021). Modern agricultural systems focusing on monoculture have consequences such as erosion of farmland biodiversity (Millennium Ecosystem Assessment 2005; IPBES 2019) and an increase in the incidence of many zoonotic diseases (IPBES 2019). Given the global realization of the unsustainability of modern agricultural practices and the threat of climate change, there is a need to explore sustainable agricultural practices to ensure food security. The recent Global Food Policy Report has highlighted the overriding need for food system transition to regain the lost ground for achieving the SDGs by 2030 (IFPRI 2021).

Agroforestry, an integrated land management system of growing food crops, trees, and/or animals together for multiple benefits from the same land parcel, is a diversified land-use system reported to be practiced by farmers throughout the world for a long time (Nair et al. 2021b). Agroforestry systems can be classified into agriliviculture (crops including shrubs/vines and trees), silvopastoral (pasture/animals and trees), and agrosilvopastoral (crops, pasture/animals, and trees) systems (FAO 2015). Homegardens (HG) represent a type of agroforestry (agrosilvopastoral) involving “multispecies combinations of a variety of economically useful plants including trees, shrubs, vines, and herbaceous species, often in association with livestock, in small landholdings around or adjacent to the home” (Figs. 1 and 2) (Nair et al. 2021a). It is regarded as a “time-tested example of sustainable agroforestry” (Kumar and Nair 2006). It is practiced extensively in tropical and temperate regions (Nair et al. 2021b). The homegardens, thus, represent a farming system, which blends diverse production functions, enhances food supply, and increases food diversity. Homegardens provide easy access to fresh vegetables and fruits daily, leading to enriched and balanced diets with protein, vitamin, and mineral supplements (Galhena et al. 2013).

An attempt to link the agroforestry systems to the potential achievement of global goals is not new. Previously, agroforestry systems’ contributions to achieving the MDGs, namely eradicating hunger, uplifting the rural poor from poverty, conserving biodiversity, protecting watershed, and building human and institutional capacity to adapt to climate change, have been reported (Garrity 2004; Mbow et al. 2014). Table 1 shows the historical distribution of publications in this respect. Homegardens, especially their tropical form, are second only to shifting cultivation among the earliest food production methods (Kumar and Nair 2004). Fernandes et al. (1984) described homegardens as a land-use system that involves a range of practices from vegetable planting to complex multi-storeyed systems around the house. FAO defined HG as a “small-scale, supplementary food production system by and for household members that mimic the natural, multi-layered ecosystem” (Hoogerbrugge and Fresco 1993). One of the most widely used definitions of HG, however, is as the “intimate, multi-story combinations of various trees and crops, sometimes in association with domestic animals, around homesteads” (Kumar and Nair 2006) (Fig. 3). Table 2 lists the characteristics of HG, and the salient ones include the following: (1) located near the residence of the gardener (Mitchell and Hanstad 2004); (2) accommodate high plant diversity (Galluzzi et al. 2010; Mitchell and Hanstad 2004); (3) the production of complementary food rather than being the main source of income and consumption (Nair 1985); (4) involves a small area (Brownrigg 1985); and (5) being a system that requires minimal financial investment for initiation; HG are the system of production that the poor can easily enter at some level (Marsh 1998).

HG have been documented worldwide, mainly in the tropical regions where profound variability in size, frequency, and function of HG has been noted (Kumar and Nair 2004). According to published data, the Indonesian homegardens, or pekarangan, cover around 5.13 million ha of land, with about 1.74 million ha in Java alone (BPS 2000). In Bangladesh, homegardens occupy around 0.88 million ha, with 0.81 million ha in rural areas (BBS 2020). In Sri Lanka, the extent of homegardening is approximately 1.05 million ha (LUPPD 2020), about 60% of the landholdings of size <8 ha. Similarly, in the Philippines, HG are maintained by nearly 70% of households (Landauer and Brazil, 1990). A rough estimate suggests that HG forms the 15–36% residential area in countries like China, the UK, Africa, and India (Clarke et al. 2014). Differences in soil, topography, and species diversity determine the choice of crops and other species in HG. While HG are sometimes referred to as the epitome of sustainability (Torquebiau 1992), it is sometimes considered an enigma (Kumar and Nair 2004). In any case, they are a time-tested example of sustainable agroforestry. The HG structure is also
reportedly variable among different traditional societies (Altieri et al. 2015).

As per the recent reports by the Agroforestry Network, land management systems such as agroforestry have the potential to achieve nine out of the 17 SDGs. With a relatively higher focus on goals such as 1 (No Poverty), 2 (Zero Hunger), 13 (Climate Action), and 15 (Life on Land) than others (Agroforestry Network 2018). With this background, a review aiming at analyzing the role of HG in the achievement of 17 SDGs was attempted (based on knowledge generated on them.

Figure 1  A few examples of homegardens in India: a Crops like cassava (Manihot esculenta), and several tree species including jackfruit tree (Artocarpus heterophyllus) and kumkum tree (Mallotus philippensis) from Idukki district, Kerala (Photo: BM Kumar). b A multi-species homegarden in Thrissur, Kerala: coconut palm (Cocos nucifera), areca palm (Areca catechu), and other miscellaneous species (Photo: BM Kumar). c A women-owned homegarden in Sonitpur district, Assam: areca palm (Areca catechu), black pepper (Piper nigrum), and other miscellaneous species (Photo: R Sharma). d Animals as important component of HG in Sonitpur district, Assam (Photo: R Sharma).

Figure 2  Classification of agroforestry systems.
in the last 11 years, i.e., 5 years before and 6 years after formulating the SDGs). As proposed by van Noordwijk et al. (2018), the SDGs were organized into five categories—Poverty Dimensions, Development Infrastructure, Sustainable Production and Consumption, Ecological Infrastructure, and Institutions. We provide a descriptive overview of the challenges involved in the particular category of SDGs, and then analyze the literature on HG published over the previous 11 years to explore how HG are linked to these challenges, including food insecurity, malnutrition, agrobiodiversity loss, unsustainable agricultural practices, biodiversity loss, and loss of food sovereignty. This review has three contributions: first, it provides policymakers with a knowledge base for considering HG as a policy option for achieving the SDGs; second, it identifies the gaps in scholarly evidence needed to situate HG in the achievement of SDGs; and third, it attempts to address the synergies between diverse SDGs in the design of sustainable food systems.

![Image of typical benefits derived from homegardens.](image-url)

**Table 1** Role of agroforestry systems in attaining Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs).

| Focused global goals | Study type           | Location | System considered                      | Major outcomes                                                                                                         | References                        |
|----------------------|----------------------|----------|----------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| SDGs 1, 2, 3, 8,    | Case study and review| Global review with the case study in the UK, Uganda | Small-scale food production systems in an urban area, Homegardens | Reduced poverty, improved health outcomes, reduced pressure on the environment, and improved climate resilience. | Nicholls et al. (2020)            |
| 11, 12, 13, and 15  | Field-based study    | Uganda   | Homegardens                            | Enhanced food and nutritional security                                                                                  | Whitney et al. (2018a)           |
| SDG 2                | All MDGs             | Africa   | Agroforestry                           | Poverty reduction, improved health, avenue of income for women, environmental sustainability                           | Garrity (2004)                   |
| All SDGs             | Review               | Africa   | Agroforestry                           | Enhanced food security, improved farmer livelihoods, and environmental resilience                                       | Mbow et al. (2014)               |
| All SDGs             | Review               | Global   | Agroforestry                           | Useful in sustaining all aspects of human growth in sustainable ways                                                  | van Noordwijk et al. (2018)      |
| SDG 2                | Review               | Global   | Agroforestry                           | Decreased rural poverty and hunger and maintaining better provisions of ecosystem services                           | Montagnini and Metzel (2017)     |

**Figure 3** Typical benefits derived from homegardens.
2 Methodology

The 17 SDGs are interconnected either in the form of synergy, i.e., achievement of one goal helps in the achievement of another, or in the form of trade-offs, i.e., potential achievement of one may disrupt the achievement of another (Dolley et al. 2020). In the present review, for analyzing the potential of HG for achieving the SDGs, 17 SDGs are grouped into five categories following the classification scheme proposed by van Noordwijk et al. (2018) and Cumming et al. (2017) (Fig. 4).

