Tropical Agricultural Research (2023) 34(4):289-303

Contents available at: Sri Lanka Journals Online

Tropical Agricultural Research

Journal Home Page: https://tar.sljol.info

RESEARCH

Selection of Model Homegardens: Does the District Heterogeneity Classifies the Homegardens?

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ARTICLE INFO

Article history:
Received: 28 September 2022
Revised version received: 30 October 2022
Accepted: 31 August 2023
Available online: 01 October 2023

Keywords:
Classification
Cluster analysis
Discriminant variables
Model Homegarden

Citation:
Kuruppuarachchi, N., Suriyagoda, L.D.B., Pushpakumara, G.K.N.G. and Silva, G.L.L.P. (2023). Selection of model homegardens: Does the district heterogeneity classifies the homegardens? Tropical Agricultural Research, 34(4): 289-303.

DOI:
https://doi.org/10.4038/tar.v34i4.8670

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ABSTRACT

Among numerous studies done with homegardens (HGs), few efforts have been drawn up to examine biodiversity, input availability and the influence of the complex environment of households and HGs on its produce. Interventions to improve HGs are generally done within the administrative boundaries of the region and the success of such attempts should be evaluated using appropriate tools. To address this research gap a study was formulated aiming at grouping selected HGs and identifying the variables contributing to grouping; and thereby suggesting the characteristics of a model HG. A HG survey was conducted focusing Ratnapura and Hambantota districts of Sri Lanka. Pooled and separated samples of HGs in the two districts were employed in K-means cluster analysis and the groups obtained were subjected to discriminant function analysis to derive the important variables in discriminating HGs. The HGs in Ratnapura were grouped into three categories and key variables contributing to differentiate those were annual expenditure for HG, labor usage, above ground biomass, disease occurrence, species density of trees, and tree density. There were four groups of HGs in Hambantota and key variables that contributed to their differences were; annual expenditure for HG, pest occurrence, annual income from HG, species density of trees, the total share of produce in HG used for consumption, technical knowledge on farming and land extent. Accordingly, the income-driven and diversity-enhanced components of a HG would make it a model HG achieving maximum productivity. However, due to the heterogeneity of HGs, distinct groups within a district could not be identified, suggesting the inappropriateness of making administrative boundaries-based decisions on the interventions in HGs.

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INTRODUCTION

Defining a model home garden (HG) is a critical task since HGs possess diversified characteristics with respect to various aspects. The inter- and intra-specific features of HGs are influenced by five key factors, namely individual, agro-ecological, political, socio-cultural, and economic factors (Pushpakumara et al., 2021).

The productivity of a HG can be gauged through several aspects, including ecosystem services, biodiversity, food and nutritional security, dietary diversity, income generation, and the well-being of households (Santhoshkumar and Ichikawa, 2010; Pushpakumara et al., 2021). However, it's essential to recognize that the emergence of one component may inhibit another. For example, an increased abundance of trees may limit tree biomass, and dense perennial crops could hinder the healthy growth of annual plants. Additionally, cultivating specific income-generating crops might diminish species richness and overall diversity. To accommodate annual crops and animal rearing, some HGs may need to exclude or effectively manage perennial crops (Abdoellah et al., 2020; Pushpakumara et al., 2012).

In general, government interventions for developing HGs are typically implemented based on administrative boundaries, such as provincial, district, divisional, and *Grama Niladhari* divisions. However, these interventions often overlook the crucial factors of climatic aspects and agro-ecological diversity (Sangakkara and Frossard, 2016).

Considering the significant diversity among HGs, it becomes essential to appreciate the specific differences and similarities when grouping them within an administrative division. Such an approach would greatly support government policy-making and decision-making procedures, ensuring that HGs receive the necessary attention and support, thus making them more effective and efficient than they currently are.

Given the considerable diversity both within and between administrative districts in Sri Lanka, it becomes imperative to take into account agro-ecological and socio-economic variables when describing HGs. By doing so, a comprehensive and well-informed understanding of HGs' agricultural importance can be achieved, leading to more targeted and successful government interventions.

In addition to distinguishing various HGs within an administrative district, it becomes crucial to identify specific groups of HGs that can serve as model examples. These exemplary cases should be representative of given agro-ecological and socio-economic conditions, allowing others to adopt and test similar approaches. To comprehensively assess the diversity of the HG system, all possible factors affecting it must be considered.

Maximizing the output of a HG involves a harmonious integration of annual crops, perennial crops, livestock, and poultry. Therefore, when selecting a model HG, it is advisable not to evaluate individual parameters in isolation but to take a holistic approach. Consequently, the general objective of this study was to examine whether there are any discernible differences in HGs between administrative districts. The specific objectives were as follows: (i) to categorize the selected HGs in Ratnapura and Hambantota districts of Sri Lanka based on their ecological and socio-economic characteristics, (ii) to identify the variables contributing to the grouping of these HGs, and (iii) to propose the defining characteristics of an ideal model HG.