Category 1 focusing on multiple poverty dimensions includes SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Human Well-being), SDG 4 (Quality Education), and SDG 5 (Gender Equality). We analyzed the challenges of Category 1 and how HG addressed them through the literature on income

Table 2  General characteristics of homegardens.

| Characteristic | General practice |
|----------------|------------------|
| Size           | Variable; generally the size is less than that of the cropland owned by the household (Brownrigg 1985). |
| Structure      | Each has a unique structure because of variation in natural conditions, available family resources, i.e., labor, skills, preferences, and enthusiasm of household members (Nair 1985) |
| Species density| High (Galluzzi et al. 2010) |
| Species type   | Vegetables, fruits, staples, medicinal plants (Mattsson et al. 2018) |
| Production objective | Home consumption (Mitchell and Hanstad 2004) |
| Labor source   | Family (elderly, women, children) (Mattsson et al. 2018) |
| Labor requirements | Part-time (Mitchell and Hanstad 2004) |
| Harvest frequency | Daily, seasonal (Marsh 1998) |
| Space utilization | Horizontal and vertical (Kumar and Nair 2004) |
| Location       | Near the residence (Nair 1985) |
| Cropping pattern | Irregular and row (Fernandes et al. 1984) |
| Technology     | General and simple hand tools (Torquebiau 1992) |
| Input-cost      | Low (Marsh 1998) |
| Distribution   | Rural and urban areas, tropical and temperate regions (Kumar and Nair 2004) |
| Skills         | Gardening and horticultural skills (Mitchell and Hanstad 2004) |
| Assistance     | None or minor (Mitchell and Hanstad 2004) |

Figure 4  Sustainable Development Goals under five categories and homegarden potential role in their achievement.
improvement (1.2), food security (2.1), nutritional security (2.2), farm income (2.3), sustainable agricultural practices (2.4), agrobiodiversity (2.5), preventing non-communicable disease (3.4), contribution to education initiatives (4.7), and women role in HG (5.4). Category 1 involving SDGs 1 to 5 is among the most crucial goals essential for the very sustenance of human life across the globe. At times, when poverty (SDG 1) and food security (SDG 2) are emerging as the major challenge across the globe, concerted global efforts are necessary to achieve these goals (Blesh et al. 2019; World Bank 2020). Previously, eradication of hunger mostly involved counting the intake of calories; however, only calorie intake would not suffice for this purpose. Nutritional needs, if not satisfied, can lead to severe stunting, wasting, and improper brain development, affecting the overall health (SDG 3) of individuals as well as the educational outcomes (SDG 4) of children (Darteh et al. 2014). Rising atmospheric CO$_2$ concentrations can drastically reduce the iron, zinc, and protein contents of crops, which in turn can again push 175 million people to the risk of mineral and protein deficiencies, especially in the poorer countries (Smith and Myers 2018). The importance of designing a system that women and marginalized people can easily practice (SDG 5) is also essential since 70% of the world’s poor people are women and are vulnerable to climate change and environmental and economic shocks (IPBES 2020).

Category 2 focusing on development infrastructure includes SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation, and Infrastructure). We analyzed the challenges of Category 2 and how HG addressed them through the literature on water conservation (6.4), availability of renewable energy (7.4), decent livelihood (8.5), and opportunities of non-farm livelihood (9.1) aspect of HG. In the wake of the reports of dwindling groundwater resources worldwide (Turner et al. 2019), there is a need for farming systems with efficient groundwater use (SDG 6). Similarly, finding more environmentally friendly ways to gather fuelwood (SDG 7) remains a significant challenge, with about 2.4 billion poor people around using this form of energy (Rahman et al. 2021). Also, exploring small-scale systems that can provide better employment opportunities at the local level is essential (SDG 8). The Mitchell and Hanstad (2004) training sheet mentions HG as the systems that can provide the products for the agro-processing industry at the local levels (SDG 8 and SDG 9).

Category 3 focusing on sustainable production and consumption includes SDG 10 (Reduced Inequality), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). We analyzed the challenges of Category 3 and how HG addressed them through HG literature on the improvement of income of marginalized groups (10.1), the contribution of HG in urban green space and agriculture (11.7), and productivity aspects of HG (12.3). To improve the income opportunities of the bottom 40% of people, target 10.1 of SDG 10 seems relevant for HG. It is a system that the poor and marginalized can easily practice (Mitchell and Hanstad 2004). Also, with the poor concentrating in the cities, designing production systems in which the poor can easily participate is urgently needed (World Bank 2020). In developing countries, urban agriculture is associated with better income and nutritional needs. In contrast, in the developed countries, they are more of the symbolism of ecotechnological approaches and getting reconnected to nature (Amos et al. 2018). Generally, food comes from long distances in the cities, often covering 800 to 1500 km, substantially increasing the carbon and water footprints. However, the current thrust is on food production systems that are more sustainable, emphasizing local production (Lal 2020; Nicholls et al. 2020).

Category 4 focusing on ecological infrastructure includes SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land). We analyzed the challenges of Category 4 and how HG could be beneficial through the literature published on carbon sequestration potential (13.2), nutrient flow to water bodies (14.7), and biodiversity conservation (15.2, 15.3, 15.4, 15.5). The modern agricultural sector is the emitter of three major greenhouse gases, i.e., carbon dioxide, methane, and nitrous oxide, contributing to a total of one-third of the greenhouse gas emissions (Vermeulen et al. 2012; Secretariat of the Convention on Biological Diversity 2020). Therefore, farming practices need to be reoriented, as we desperately need to move to a low emission world. Water bodies worldwide suffer from nitrogen- and phosphorus-based eutrophication, and acidification of soils, worsening water quality with nitrates and nitrates entering the water supply caused due to excessive agricultural wastes (Kanter et al. 2020). Biodiversity loss is another major factor affecting the agroecosystems worldwide, threatening primary ecosystem functions and services (Skogen et al. 2018). In particular, pollinator populations of honey bees and others vital for sustaining productivity of fruits and other types of flowering plants are declining in many parts of the world (Secretariat of the Convention on Biological Diversity 2020; IPBES 2016).

Category 5 (Institutions) comprises SDG 16 (Peace, Justice, and Strong Institutions) and SDG 17 (Partnerships for the Goals). We analyzed the challenges of Category 5 and how HG addresses them through the literature published on the role of community in the maintenance of HG and the concepts of food sovereignty (16.7), and the probable value addition of HG products for export (17.1). The Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework suggests that institutions and governance systems significantly affect the ability of nature’s contribution to people to provide good quality of life and human well-being (Diaz et al. 2015).
Out of the many benefits that nature can produce, humans have extensively used the provisioning benefits, grievously neglecting the regulating ones (IPBES 2020). A focus on this, although required for finding the systems which balance human interactions, is lacking.