METHODOLOGY

Selection of study locations and sample

In this study, it was considered essential to ensure the representation of maximum possible diversity in terms of agro-ecology within the study locations. Among the 25 districts in Sri Lanka, Ratnapura (latitudes 6° 34' 59.99" N and longitudes 80° 34' 59.99" E) and Hambantota districts (latitudes 6° 07' 16.80" N and longitudes 81° 07' 12.60" E) exhibited a high level of diversity in climatic conditions, including variations in rainfall, soil types, and vegetation types. As a result, these districts were selected as the study locations.

To conduct a detailed assessment of HGs in 2019, a field survey was carried out in Ratnapura and Hambantota districts. The sampling technique employed was the Latin hypercube sampling, wherein a transect from forest to urban areas was used for sampling within each district. Expert views from specialists in soil science, agronomy, and environmental science were also incorporated in the sampling process. Approximately 4-5 sampling locations were identified as circles with a 5 km radius, capturing the maximum number of Agro-ecological Regions (AERs) along each transect. Within each circle, 8-12 locations were marked as survey points to select representative samples.

From each location, 3-4 households were randomly selected, resulting in a total of 150 households sampled from each district. All samples were drawn along transects, effectively representing the climatic zones, AERs, and vegetation types present in each district. The final data set with comprehensive information consisted of 90 and 84 HGs, respectively, for Ratnapura and Hambantota districts.

Survey tool

A comprehensive questionnaire was employed to gather information about HG, encompassing details about the activities within them, as well as information on the plants and animals present. The respondents for the survey were either the household head or the key decision maker. To ensure accurate data collection, trained enumerators were engaged over a one-month period to conduct the survey. The information collected from each household was based on one-time measurements. In addition to recording the responses provided by the head or key decision maker, the enumerators also documented their own observations during the survey process.

Variables used

The measurement strategies for the variables utilized in the study are presented in Tables 1, 2, and 3. All these parameters were treated as continuous and ordered scale data. During the analysis, the variables were standardized to ensure consistency, and no prior-standardization was carried out.

Table 1: Measurement strategies of the employed variables associated with agronomic practices and outputs in the homegardens (HGs)

Variable	Measurement strategy
Land Extent (ha)	Directly response of the household
Time allocation for the HG (hours)	Summing the allocated hours by each member of the family
Labor usage per year (days)	Summing total number of days spent annually by the households for the HG activities
Water availability (score)	Counting the number of water sources inside the HG
Fertilizer availability (score)	Counting the number of fertilizer sources inside the HG
Application of soil & water conservation methods (score)	Number of measures households have applied
Technical knowledge on farming (score)	Aggregating the scores given for commitments of households on changing technology, changing planting dates, introducing high yielding and pest and disease resistant varieties, changing agronomic practices, integration of several practices, managing fertilizer and utilizing materials.
Experience in farming (years)	Directly response of the household
Annual expenditure for the HG (LKR)	Aggregating the income and expenditure applied on cereals, pulses, vegetables, leafy vegetables, yam, coconut, fruit, condiments,
Annual income from the HG (LKR)	medicinal plants, firewood, timber, meat, egg, milk, animal and manure in the HG
Total share of produce in HG used for consumption	dividing total production in the HG by total consumption with regard to different food items and aggregating those, total share was calculated

Table 2: Measurement strategies of the employed variables associated with tree diversity in the homegarden (HG)

Variable	Measurement strategy
Tree density per ha	Total number of woody trees/land extent of the HG
Species density of tree per ha	Total number of woody tree species/land extent of the HG
Shannon–Wiener Index (SWI) of trees	Derived from Lowe et al. (2022)
Above ground biomass (AGB) (C Mg per ha)	Derived from Lowe et al. (2022)

Tree diversity in the HG was measured considering the available woody trees in the HG.

Table 3: Measurement strategies of the employed variables associated with effects of other living beings of the homegarden (HG)

Variable	Measurement strategy
Species richness of beneficial insect	Counting the number of species in the HG
Species richness of harmful insects & animals	Counting the number of species in the HG
Occurrence of disease incidences Occurrence of pest incidences Occurrence of weed incidences	Counting the occurrence of incidences in trees, vegetables, other field crops and grain crops in the HG

Analysis

The samples from Ratnapura and Hambantota districts were considered separately as two cases in the cluster analysis. Additionally, a pooled sample was created to assess whether the clustering behavior was similar within and across districts, helping to evaluate the reasonableness of district classification.

Various clustering methods were applied to analyze the samples, including the single linkage method, average-linkage method, complete linkage method, ward minimum-variance method, centroid method, and K-means method. While dendrograms could be obtained through hierarchical clustering methods, they did not separate the groups. Therefore, the K-means clustering method was employed, which assigns all observations to different groups. To optimize the number of clusters, "Pseudo F" statistics, a validity index proposed by Caliński and Harabasz (1974), was used. A higher "Pseudo F" value indicates better clustering.