We then systematically searched the Science Direct, Web of Science, and Google Scholar databases for articles on HG using the keywords “homegardens,” “home gardens,” and “homegarden agroforestry” for the 2010–2021 (February) period. We searched these keywords in the title of the articles and obtained a total of 732 articles. For reviewing, we considered original and peer-reviewed research articles only. After these filtrations and duplicate removal, 224 articles were then studied by abstract to judge the relevance to targets of SDGs by whether they mention any of the keywords as mentioned in Table 3. From it, we found 117 articles to be relevant to the study. We then studied the full text of these articles for the empirical data, and 90 peer-reviewed publications were shortlisted. We also checked the literature citation sections of the selected papers for any additional references. At last, a total of 94 articles were found suitable for this review. The articles were further sorted into five categories as per their relevant keywords of SDGs, as mentioned in Table 3. The relative distribution of the publications obtained from different countries and the frequency of publications in each category is as shown in Fig. 5. Most studies were reported from India (14%), followed by Mexico (12%). The papers often reflected more than one category of SDGs, especially for Categories 2, 4, and 5.

3 Results

3.1 How HG literature has addressed challenges in Multiple Poverty Dimensions (Category 1)

We found 86 (92%) papers referring to Category 1 of SDGs. Most of the publications (89%) referred to one or the other aspects of SDG 2 (Zero Hunger). Regarding SDG 1, 20% of the total publications referred to considered indicator 1.2 of improvement of income (Whitney et al. 2017; Abdoellah et al. 2020; Whitney et al. 2018b; Wiehle et al. 2014; da Cunha Salim et al. 2018). The publications interrelated with targets 2.1 (food security) and 2.2 (nutritional security) of Goal 2 were 38% and 15%, respectively. The production of food rich in vitamins and micronutrients, especially vitamin A, was reported to be substantially high in the HG compared to other agriculture systems (Whitney et al. 2017; Castaño-Navarrete 2021; Pinela et al. 2012). The importance of HG in providing food and nutritional security has already been reported from Thailand, Uganda, Mexico, Ethiopia, India, and Bangladesh (Cruz-Garcia and Struik 2015; Whitney

| Category | Sustainable Development Goals | Keywords/Thematic areas used | Publications |
|----------|-------------------------------|-----------------------------|--------------|
| 1: Multiple Poverty Dimensions | 1: No Poverty | Poverty, income | 19 (20%) |
| | 2: Zero Hunger | Food security, nutrition, malnutrition, anemia, farm income, agrobiodiversity, small-scale producers | 83 (88%) |
| | 3: Good Health and Well-being | Medicinal plants, mental health | 31 (33%) |
| | 4: Quality Education | Education, learning, knowledge | 0 (0%) |
| | 5: Gender Equality | Women, gender | 10 (11%) |
| | 6: Clean Water and Sanitation | Water, irrigation | 3 (3%) |
| | 7: Affordable and Clean Energy | Energy, fuelwood | 7 (7%) |
| | 8: Decent Work and Economic Growth | Livelihood, employment | 21 (22%) |
| | 9: Industry, Infrastructure, and Innovation | Industries, factory, enterprise | 0 (0%) |
| 2: Development Infrastructure | 10: Reduced Inequalities | Equality, marginalized | 19 (20%) |
| | 11: Sustainable Cities and Communities | Cities, urban, green space | 10 (11%) |
| | 12: Responsible Consumption and Production | Food waste, sustainable food consumption, sustainable food production | 17 (18%) |
| 3: Sustainable Production and Consumption | 13: Climate Action | Carbon sequestration, soil carbon, standing biomass | 12 (13%) |
| | 14: Life Below Water | Eutrophication, organic fertilizers, fewer pesticides | 0 (0%) |
| | 15: Life on Land | Biodiversity, pollination, wild animals, habitat services | 43 (46%) |
| 4: Ecological Infrastructure | 16: Peace, Justice and Strong Institutions | Traditional systems, personalized space, intervention | 47 (50%) |
| | 17: Partnership for Goals | Value addition, exports | 0 (0%) |
et al. 2018a; Wolka et al. 2021; George and Christopher 2020; Panyadee et al. 2018; Schreinemachers et al. 2015; Ferdous et al. 2016). Also, there were papers relating that agrobiodiversity in HG positively affects dietary diversity. Such studies relating agrobiodiversity in HG have used indicators of household dietary diversity score, child dietary diversity score, toddler dietary diversity score, and the minimum dietary diversity for women (Whitney et al. 2018b). The 24-h recall method used in the study highlighted that the majority of the food recalled was harvested and ingested the same day, highlighting a steady supply from HG (Whitney et al. 2018b).

Ethiopian HG contributes 25–85% food demand of the house, more than that of croplands (Wolka et al. 2021). Also, in India, edible plants form 39% of the total plant species in HG (George and Christopher 2020). Complementing a similar study in the Yucatán region of Mexico highlighted a positive relationship between plant diversity and animal diversity in HG to better dietary intake (Castañeda-Navarrete 2021).

Domestication of the diverse landraces and species which are not otherwise easily cultivated is the feature of homegardeners (Wiehle et al., 2014). Corresponding to this, target 2.5 (Agrobiodiversity Conservation) was the next frequently mentioned criteria in HG, with 48% of studies referring to it. One of the reasons for getting more diverse landraces in HG is the cross-breeding between wild and domesticated varieties. Many relic crops that are not common in the commercial farms prosper in HG, making them important in situ conservation sites for landraces. As many as 39 landraces of 31 species are reported from the HG of the Iberian Peninsula and 269 species in 70 HG of Central Amazon (Calvet-Mir et al. 2011; Junqueira et al. 2016). In Hungary, the HG of Csinod contained most planted species grown from their seeds and those available from the adjacent mountains (Papp et al. 2013). Fennoscandian HG had the indigenous variety of shallot, also called potato onion (*Allium cepa*) (Leino et al. 2018). In Sweden, the HG have local cultivars of *Pisum sativum* (Solberg et al. 2015). HG of Mesoamerica conserved the germplasms of wild species of *Brosimum alicastrum* (Breadnut), *Cordia dodecandra* (Ziricote), and *Spondias purpurea* (Jocote) (Ferrer et al., 2020). However, almost 70% of the plant varieties in HG were of the multi-use category (Vlkova et al. 2011), making them an important example of conservation models by use.

Target 3.4 (Better Health) under Goal 3 has been mentioned in 31 (33%) publications, with the publications related to prevention of non-communicable disease (indicator 3.4.1) and improvement of mental health (indicator 3.4.2). In Ecuadorian HG, the medicinal plants are used for primary healthcare by 91% of gardeners (Caballero-Serrano et al. 2016). Infections, infestations, nutritional diseases, and digestive disorders were the most reported ailments for which the medicinal plants in the HG of four ethnic tribes in Thailand were used (Panyadee et al. 2019). The Naxi healers from the Sino-Himalayan region cultivate key medicinal plants, which play a crucial role in community well-being (Yang et al. 2014). HG formed an essential part of the folk therapeutic system of Transylvania, a fast depleting bio-resource that needs to be conserved (Papp et al. 2013). Paraguayan migrants living in Argentina conserve medicinal plants (Kujawaska et al. 2018).