In the literature, clustering techniques have been frequently used to group individuals based on several variables. However, research on grouping HGs and identifying important variables for such grouping in Sri Lanka is limited (Pushpakuamra et al., 2012). Nevertheless, clustering techniques have been applied in similar studies conducted elsewhere (Brauksa, 2013; Mardaneh, 2015; Aungkulanon et al., 2017; Balasankar et al., 2021).

Initially, the clustering process was initiated with a cluster size of two as the first approach. Subsequently, each observation was assigned to one group through the clustering process. Next, a Multivariate Analysis of Variance (MANOVA) was conducted to determine if significant differences existed between the identified clusters.

Following that, the Discriminant Function Analysis (DFA) was performed, considering the clusters as a classification variable, with the aim of identifying the parameters that significantly contributed to the clustering process. To develop the discriminant function, the K-nearest-neighbor method was utilized, and the prior probabilities of the groups were taken into account (Rosenblatt, 1956). A stepwise selection procedure was then employed, retaining variables that contributed significantly to the discriminatory power of the model while excluding those with lesser contributions. The discriminating power was evaluated using Wilks' lambda (Rosenblatt, 1956), allowing variables that significantly contributed to the formation of distinct groups at a given significance level to remain in the model. The explained variability of each parameter was measured by the Partial-R square, which is not cumulative.

The procedure of the K-means clustering method, MANOVA, and DFA was iterated by obtaining different cluster sizes in the K-means clustering method. The observations of the groups obtained from the cluster analysis and the resulting discriminant variables from DFA at each step were compared with the outputs given when different cluster sizes were assigned. This process aimed to identify a better clustering approach by considering how observations were assigned to groups and which variables played a significant role in selecting model HGs.

To further analyze the data, the means of the variables selected in DFA were compared among different groups using ANOVA and Duncan's New Multiple Range Test (DMRT) procedures with a significance level of P=0.05. The mean values of the discriminant variables, along with the behaviors of the remaining variables, were described to present the characteristics of each particular group. This comprehensive analysis helped to identify the most effective groups of HGs and important variables for the selection of model HGs.

RESULTS AND DISCUSSION

Characteristics of HGs

The parameters employed in the series of analyses including cluster analysis, MANOVA and DFA, i.e. agronomic practices and outputs, tree diversity and effects of other living beings, are presented in Tables 4, 5 and 6.

Table 4: Factors related to agronomic practices and outputs provided by the homegardens (HG) in the two districts (Mean±SE).

Variable	Ratnapura n=90	Hambantota n=84
Land Extent (ha)**	0.13±0.01^{b}	0.22±0.02^{a}
Time allocation for the HG per week (hours)	22.28±2.26	23.04±3.72
Labor usage per year (days)	57.37±14.51	79.86±11.18
Water availability (score)	1.08±0.03	1.07±0.03
Fertilizer availability (score)	2.47±0.09	2.64±0.08
Application of soil & water conservation methods (score)**	0.34±0.07^{b}	0.13±0.04^{a}
Technical knowledge on farming (score)	5.24±0.31	5.96±0.37
Experience in farming (years)**	13.72±1.39^{b}	23.52±1.32^{a}
Annual expenditure for the HG (LKR)	6,333±1,670	3,372±1,608
Annual income from the HG (LKR)*	58,962±22,616^{b}	18,033±4961^{a}
Total share of produce in HG used for consumption (score)	3.06±0.18	2.69±0.21

Values with different superscript within a row are significantly different * - P<0.1, ** - P<0.05

Table 5: Factors related to tree diversity in the homegardens (HGs) in the two districts (Mean±SE).

Variable	Ratnapura n=90	Hambantota n=84
Tree density per ha (number of trees per ha)	330.68±28.48	311.23±25.41
Species density of tree per ha (number of species per ha)**	110.21±9.59^{b}	85.84±7.21^{a}
Shannon–Wiener Index (SWI) of tree	1.80±0.06	1.90±0.06
Above ground biomass (AGB) (C Mg per ha)**	27.27±3.17^{a}	16.33±2.01^{a}

Values with different superscript within a row are significantly different. ** - P<0.05

Table 6: Effects of other living beings of the homegardens (HG) in the two districts (Mean±SE).

Variable	Ratnapura n=90	Hambantota n=84
Species richness of beneficial insects*	3.29±0.21[b]	3.81±0.23[a]
Species richness of harmful insects & animals	1.96±0.10	2.08±0.11
Occurrence of disease incidences**	0.96.0±0.11[b]	1.44±0.13[a]
Occurrence of pest incidences**	0.59±0.09[b]	1.38±0.13[a]
Occurrence of weed incidences	0.82±0.09	0.70±0.09

Values with different superscript within a row are significantly different. * - P<0.1, ** - P<0.05

Table 7: The important variables contributing to distinguishing homegardens (HGs) among three groups in the Ratnapura district (Mean±SE).