Regarding indicator 3.4.2, which relates to improving mental health, there are 4 (4%) publications. A study from Scotland mentions that HG are the great contributor to managing older adults’ physical, mental, and emotional health at COVID-19 times (Corley et al. 2021). Another study from Spain mentions the crucial role of HG in suicidal tendency prevention (Calvet-Mir et al. 2012). Also, immigrant HG are the vital component of better mental health in Southern California (Mazumdar and Mazumdar 2012).

Regarding Goal 5, the gendered effect of the HG corresponding to target 5.4 was reported from many traditional societies around the world. Ten (11%) publications have mentioned this target of Goal 5. In rural Bangladesh and the Yucatan region of Mexico, HG are generating employment.
for rural women (Kabir et al. 2016; Castañeda-Navarrete 2021). Studies from the Iberian Peninsula and Mexico reported that HG managed by women was more species-rich on a unit area basis than gardens managed by men. Moreover, women favored household consumption compared to sale or gifting (Reyes-García et al. 2010; Buechler 2016). However, women often do not have land ownership, which affects the women-managed HG structure, composition, and functions. For example, in rural Ethiopian HG, women had a significant role in the overall production and processing of HG. However, with the advent of more commercialized HG involving monoculture khat (Catha edulis) production, the women’s role was substantially diminished (Gebrehiwot et al. 2018).

3.2 How HG literature has addressed challenges in Development Infrastructure (Category 2)

We found 21 (23%) publications related to this category of goals. Though intuitively, HG are the systems that require less water due to lower evapotranspiration and lower soil moisture losses (Kumar and Nair 2004; Fernandes and Nair 1986). Studies directly linking HG to water conservation corresponding to target 6.4 of Goal 6 are scanty. Only three studies, one from Oman, another from the Kerala state of India, and a third from northeastern Thailand, have reported the role of HG in sustainable water management. In the study from Oman, the designing of better irrigation techniques uses the capillary barrier wick irrigation system in the HG (Al-Mayahi et al. 2020). The second study from Kerala reported that diverse cultivated plant species in the HG support the quick recovery of crucial soil microarthropods, making HG a resilient agroecosystem in extreme meteorological events of drought and flood (Lakshmi et al. 2021). In northeastern Thailand, the rain-fed HG systems required very little groundwater for irrigation (Cruz-Garcia and Struik 2015; Goenster et al. 2014).

HG are often an important source of fuelwood corresponding to target 7.2 of SDG 7 (Agroforestry Network 2018). This target is critical when approximately 2.4 billion poor people worldwide use fuelwood as the main form of energy (Rahman et al. 2021). There were 7 (8%) publications focusing on this target. Fuelwood harvested from the HG of Bangladesh provides USD 71.9 per homegarden per year, and fuelwood was the only commodity gathered around the year (Alam 2012). In rural Vietnam, the fuelwood collected from HG constituted 32% of the total material collected (Vlkova et al. 2011). Also, HG in Thailand and India provides primary fuelwood sources (Panyadee et al. 2018; Das and Das 2015).

Nineteen (20%) publications mentioned HG as the source of livelihood corresponding to target 8.5 of SDG 8. Worldwide, the HG can improve the farm incomes of marginalized groups and women (Kabir et al. 2016). In rural Uganda, the high crop diversity positively impacted rural livelihoods (Whitney et al. 2018b). Commercialization (i.e., the introduction of high fetching cash crops) may further increase the cash income of the gardeners (Mellisse et al. 2018; Wielhe et al. 2014). Also, HG can improve the income by being the sites of eco- and ethnotourism where the traditional lifestyles, local customs, and biocultural heritage of the homegardeners would be presented (Vlkova et al. 2011).

3.3 How HG literature has addressed challenges in Sustainable Production and Consumption (Category 3)

We found a total of 31 (33%) publications relating to this category of goals. Nineteen (20%) examples mention target 10.1 (improvement of income of marginalized groups) of SDG 10 (Reduced Inequality). For instance, the marginalized people of Barak Valley in the Indian state of Assam use HG products as an instant source of cash during emergencies (Das and Das 2015). In Java, Indonesia, the marginalized groups are commercializing the HG for better income opportunities (Abdoellah et al. 2020). In HG of Ethiopia, commercialization positively affected income (Mellisse et al. 2018). Also, the HG are known to preserve high levels of agrobiodiversity. A future research initiative on payments for agrobiodiversity conservation and conducting fairs for highlighting traditional food items to improve the income of the marginalized can be thought of (Vlkova et al. 2011).

Eleven (12%) of the publications mention target 11.7 (urban green space and agriculture) of SDG 11 (Sustainable Cities and Communities). In the urban areas, HG are the dominant land-use type, helping preserve the native biodiversity and providing opportunities for the people to connect with nature (Freeman et al. 2012; Jaganmohan et al. 2012). HG in Spain and China provide cultural ecosystem services (Clarke et al. 2014; Calvet-Mir et al. 2012). The themes related to HG role in urban green infrastructure focusing on biodiversity and human well-being are already well studied in Thailand (Panyadee et al. 2016). However, Balooni et al. (2014) reported that the homegardens are losing most of their species diversity due to rapid urbanization. Also, urban homegardens are at the risk of extinction from rising real estate dealings as observed in the urban HG of Costa Rica (González-Ball et al. 2017).

There is a potential for urban HG to satisfy indicators 11.6.1 (reduced municipal waste) and 11.6.2 (reducing particulate matter concentration) under target 11.6 (reduce environmental impacts in cities) of SDG 11. However, studies in these dimensions are scarce. As regards waste management, the use of livestock sludge and other domestic wastes as manure in the HG has been mentioned (Ichinose et al. 2020). However, only one paper used the word “waste” in the context of HG. Wolka et al. (2021), in a study on the rural HG of southwest Ethiopia, mentioned that enset (Ensete ventricosum)—based HG received most of the household wastes and manure.
Target 12.3 (productivity) of SDG 12 (Responsible Consumption and Production) accounted for 15 (16%) publications. The wholesomeness of the HG system involving less intensively tilled soil and non-complete harvest balances the evapotranspiration rates and soil moisture availability (Nair 1985). The croplands are plowed thrice annually; however, HG are never plowed in Uganda (Ichinose et al. 2020). The HG in the Indian state of Assam produced an annual litterfall of 6.27 Mg ha⁻¹, and the nitrogen input to the soil through litterfall accounted for 48.17 kg ha⁻¹ year⁻¹, implying sustainability of the system (Das and Das 2010). Also, as reported from Central Amazonia, Brazil, the aluminum, organic carbon, calcium, magnesium, and potassium levels in soils reported from the HG were not significantly different from those of a primary or secondary forest (da Cunha Salim et al. 2018).

3.4 How HG literature has addressed challenges in Ecological Infrastructure (Category 4)

We found 48 (52%) publications in this category. Out of these, the carbon sequestration potential of HG related to target 13.2 of goal 13 (Climate Action) is highlighted by 15 (16%) publications. Due to the high diversity of the perennial trees and shrubs, which do not get harvested entirely, the HG have enhanced soil carbon storage (Islam et al. 2015; Barbhuiya et al. 2016). The tree component of the traditional HG is an important avenue for carbon sequestration both within the soil and vegetation. In Ethiopian HG, the soil carbon stocks were as high as 156.17 Mg ha⁻¹ (Birhane et al. 2020). Due to increased carbon sequestration potential, HG can contribute to the REDD+ initiatives and clean development mechanisms (Kumar 2011). Furthermore, a study on tree diversity in the HG of Mizoram state of India showed that the carbon sequestering potential of older HG systems was comparatively very high compared to the new HG (Singh and Sahoo 2021), implying the need for conserving the species-diverse older HG.