Variable	Partial R^2	Group 1 n=1	Group 2 n=2	Group 3 n=87
Annual expenditure for the HG(LKR)**	72%	132,200[a]	0[b]	5032±915[b]
Labor usage per year (days)	35%	20	0	59.11±14.97
Above ground biomass (C, Mg per ha)**	24%	50.70[a]	136.66±51.30[b]	24.49±2.58[a]
Occurrence of disease incidences	13%	0	0	0.99±0.12
Species density of tree per ha**	12%	177.92[a]	440.08±11.77[b]	101.85±8.24[a]
Tree density per ha**	21%	375.60[a]	957.83±2.35[b]	315.75±27.58[a]

Values with different superscript within a row are significantly different. **- P<0.05

Grouping of the HGs and identifying important variables for clustering

Ratnapura district

During the cluster analysis, one HG stood out and formed a separate cluster from the rest. This particular observation exhibited exceptional performances, surpassing the other HGs. When this outlier was excluded from the analysis, another observation showed similar behavior therefore, first outlier was retained as the sole member of one group. As a result, three groups were formed to evaluate the HGs based on their performances, which were found to be significantly different according to the MANOVA (P<0.05).

Out of all the HGs, one fell into the first cluster, two into the second cluster, and eighty-seven into the third cluster. The clustering was based on various factors, including annual expenditure for the HG, labor usage per year, above ground biomass (AGB), incidence of disease, species density of trees per hectare, and tree density per hectare. These variables contributed to the formation of the three distinct groups, with moderate variability as indicated by the partial R^2 values presented in Table 7.

The most significant characteristic observed in Group 1, consisting of a single observation, was that the owner of the HG spent 132,200 LKR annually on raising chickens and cows, as well as managing coconut (Cocos nucifera L.), condiments, and fruits in the HG. This expenditure was the highest among all households in the Ratnapura district, and it explained 72% of the substantial variability within the group. In comparison, the AGB, species density of trees per ha, and tree density per ha in Group 1 were significantly lower (p<0.05) than those observed in Group 2. On the other hand, Group 2 exhibited better overall performance compared to the other groups. Specifically, the AGB, species density of trees per ha, and tree density per ha in

Group 2 were 136.66±51.30 C, Mg per ha, 440.08±11.77, and 957.83±2.35, respectively.

Interestingly, the annual expenditure incurred on HGs was found to be similar between Groups 2 and 3. In Group 3, specific performance patterns were not observed concerning the discriminant variables, and this group comprised all the remaining HGs. The variables of labor usage per year and occurrence of disease incidences did not show significant differences among the three groups (see Table 7).

Hambantota district

Similar to Ratnapura, one observation in the Hambantota district also formed a separate cluster, resulting in four clusters for Hambantota. The clusters comprised one, three, 26, and 54 observations, respectively (Table 8). The MANOVA revealed that these four groups were significantly different (P<0.05).

Several variables significantly contributed to distinguishing these groups, including annual expenditure for the HG, occurrence of pest incidences, annual income from the HG, species density of trees per ha, total share of produce in the HG used for consumption, technical knowledge on farming, and land extent. The Partial R^2 values ranged from 90% to 11% (Table 8).

The four groups did not show significant differences in terms of land extent. In Group 1, the household invested LKR 130,000 annually in raising chickens and buffaloes, as well as farming cereals in the HG, resulting in an impressive annual return of LKR 344,000 from the HG (p<0.05). However, apart from this outstanding performance, no distinct characteristics were observed within this HG regar''[ding the other discriminant variables.

Group 1 allocated a higher proportion of the HG produce for consumption (6) compared to Groups 3 and 4, although it was similar to Group 2 (P<0.1). The HG in Group 1 displayed a moderate level of tree species density, which was lower than that of Group 2 but higher than Groups 3 and 4 (P<0.1).

The household in Group 1 possessed an average level of technical knowledge (score of 6) and land extent (0.10 ha) which was significantly different from Group 3 (P<0.1). Interestingly, no pest attacks were recorded within this group (see Table 8).

The mean tree species density was the highest (P<0.05; 273±29.28 trees per ha) in Group 2 compared to the rest. A Moderate level of technical knowledge (P<0.1), slightly higher amount (P<0.1) of total share of produce in the HG used for consumption than Group 4, higher rate (P<0.1) of pest attacks than Groups 1 and 4, and low mean value (P<0.1) of land extent were the highlights in Group 2 (Table 8).

Significantly higher scores for technical knowledge of farming and the occurrence of pest attacks were observed in Group 3 than in Groups 1 and 4 (P<0.1). Households in Group 3 received a lower mean value (P<0.1) for the total share of produce from the HG used for consumption than Group 1. Species density of trees was lower (P<0.1) in the HGs in Group 3 than in Groups 1 and 2, occupying a higher land extent (P<0.1) than Groups 1 and 2 (Table 8).