Targets 15.2 (sustainable management forests), 15.3 (restore degraded lands), 15.4 (conservation of mountain biodiversity), and 15.5 (halt loss of biodiversity) of SDG 15 (Life on Land), referring to the conservation of biodiversity on land, are reported by 43 (46%) publications in this analysis. HG compose an essential locus for trees outside the forest (Cruz-Garcia and Struik 2015) and could help achieve target 15.2 under SDG 15 of sustainable forest management. Regarding target 15.3, the HG are the crucial component for eco-restoration of degraded lands as reported from Spain, Sri Lanka, and Mexico, respectively (Calvet-Mir et al. 2012; Mattsson et al. 2013; Rooduijn et al. 2018). HG are also forming critical green areas in the mountains (Wiehle et al. 2014; Calvet-Mir et al. 2012; Barbhuiya et al. 2016), corresponding to target 15.4.

Aquilariia malaccensis, a critically endangered tree species, is widely cultivated in the HG of Assam, India (Das and Das 2015; Barbhuiya et al. 2016). Furthermore, Calaverita, an endangered orchid of Mexico, was cultivated in the Mexican HG (Salazar-Rojas et al. 2010). Plant varieties and the HG in the Philippines have more bees than the nearby rice fields (Schrader et al. 2018). Also, high pollinators’ diversity was observed in the HG near the forests in Central Sulawesi, Indonesia (Motzke et al. 2016). HG were also found to contain diverse arthropod communities in Indonesia, India, and Mexico (Toledo-Hernández et al. 2016; Lakshmi and Joseph 2017; Huerta and van der Wal 2012). Besides these services, HG provides a habitat for wild animals and birds. For example, in the Eastern Himalayan regions of India, HG were found to act as refuges for great hornbill (Buceros bicornis), red-breasted parakeet (Psittacula alexandri), capped langur (Trachypithecus pileatus), and lesser adjutant (Leptoptilos javanicus), and to contain as many as 140 species of butterflies (Singh et al. 2021). Also, in Brazil, the HG are the dominant habitat for five species of large frugivorous birds (Goulart et al. 2011). All these correspond to target 15.5 of protection of endangered plants and animals in HG (Gbedemon et al. 2016).

3.5 How HG literature has addressed challenges in Institutions (Category 5)

We found 47 (51%) publications in this category. Target 16.7 (food sovereignty) related to SDG 16 (Peace, Justice, and Strong Institutions) is in 47 publications. The agrobiodiversity distribution in the HG varies with the cultural practices of the region, as reported from Mexico and Uganda (Alcudia-Aguilar et al. 2018; Whitney et al. 2018b). In the Amazonian HG of Bolivia, the Tsimane social organization influenced the patterns of exchange of medicinal plants in the HG. People at the center of the community chain maintain a greater richness of medicinal plants in their HG than informants in the more isolated villages (Díaz-Reviriego et al. 2016). In rural Indonesia, the commercialization of the HG indeed improved the farmers’ livelihood; however, it negatively influenced food security and food sovereignty and weakened the traditional institutional setup of Gapoktan (a form of traditional farmer cooperative) in the area (Abdoellah et al. 2020). In the Iberian Peninsula, HG systems incorporate both traditional and modern agriculture knowledge, showing that they are resilient systems that can adapt even if knowledge systems and management practices change (Reyes-Garcia et al. 2014). In the Mizoram state of India, the ownership of HG is passed from one generation to another as permanent family gardens, without significant changes in the composition of plant varieties (Barbhuiya et al. 2016). Also, the non-market food provisioning services by HG and the Satoyama systems of Japan revealed that productions from the HG are shared within the community rather than being sold in the market, and human nutritional well-being and
social relations were positively correlated in these systems (Kamiyama et al. 2016). Specific local knowledge about the cultivated plants in the HG varies in different regions; for example, the seeds of *Phaseolus lunatus* were used differently even in adjacent Indonesian villages (Sujarwo and Caneva 2015). HG are critical components for food sovereignty as reported from studies on the Paraguayan migrant rural HG in Argentina, the high mountain HG of Spain, Orang Asli HG of Malaysia, Segovias HG of Nicaragua, and the rural HG of Cyprus, Indonesia, and Mexico (Kujawska et al. 2018; Boone and Taylor 2016; Calvet-Mir et al. 2012; Milow et al. 2013; Cifteoglu 2017; Abdoellah et al. 2020; Avilez-Lopez et al. 2020).

### 4 Discussion

The highest number of research papers found in category 1 (91%), specifically SDG 2 (Zero Hunger) (88%), provides scope for the inclusion of HG in the holistic development of sustainable food systems. The finding that HG plays a crucial role in food and nutritional security aligns with the conclusions made in the review of Sri Lankan HG (Mattsson et al. 2018) that argues that HG are crucial for food security especially for the poor and vulnerable groups. Even though HG are an age-old practice in many regions of the tropics and the rest of the world (Kumar and Nair 2006), there is little or no information available on the quantity of food produced worldwide by HG, and how many families depend on it, and the actual extent of HG. Therefore, more focus should be on compiling the HG systems’ vital statistics at local, regional, national, and global levels (Nair 2001; Kumar and Nair 2004). Previously Torquebiau (1992) reported that homegarden dietary supplies contribute 3 to 44% of total calories and 4 to 32% of protein intake. Furthermore, homegardens are rarely known to be a system supplying the entire household’s basic staple-food requirements. Indeed, they are part of the overall farming system and coexist with other production methods involving staple food crops like rice (*Oryza sativa*), maize (*Zea mays*), and cassava (*Manihot esculenta*). However, recently, Wolka et al. (2021) have mentioned that HG consists of 25–85% household food requirements in Ethiopia. The improved HG supplies annual vegetable requirements to households between 55 and 79 kg/head/year in Bangladesh (Ferdous et al. 2016). This is an important area of research that would be crucial for the future role of HG in the achievement of food and nutritional security corresponding to SDG 2.

Also, the high diversity of landraces of crop plants in the HG is consistent with the reviews on HG that describe them as loci for conserving the indigenous and rare germplasm (Galluzzi et al. 2010; Kumar and Nair 2004). Figure 6 shows how HG can be connected to SDG 2: the inner pentagon refers to the targets that HG can help achieve. The outer pentagon focuses on the tools and methodologies used for this purpose. Goal 4 is not directly addressed in HG literature; however, HG nutritional outcomes seem to significantly improve children’s educational outcomes (FAO, IFAD, UNICEF, WFP and WHO, 2020). Also, HG can be crucial in imparting knowledge related to sustainable living to children (target 4.7 of goal 4). HG are reported to be the storehouses of traditional knowledge in communities worldwide (Reyes-Garcia et al. 2014; Calvet-Mir et al. 2012), and this knowledge is often embedded within sustainability principles. When looking at HG as loci for knowledge sharing, the most important feature would be HG as a site for agronomic and traditional innovations (Avilez-Lopez et al. 2020; Panyadee et al. 2019).

The high proportion of publications in category 4 that detailed studies on the carbon sequestration potential of HG is consistent with the results from other agroforestry systems. In the Indian context, a 30% increase in the land area under agroforestry, as per the provisions of the National Agroforestry Policy of 2014, will have the potential to completely fulfill the target of Nationally Determined Contribution (NDC) of the country for sequestering atmospheric CO₂ (Nath et al. 2021). Similar conclusions were made for the Sri Lankan HG earlier (Mattsson et al. 2018). However, the age of the HG is a cardinal determinant of the carbon sequestration potential. Older HG have more significant carbon sequestration potential than younger gardens (Singh et al. 2021), implying the need to preserve the older HG with a diverse range of mature woody perennial species from annihilation (Kumar et al. 1994). Target 14.1 (reduce marine pollution due to nutrient flow) of SDG 14 (Life Below Water) is also interrelated with HG. The HG produce is never entirely harvested and produces minimum soil runoff. The HG generally employs few fertilizers (Islam et al. 2015), so nutrient loading of water bodies causing eutrophication due to agricultural non-point source pollution could be less than that of intensive agricultural production systems. However, there have been no studies on this dimension in the last decade.

Many publications on urban HG and productivity are available, signifying Category 3 goals. However, the prevailing dogma is that HG are the systems suitable for rural settings; but based on the results from this analysis, this vision will change drastically. Indeed, there are a large number of publications focusing on urban HG. This is perhaps consistent with the studies linking small-scale production systems in urban areas to SDG achievement (Nicholls et al. 2020; Lal 2020). Some papers also connect the urban HG to ecosystem services (Calvet-Mir et al. 2012; Caballero-Serrano et al. 2016; Clarke et al. 2014). Reports on the productivity of HG also abound and indicate that HG are the low input system, which favors nutrient sharing (among the components of the system) and nutrient conservation (Das and Das 2010).
Category 2 had fewer publications (22%), signifying those studies relating to HG and water conservation are scarce. This is, however, in contrast to the findings of a recent global review, which highlighted the role of small domestic gardens in rainwater harvesting and groundwater recharge (Amos et al. 2018). Fuelwood supply from the agroforestry systems is one of the major thematic areas in the report by the agroforestry network (Agroforestry Network 2018). Many previous authors too reported on the contribution of HG as a source of fuelwood supply (Das and Das 2005; Shanavas and Kumar 2003); yet, such studies are somewhat waning in recent times. Although HG are providing livelihood opportunities, aspect relating to target 9.3 (small scale factory) of Goal 9 is missing. However, there is a possibility of providing local livelihood by setting up small factories that can use HG products and convert them into more valuable ones (value addition through post-harvest processing). Homegardeners were reported to favor handicrafts such as basketry, which can be useful in setting up small industries (Vlkova et al. 2011; Avilez-López et al. 2020). An example of this is the cooperative societies (Ma and Abdulai 2017) which can be set up locally for value addition of HG produce helping the homegardeners to increase their income.

Many publications on Category 5 are consistent with HG being personalized by individuals, traditional communities, and local institutions (Kumar and Nair 2004). In traditional societies, informal knowledge sharing in HG has been prominent (Kujawska et al. 2018). However, in modern times, many NGOs and government organizations promote and maintain HG (Ferdous et al. 2016; Schreinemachers et al. 2015). Although organizations at any level can play a role in the maintenance of the system, local communities are often the best managers of traditional systems (Ostrom et al. 1999). Similar conclusions were reported from the HG literature of this decade also (Barbhuiya et al. 2016). The bottom line is that such interventions should improve nutritional and livelihood outcomes (Ferdous et al. 2016; Schreinemachers et al. 2015). Farmers seek institutional support for procuring quality planting materials, credit, and other knowledge systems (Alam et al. 2010). Therefore, although HG are the private green space, they require unique policy instruments for governance; ideally, such policy interventions should aim to preserve these traditional systems (Balooni et al. 2014). Figure 4 shows how HG can potentially contribute to each of the SDG. Also, homegardens are an essential component in the Osusowake tradition of food sharing in Japan. On the island of Hachijo, the food sharing network of HG provides more than 20% of the consumption of daily fruits and vegetable (Tatebayashi et al. 2019). Target 17.1 (product for export) of SDG 17 (Partnership for Goals) is also interrelated with HG. The products obtained from HG can be marked with sustainability labels and exported outside.

An initiative for providing labels for sustainable production can probably enhance the marketability of the HG produce,
thereby augmenting income generation for homegardeners (Flinzberger et al. 2020). However, at present, no such studies have been mentioned. HG could play a crucial role in a global attempt to design systems that enhance the potential synergistic pathways between different SDGs (Lima et al. 2017). The review of HG literature in this study shows many synergistic pathways for linking up SDGs. For example, SDG 2 (Zero Hunger) and SDG 15 (Life on Land) are crucially interrelated, with 39% of publications covering both thematic areas. Furthermore, both are highly achievable by HG, as shown in Table 4. This is important when the search for food systems with a minimum negative impact on the environment is being promoted (IFPRI 2021). The HG could be one of the ideal systems in this context. Apart from analyzing the potential contribution of HG to SDGs, this study also underscores that they are flexible systems with the potential to incorporate both modern and traditional methods of cultivation (Reyes-García et al. 2014). Although traditional communities have been using these systems for a long time, there is a newfound acceptance in urban areas. As a result, HG are being promoted extensively in urban areas. This corroborates the point that HG are the time-tested example of sustainable agroforestry that is spatially replicable (Kumar and Nair 2004).

5 Use of HG in COVID-19 times and future implications on achievement of SDGs

Literature on calamities has shown that agroecosystems with high diversity are highly resilient to external shocks (Cabell and Oelofse 2012). This aspect is probably reiterated in a recent study from Nepal, which highlighted that traditional diversified farming systems such as HG became more important and significant during the COVID-19 pandemic and were able to absorb about a half-million youth who returned from cities owing to the “reverse trans-migration” after lockdown (Adhikari et al. 2021), corresponding to probable attainment of SDG 1, SDG 2, and SDG 8. Even in India, the local community–based food systems like HG were quite resilient at COVID-19 times (Mina and Kumar 2021). The importance of HG in providing urban food security in COVID-19 times is also well summarized in the review by Lal (2020), also providing a technical term, HGU (homegardening and urban agriculture), for highlighting the high importance of HG in urban areas in pandemic times. Apart from providing alternate livelihood opportunities and improving food security, recent studies have indicated the role of HG in improving mental health in the COVID-19 times, corresponding to SDG 3 (Marques et al. 2021; Corley et al. 2021). New emerging trends of homegardening in COVID-19 times from the USA, Canada, and Russia indicate large number of people signing up for online courses on gardening, and almost a four times rise in demand for seeds of vegetables and fruits for homegarding purposes (Walljasper and Polansek 2020), implying a growing interest in homegardening during COVID-19 times.