The HGs in Group 4 Had a lower total share of produce in HG used for consumption and species density of trees than Groups 1 and 2 (P<0.1) even though the land extent in HGs was not significantly different from the rest of the groups. Further, these households had substantially lower levels of technical knowledge on farming than Group 3. The rate of pest attacks was also lower compared to Groups 2 and 3. The annual investment on and returns from HGs in this group were similar to those in Groups 2 and 3 (Table 8).

Pooled sample of HGs in Ratnapura and Hambantota districts

The HGs allocated in Group 1 of both Ratnapura and Hambantota districts represented by one HG in each group in individual analysis had exceptional characteristics. Those two HGs and another similar HG were assigned to a single group when the pooled sample was employed to cluster analysis. Two HGs and one HG clustered in Group 2 of Ratnapura and Hambantota individual analysis, respectively were positioned into another single group. In addition, the other HGs which were appearing as outliers in the individual analysis were also accommodated in this group. Similar results were observed when the analysis was repeated by assigning cluster sizes of 2, 3, 4 and 5, where the above mentioned clustering pattern remained unchanged.

All these groups were significantly different as per MANOVA (P<0.05). Variables important in grouping HGs in the pooled sample analysis were similar to the results generated for the two districts separately. However, the number of variables important in the grouping were increased with the increment of assigned cluster sizes.

DISCUSSION

Ratnapura

The HG identified in Group 1 in the Ratnapura district can be considered as an outlier. Household raring livestock and poultry incurred a high cost. As a result, the annual return was LKR 1,385,800 from HG by selling eggs, milk, manure and animals. Further, the HG consisted of coconut (*C. nucifera*), areca nut (*Areca catechu* L), mango (*Mangifera indica* L.), citrus (*Citrus sinensis* Pers), pomegranate (*Punica granatum* L), rambutan (*Nephelium lappaceum*) and durian (*Durio zibethinus*) providing income and support for the households in achieving food security. Due to the availability of coconut, fruits, condiments, livestock and poultry, this household could gain a considerably high total share of produce in HG used for consumption. High level of technical knowledge of the household on farming, high availability of fertilizer and moderate level of time allocation to HG activities may have a notable effect on exceptional production (Kumari, 2009) irrespective of low degree of AGB, species density of trees per ha, tree density per ha and the land extent.

Table 8: The important variables contributing to distinguishing HGs among four groups in the Hambantota district (Mean ±SE).

Variable	Partial R^2	Group 1 n=1	Group 2 n=3	Group 3 n=26	Group 4 n=54
Annual expenditure for the HG (LKR)**	90%	130,000^{a}	1,233±669^{b}	2,696.00±789^{b}	1,472±690^{b}
Availability of pest incidences**	59%	0^{a}	2.33±0.33^{b}	2.62±0.10^{b}	0.76±0.12^{a}
Annual income from the HG (LKR)**	42%	344,000^{a}	12,833±9,549^{b}	17,523±4,307^{b}	12,531±4220^{b}
Species density of tree per ha*	40%	128.49^{a}	273.46±29.28^{b}	47.79±6.46^{c}	92.95±7.98^{ac}
Total share of produce in HG used for consumption *#	23%	6.00^{a}	5.76±0.72^{ab}	3.58±0.39^{bc}	2.03±0.20^{c}
Technical knowledge on farming*	26%	6.00^{a}	6.67±1.67^{ab}	9.73±0.39^{b}	4.11±0.32^{a}
Land extent (ha)*	11%	0.10^{a}	0.08±0.02^{a}	0.32±0.03^{b}	0.19±0.02^{ab}

Values with different superscript within a row are significantly different. *- P<0.1, ** - P<0.05
Higher values indicate a higher total share.

The two HGs in Group 2 were superior in terms of tree diversity. However, the owners of those two HGs have neither spent on their HGs nor obtained any monetary return. Their low degree of technical knowledge of farming, low labor usage per year, frequency of time allocation and availability of fertilizer have led to zero income from the HGs. Those households have not made efforts to grow income-driven crops by spending time and investing in fertilizer. The high density of perennial trees and species have been allowed to remain without any management, resulting in a high mean AGB. These HGs have used a greater total share of produce in HG used for consumption resulting from the availability of coconut (*C. nucifera*) and jackfruit (*Artocarpus heterophyllus* Lam). However, such species provide little support to the household's dietary habits as vegetables, eggs, milk and meat were not produced in those HGs. This group of HGs does not support enhancing livelihood in terms of income, coupled with less involvement of households in HG activities and low input. Nevertheless, it provides ecosystem services accompanied by great tree diversity, biomass and high species-richness of insects.

Group 3 comprised differently featured HGs. The HGs with high input availability together with high expenditure made by respective owners, have resulted in more monetary return to the households, than those which were not financed by the households. Such income resulted mainly from condiments, livestock and poultry. Further, those HGs were occupied with perennial crops such as coconut, fruits and condiments at a high density providing a moderate income, and supporting the food security of the households even though input availability was low.

Hambantota

The HG that was recognized as an outlier in the Hambantota district reared livestock and cultivated cereals. The household has achieved high annual returns by selling milk, animals and cereals, owing to the effort and time spent, and a moderate level of technical knowledge, in addition to the large investment. Even though species density of trees, tree density and AGB were evaluated as moderate, it is a high-productive HG due to the availability of livestock components and perennial trees such as coconut and fruits thus, reducing the food expenditure.

The HGs in Group 2 consisted of coconut (*C. nucifera*), mango (*M. indica*), arecanut (*A. catechu*), jack fruit (*A. heterophyllus*), neem (*Azadirachta indica* A. Juss), guava (*Psidium guajava* L), rose apple (*Syzygium jambos* L.), citrus (*C. sinensis*), lime (*C. aurantiifolia*), jam (*Syzygium cumini* (Linn.) Skeels), gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.), chinaberry (*Melia azedarach* L.), soursop (*Annona muricata* L.), cashew nut (*Anacardium occidentale* L.), garcinia (*Garcinia gummi-gutta* L.) and cinnamon (*Cinnamomum zeylanicum* Blume) even though the land extent was low. Moreover, the high species diversity was supported by households' technical knowledge. Even though the land extent of the HG is a limiting factor, interventions such as changing technology such as agronomic practices, managing fertilizer and introducing high yielding and pest and disease resistant varieties can overcome such limitations (Pushpakumara et al., 2012). Consequently, the species density of trees in the HGs has become higher than those in other groups where perennials such as coconut (*C. nucifera*), neem (*Azadirachta indica*), cashew nut (*A. occidentale*) and mango (*M. indica*) have dominated. The output of these trees supported the dietary requirement of households with limited effort and available inputs. Tree density was also high along with increased species density leading to a high AGB. A moderate level of annual return was also achieved by the owners of these HGs in Group 2. Overall, those in Group 2 can be considered as moderately productive HGs.

The HGs in Group 3 performed satisfactorily, better than HGs in other groups identified in the Hambantota district. The interactions between the households and HGs have resulted in mutual benefits. Inputs such as fertilizer, water, labor, land and some money were invested in the HGs at a moderate level by the households. The technical knowledge and farming experiences of the households were also high. As a result, most of the households could earn moderate to high annual income and a higher total share of HG-produce was used for consumption. Further, the tree density inhabited by the HGs was high even though the species density of trees and AGB were marginally lower than those in the other groups. Consequently, the SWI of trees as well as the number of insect species was also high signifying the enhanced agro-ecosystem of those HGs (Gajaseni and Gajaseni, 1999). Accordingly, Group 3 consisted of productive HGs.

In Group 4, most of the households have not invested in their HGs in respect of capital and family labor, even though water and fertilizer were available in the HGs. Consequently, these households have not been able to gain any significant income from the HGs. They received a low amount of produce as food sources from the HG only resulted from perennial trees such as coconuts and fruits, and leafy vegetables which were found naturally or already grown in the HG. The moderate level of technical knowledge and experience of the households in farming may also have contributed to this low income. Accordingly, the majority of the HGs in Group 4 were considered as low-productive mainly due to the less involvement of households. However, those HGs have the potential to be valued in monetary terms. A few HGs were productive with the engagement of households in using many resources. As in the case of Group 2, tree density, SWI and AGB in HGs of Group 4 were assessed as satisfactory even though the species density of trees was low along with the limited interaction with HGs by the households. There was also a moderate presence of different species of insects contributing to the higher biodiversity of these HGs.

Comparison of two districts

A substantial contribution of animal component in HGs to the income and protein supply of households was observed in the study thus, highlighting the high potential of livestock component in HGs in contributing to income generation and food security of households in both districts. The higher the effective investment in HGs, the better the return in both districts. Perennial trees played a major role in the Ratnapura district. The differences in tree diversity among HGs have created easily distinguishable characteristics where the amount of income and food sources substantially differed among HGs. In contrast, as the tree diversity of HGs in Hambantota was relatively low, variations among HGs were also low. The perennial trees are less productive in the Hambantota district having a low amount of feedable tree species whereas condiments played a major role in HGs in the Ratnapura district. The mean land extent of the HGs in the Hambantota district was higher than that in the Ratnapura district. Further, the land extent has influenced the grouping of the HGs in the Hambantota district. High land extent tends to increase both annual and perennial crops whereas small extents have mainly occupied with perennial crops. However, a few HGs to a small extent have utilized the land effectively with both annual and perennial crops using appropriate technological farming interventions. According to the LUPPD (2020a) around 67% of HGs in the Hambantota district are underutilized owing to lack of water and capital, wild animal threats, adverse physical conditions of the land, labor shortage, etc. Further, it was highlighted that there was a considerable extent of land available for the cultivation of tree crops within the 56% of HGs in the district. The rest of the HGs are small and the existing tree density may restrict the growing of additional crops (LUPPD, 2020a). This fact validates one of the findings of the present study that the dominance of perennial crops in the HGs with a small land extent restricts the growth of annual crops. Around 43% of HG coverage is underutilized in the Ratnapura district (LUPPD, 2020b), which is lower than that of the Hambantota district. However, the reasons for the underutilization of HGs are similar in both districts, with further restrictions from lack of planting materials and technical know-how. Even though some of the HGs are fully utilized, productivity was low due to the unplanned dense vegetative cover. Tree crops can be cultivated having enough space in 77% of the HGs in the Ratnapura district (LUPPD, 2020b).