In Sri Lanka, HG prominently features the government agenda of meeting REDD + targets (SDG 13 and SDG 15). In 2018, HG represented 15% of the land area and a recent report suggests they increased to 18% (Mattsson et al. 2018; LUPPD 2020). However, as the HG are booming worldwide, their structure, composition, and types are changing. For example, the structure and functioning of the Indonesian pekarangan HG have changed considerably due to commercialization (Abdoellah et al. 2006). Though commercialization has increased the farmers’ income, it has led to a decline in the aspects of food accessibility considerably (Abdoellah et al. 2020). Historically, Agelet et al. (2000) had mentioned that in Catalonia (Spain), migration of the labor force to urban areas, mechanization of agriculture, and the accompanying specialization of agricultural duties have resulted in the degradation of the traditional family garden system. However, a more recent study (Reyes-García et al. 2014) mentions that HG systems are still thriving in Spain through the amalgamation of traditional and modern knowledge. A substantial number of Kerala homegardens have also been transformed into small-scale coconut and rubber plantations (Hevea brasiliensis) or cropping systems with a limited range of crops (Kumar and Nair 2004; Balooni et al. 2014). These and several findings suggest that we need studies to understand the changes in traditional HG systems. One of the threats to the traditional homegarden is the large-scale influx (both intentional and unintentional) of invasive alien species (e.g., Australian and meso-American species such as Acacia spp., Eucalyptus spp., Mimosa invisa, and Mikania micrantha, especially into South Asia) that can potentially out-compete the native flora. It is in the interest of all to save traditional HG as they are harbingers of biodiversity (Table 4). Indeed, they represent the *circa situm* pathway for biodiversity conservation (Barbhuiya et al. 2016). These land-use regimes also serve as wildlife refuges (Ulman et al. 2021). As a result, homegardens may act as crucial linkages to other agricultural and natural landscapes, resulting in a variegated landscape mosaic.

Looking into the benefits of HG, it represents a “win-win” strategy, considering the overall ecological benefits of mixed-species communities and, above all, their possible economic gains and the possibility of achieving many crucial targets of SDGs. Future efforts should save traditional HG and design HG that mimics the traditional ones with opportunities to incorporate modern technologies. Land fragmentation is a significant issue concerning the HG; the schemes like payment of ecosystem services for people protecting traditional HG could be crucial in the achievement of many SDGs. Furthermore, intervention in the areas where people already have some land but do not have homegarding expertise could also help.
Table 4  Summarized quantitative estimates of HG probable contribution in achieving different SDGs (very high, more than 50% contribution to household; high, 30–50% contribution to household; medium, 10–30% contribution to household; low, less than 10%; NQE, no quantitative estimate; NA, not available).

| SDGs                      | Country   | Relevance of homegardens                                        | Contribution of HG | Reference                                 |
|---------------------------|-----------|-----------------------------------------------------------------|--------------------|-------------------------------------------|
| Goal 1. No Poverty        | Bangladesh| Annual income of USD 53.5                                       | Low to medium      | Alam (2012)                               |
|                           | Thailand  | USD 5–80 per year per tree                                       |                    | Panyadee et al. (2016)                    |
|                           | Mexico    | Annual income of 6.4% (for poor) and 0.8% (for rich)            |                    | Poot-Pool et al. (2012)                   |
|                           | Thailand  | White fig (*Ficus virens*) produce income of USD 40 twice a year per tree. |                    | Panyadee et al. (2016)                    |
|                           | Indonesia | Monthly income of IDR 630,674 (USD 44.47), representing about 24% of mean monthly income |                    | Abdoellah et al. (2020)                   |
| Goal 2. Zero Hunger (Food)| Bangladesh| Annual vegetable requirement supply to household between 55 and 79 kg/head/year | Very high          | Ferdous et al. (2016)                     |
|                           | Brazil    | Contribute to 70% of household food requirements                 |                    | Rayol et al. (2019)                       |
|                           | Ethiopia  | Contribute to 25–85% food requirements of the house which was more than that of farmland |                    | Wolka et al. (2021)                       |
|                           | Ethiopia  | Positive dietary diversity score was observed with respect to farm size, livestock holding, and land to adult eq. ratio |                    | (Mellisse et al. 2018)                    |
|                           | Vietnam   | 86% of the major plant use was for food                         |                    | Vlkova et al. (2011)                      |
|                           | Thailand  | 39.4% species per homegarden was food species                    |                    | Panyadee et al. (2018)                    |
| Goal 2. Zero Hunger (Agrobiodiversity) | Brazil | Average 34.4 landraces per HG                                     | Very high          | Junqueira et al. (2016)                    |
|                           | Argentina | Average 82 landraces per HG                                      |                    | Kujawska et al. (2018)                    |
|                           | Spain     | Average 39 landraces per HG                                      |                    | Calvet-Mir et al. (2011)                  |
|                           | Malaysia  | 45.8% of total species were landraces per HG                     |                    | Milow et al. (2013)                       |
|                           | Yucatán Peninsula | 38.2% of total species were landraces per HG |                    | Poot-Pool et al. (2012)                   |
|                           | Ecuador   | 74.6% of total species were landraces per HG                     |                    | Serrano-Ysunza et al. (2018)              |
|                           | Thailand  | Average of 48 of total species were landraces per HG             |                    | Panyadee et al. (2016)                    |
|                           | Mexico    | 53% of total species were landraces per HG                       |                    | Rooduijn et al. (2018)                    |
|                           | Benin     | Average of 20 crop wild relatives per HG                         |                    | Salako et al. (2014)                      |
|                           | Benin     | At least 60% of plant species were landraces                     |                    | Gbedomon et al. (2016)                    |
| Goal 3. Good Health and Well-being | Nicaragua | 90% of gardeners perceived HG provides food diversity and healthy diet. | High to very high | Boone and Taylor (2016)                   |
|                           | India     | 33% of total plant species were medicinal plants per HG          |                    | Barbhuiya et al. (2016)                   |
|                           | China     | 67% of total plant species were medicinal plants per HG          |                    | Yang et al. (2014)                        |
|                           | Argentina | Medicinal plant richness 136 species with an average of 11.1 per HG |                    | Kujawska et al. (2018)                    |
|                           | Vietnam   | 32% of total plant species were medicinal plants per HG          |                    | Vlkova et al. (2011)                      |
|                           | Bolivia   | 40.5% of total plant species were medicinal plants per HG        |                    | Diaz-Reviriego et al. (2016)              |
|                           | Uganda    | 52.6% of total plant species were medicinal plants per HG        |                    | Whitney et al. (2018b)                    |
|                           | Thailand  | 95% of wild food plant species were medicinal plants per HG      |                    | Cruz-Garcia and Struik (2015)             |
| Goal 4. Quality Education | NA        | HG are not reported directly relevant to education               | NA                 | NA                                        |
| SDGs                          | Country                  | Relevance of homegardens                                                                 | Contribution of HG | Reference                                      |
|-------------------------------|--------------------------|----------------------------------------------------------------------------------------|--------------------|------------------------------------------------|
| Goal 5. Gender Equality       | Iberian Peninsula        | 98.5% of women’s HG were dedicated for the household consumption. Women’s HG had a mean of 30.2 species whereas men’s HG had 15.9 species for 100 m$^2$ of cultivated area | Medium             | Reyes-Garcia et al. (2010)                     |
|                               | Bangladesh               | After intervention women’s HG produce increased in plant protein by 171%, vitamin A by 189%, vitamin C by 290%, and iron by 284% | Schreinemachers et al. (2015) |
|                               | Mexico                   | 85.16% of women are involved in inside community occupation which makes HG based livelihood important for them | Castañeda-Navarrete (2021) |
| Goal 6. Clean Water and Sanitation | India                | HG agroecosystems were more resilient in extreme meteorological events                  | NQE                | Lakshmi et al. (2021)                          |
|                               | Thailand                 | HG requires less irrigation                                                               |                    |                                                 |
| Goal 7. Affordable and Clean Energy | Vietnam              | 32% of the household firewood requirements were fulfilled                                 | Medium             | Cruz-Garcia and Struik (2015)                  |
|                               | Bangladesh               | USD 71.9 earned from fuelwood produce annually                                            | Vlkova et al. (2011) |
|                               | Thailand                 | 20% of the household firewood requirement were fulfilled                                  | Alam (2012)        |
| Goal 8. Decent Work and Economic Growth | Bangladesh        | Net benefits of USD 535.2 and USD 674.9 with and without family labor                    | Medium             | Alam (2012)                                   |
|                               | Bangladesh               | Household income USD 421 (median) and USD 1232 (maximum) yearly                           | Kabir et al. (2016) |
| Goal 9. Industry, Innovation, and Infrastructure | NA                        | HG are not reported directly to industry, innovation, and infrastructure                 | NA                 |                                                 |
| Goal 10. Reduced Inequalities | India                    | Indigenous communities can earn up to USD 3000 annually from HG                           | High               | Barbhuiya et al. (2016)                       |
| Goal 11. Sustainable Cities and Communities | India                  | Urban HG represent urban green space; provide space for urban people to reconnect with nature and function as urban food forests | High to very high | Balooni et al. (2014)                         |
|                               | New Zealand              | 93% of gardeners reported urban HG as a space of relaxation                               |                    | Freeman et al. (2012)                         |
|                               | India                    | High species diversity, 1668 trees from 91 species, 192 species of shrubs and herbs from 328 urban HG | Jaganmohan et al. (2012) |
| Goal 12. Responsible Consumption and production | Uganda              | HG were less frequently ploughed compare to croplands which were ploughed thrice yearly | Medium             | Ichinose et al. (2020)                        |
|                               | India                    | HG found to require fewer external nutrients as litterfall accounts to nitrogen input of 48.17 kg ha$^{-1}$ year$^{-1}$ indicating sustainability of the HG | Das and Das (2010) |
| Goal 13. Climate Action        | Ethiopia                 | Stores 21–32 Mg ha$^{-1}$ more soil organic carbon than farmlands                       | High               | Wolka et al. (2021)                           |
|                               | India                    | The aboveground standing biomass stock of carbon was at the range of 16 to 36 Mg ha$^{-1}$ in the HG | Kumar (2011)      |
|                               | India                    | Soil organic carbon stock was 183.42 and 123.24 Mg C ha$^{-1}$                           | Singh and Sahoo (2021) |
|                               | Sri Lanka                | Mean aboveground biomass carbon stock was 26 Mg C ha$^{-1}$, 9 Mg C ha$^{-1}$, and 8 Mg C ha$^{-1}$ in small, medium, and large HG respectively | Mattsson et al. (2015) |
|                               | Sri Lanka                | Mean above ground biomass carbon stocks was 35 Mg C ha$^{-1}$ and 87 Mg C ha$^{-1}$ in dry zone and wet zone HG respectively | Mattsson et al. (2013) |
Similarly, HG role as sites harboring crucial medicinal plants and better mental health corresponds to a new dimension for HG research. Also, the species richness of HG has implications for resilience to climate disturbance (Lakshmi et al. 2021). HG being the breeding ground for many of the experiments on plant variety selection and propagation (Kumar and Nair 2004) could help solve many of the pressing environmental and developmental paradigms issues. The complex interactions between the various components of the HG (crops, trees, livestock, and farm household) require a systems approach to understand their full functional dynamics.