Pooled sample analysis of HGs in Ratnapura and Hambantota districts

The clustering of HGs into groups and the important variables that contributed to distinguish groups were similar in both cases where districts were considered individually or pooled. However, a lower number of variables were observed when districts were considered individually. Therefore, clustering of HGs as individual districts is justifiable as a low number of variables can be used to distinguish groups of HGs. Those variables could be used in grouping HGs for intervention programs. Further, in future studies, clustering within a district could be recommended as a better strategy than clustering across districts.

Selection of model homegarden (HG)

High plant density of HGs assists in controlling the microclimate, regulating local hydrological processes, recycling nutrients and detoxifying poisonous chemicals (Kumari et al., 2009). Hence, the correct plant density and optimum species diversity need to be maintained in the HG to obtain the maximum benefits of such services. The most utilizable species in terms of food and medicinal purposes are the ecologically important species (Idohou et al., 2014) thus, indicating that ecosystem services would also be provided by particular species in HGs along with livelihood support. In terms of utilization, both tree and species density should be essentially considered to assure year-round production. A few studies have modelled HGs concerning plant species diversity including vegetables, fruits, medicinal plants, and ornamental plants to achieve household food security along with year-round production (Ferdous et al., 2016; Regassa, 2016), and socio-economic conditions in the production of annual crops and fruit trees (Schadegan et al., 2013). However, Guuroh et al. (2012), Krishnal et al. (2012), Subba et al. (2018) and Lowe et al. (2021) stressed that different income and food sources in terms of annual plants, perennial plants, livestock and poultry should be available in the HGs to enhance the food security and livelihood of the households. Further, capital, labor, planting materials, water, fertilizer, HG size, total tradable products accompanied by farm and non-farm products, arrangement of components and market access are also contributors to the functions in HGs (Guuroh et al., 2012; Subba et al. (2018). Among many contributors, the present study considered the most essential aspects, namely, input availability, floral diversity, faunal diversity and output of the HGs in defining the characteristics of a model HG.

Furthermore, the income of the HG is magnified by increased family labor, capital, land extent and tree density and cultivated species (Batagall et al., 1998). Cultivating high calorie species such as jackfruit, breadfruit, pulses, roots and tuber crops, and raring livestock and poultry would increase the food consumption score of the households (Lowe et al., 2021). Hence, the presence of diverse annual and perennial crop species and animal species is proposed in the HGs. According to Abdoellah et al. (2020), when a HG is intensified with income-driven animal component (e.g. livestock and poultry), perennial plants (e.g. coconut, fruits and condiments) and annual crops (e.g. vegetables, leafy vegetables and cereals), it will strengthen the income of the HG owner even though there is a tendency to lower the plant diversity and stability of the HG. This observation is well supported by Groups 1 and 2 in the Ratnapura district, and Groups 1 and 4 in the Hambantota district in the present study. Significantly high livestock production and output of some perennial trees were observed in Group 1 in Ratnapura and Group 2 in Hambantota, along with low to moderate levels of AGB, and tree and species density. These aspects of perennial trees were high in Group 2 in the Ratnapura district and Group 4 in the Hambantota district without having a tangible output to enhance the livelihood of the household. In contrast, Korale-Gedara et al. (2012) argued that plant diversity is always not deteriorated as a consequence of enhanced intensive cultivation. Findings about Group 3 in the Ratnapura district and Groups 2 and 3 in the Hambantota district of the present study also supported this argument. Perennial tree diversity and returns from both annual and perennial trees were moderate to high in these three groups of HGs. Therefore, both arguments were rationalized by the present study. Accordingly, Group 3 in the Ratnapura district and Groups 2 and 3 in the Hambantota district are suggested as the model HGs as those HGs carried components that deliver support to both households and the environment.