### 6 Limitations of the study

As this study focuses on all SDGs, the detailed analysis for each of the targets and indicators of individual SDGs is beyond the scope of this study. Also, the study takes a more qualitative approach using the corresponding keywords of SDG indicators and connecting them with HG, and it suffers from the limitation of any qualitative analysis (Schanes et al. 2018). Also, this study intends to be a guide to highlight trends, rather than a universalized truth which can vary in detailed studies on each target of the individual SDGs.

### 7 Conclusion

The results of this study highlight that HG can potentially contribute to the achievement of SDGs. Specifically, the synergistic prospects concern food security, agrobiodiversity conservation, and designing sustainable food systems (SDG 2). However, improving the metrics of HG productivity such as nutrition per hectare and yield per hectare to evaluate aspects such as how much nourishment is, and or could be, provided by HG can contribute more in analyzing the role of this system in the realization of SDG 2 (Cassidy et al. 2013). Being a small-scale system, HG can also facilitate the participation of women (SDG 5) and other marginalized groups (SDG 1,  

| SDGs                     | Country      | Relevance of homegardens                                                                                   | Contribution of HG | Reference                |
|--------------------------|--------------|------------------------------------------------------------------------------------------------------------|---------------------|--------------------------|
| Goal 14. Life Below Water| NA           | HG are not reported directly relevant to life below water                                                 | NA                  |                          |
| Goal 15. Life on Land    | Tabasco, Mexico | A total of 45 soil invertebrate morphospecies, belonging to 12 orders, were found in the HG               | Very high           | Huerta and van der Wal (2012) |
| India                    |               | Among the comparison of three agroforestry systems, the highest butterfly species (122 spp.) richness and the animal diversity were found in the HG (311 spp.) in 54 HG | Ulman et al. (2021) |
| Benin                    |               | 12 threatened species were reported in HG                                                                 | Salako et al. (2014) |
| Brazil                   |               | The number of feedings bouts for four species of birds out of five species studied was higher in homegardens (by more than 50%) | Goulart et al. (2011) |
| Indonesia                |               | Nine-fold higher yield and income in HGs with more flower cover and surrounded by forest patch           | Motzke et al. (2016) |
| Mexico                   |               | *Calaverita*, an endangered Mexican orchid grown and conserved in the Mexican HG                        | Salazar-Rojas et al. (2010) |
| Goal 16. Peace, Justice, and Strong Institutions | Brazil | 6.59% (mean) seedling sharing was reported                                                                | High                | Rayol et al. (2019)     |
| Uganda                   |               | Garden equipment and other requirements were largely inherited from family or received as gifts from neighbors | Whitney et al. (2018b) |
| New Zealand              |               | 72% of people responded to use HG for socializing                                                       | Freeman et al. (2012) |
| Goal 17. Partnerships for the Goals | NA | HG are not reported directly relevant to partnerships for the goals                                       | NA                  |                          |
SDG 8) in the production process. The potential of HG for improving livelihood security (SDG 2, SDG 8) constitutes another important aspect that needs urgent research attention. Yet, another theme that requires attention is the development of appropriate public policies (SDG 16) for conserving the traditional HG systems. Previously, although various ecosystem services flowing from the HG are already well studied, policy frameworks on the full-time integration of these smallholder production systems have been rare. The full-scale analysis of the economic, social, and ecological implications of the integration of HG in food systems is also important for proper appreciation of the merits of this time-tested traditional farming system. Consistent with the previous reviews, this review also found that HG are mainly distributed in tropical countries. However, it is gradually becoming popular in the temperate countries in North America and Europe. For example, the European Agroforestry Federation (EURAF 2021) has recognized HG as one of the five agroforestry practices (silvoarable or alley cropping, silvopasture, riparian buffer, and forest farming are the four other systems) that are somewhat similar to the North American practices. 

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Usha Mina: conceptual outline, discussion, writing – review, and editing
B Mohan Kumar: discussion, writing—review, and editing
All authors have contributed and approved the review in its present form.

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Declarations

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