In general, a district is spatially heterogeneous within its administrative boundaries due to the presence of more than one climatic zone, AERs and the existence of different socio-economic conditions. Similarly, the Ratnapura district mainly represents the Wet zone and Intermediate zone whereas the Hambantota district mainly represents the Dry zone and Intermediate zone. According to DCS (2019), the mean household income per month was LKR 52,956 in the Ratnapura district while it was LKR 68,528 in the Hambantota district, whereas the mean household expenditure per month was LKR 44,864 and LKR 54,169 LKR in the Ratnapura and Hambantota districts, respectively. Due to this socio-economic heterogeneity between districts, there was no contrasting difference in discriminating the HGs when data were considered, in two districts individually or by pooling them together.

Moreover, all types of characteristics such as input availability, tree diversity and livestock component affect to create a productive HG when the district classification is considered. Nevertheless, when most of the relevant socio-economic and ecological variables were included in the present analysis, no clear grouping was produced. It seems that classification of HGs is not possible by using only these variables or these variables do not focus solely on a district.

While the theoretical background is in concordance with the above described scenario, it is critical to note to what extent the practical implications are valid for a district to be considered as one unit. Sri Lankan government interventions to develop HGs (*Divineguma* program) (MoA, 2022) mainly focus on the whole island as a unit and provisions are made at the district or divisional level. However, according to the conclusion given by Jayampathi et al. (2014), the expected objective of achieving sustainable HGs has not been accomplished in the long run even though short run success was reported. The possible reasons given by the beneficiaries were the inefficiencies of extension services, lack of water and quality planting materials (Jayampathi et al., 2014). When the findings of the present study are compared, the reported failures may be the result of inappropriate designs of the implementation at the fundamental level of the *Divineguma* program. Paying no attention to agro-ecology, floral and faunal diversity and socio-economic conditions of different areas might be the reason for not achieving the objectives in the long run. Thus, the government decision-making procedure which has taken place aiming at administrative boundaries might not be appropriate. As the agro-ecological features are represented by climatic zones and AERs, focusing on the climatic zones or AERs would help achieving objectives better in the long run, given the importance of considering agro-ecological features in implementing HG intervention programs.

Implications

Within a clustered group of HGs having similar features, little diversity was also observed. The resulting groups of HGs were distinguishable to a certain degree, as different behaviors were identified even though those were not homogeneous. The major requirements to improve the performances of particular categories of HGs are related, however, such requirements can be addressed in HG development programs separately. For instance, the highest income-gaining HG in the Hambantota district was identified as an outlier, earning high returns solely from cereals, livestock and poultry. This household can be advised to increase and manage the perennial crops such as coconut, fruits, condiments and high timber-valued crops as per the availability and accessibility of land, which can be utilized in situations where performance failures occur with respect to animals or annual plants. It ensures the coping capacity during lean periods.

The productivity of HGs in Group 2 in the Ratnapura district and Group 4 in the Hambantota district can be enhanced in different ways. Even though the HGs of Group 4 in Hambantota were with high tree density and AGB, the species density was low, resulting in low support to the livelihood of the households. Given the high species density in Group 2 in the Ratnapura district, similar results were observed due to the unavailability of productive species and trees such as fruit crops and condiments. Overgrown trees and unproductive perennial crops can be replaced or substituted by other income-driven and food-producing perennial crops such as fruits and condiments. The households should be trained to prune overgrown trees and thin out the dense vegetation. Further, easily manageable annual crops such as vegetables, leafy vegetables, cereals, yams and tuber crops, and livestock and poultry can be introduced after removing the unproductive crops. Newly cultivated crops should be managed well by providing necessary inputs such as fertilizer, water and labor. Seeds and input subsidies can be supplied by the government, if those households have other inputs such as water, labor and farming interest in their HG. Moreover, awareness programs can be conducted to reinforce the households, fashion their attitudes and, to improve their technical knowledge on agronomic practices. The restrictions that occurred due to the low land extent can also be overcome by this cooperation.

As stated above, interventions were provided as a follow up to this study to develop HGs in particular groups. However, as the identified groups were not homogeneous within separate districts or pooled districts, generalized policy-based interventions cannot be suggested at a reliable level.

CONCLUSIONS

In identifying different types of HGs in a district, both socio-economic and ecological variables are important owing to the existence of vast heterogeneity within a district. Such heterogeneity prevents the assembling of distinct groups within a district as well as between districts resulting in unappealing grouping as shown by the present study. Therefore, avoiding heterogeneity in climatic and ecological aspects by keeping climatic zones or ecological boundaries a constant is necessary. Thus, deliberation of HGs as the cases derived from ecological boundaries is more advisable than focusing on administrative boundaries. From the point of view of policy making, the focus should be made based on specific example cases as given in the present study instead of merely providing inputs and advice to the households. The techniques specified as management, replacement, substitution and increasing the number of plants or species should be applied specifically to the requirement as decided by climatic and ecological aspects. Knowledge level of the households to identify the strengths, weaknesses, opportunities and threats possessed about their HGs is important to the survival of HGs even at lean periods without relying on external support. A HG must occupy annual and perennial crops along with animal components to become sustainable and resilient to survive through climatic and economic variabilities.

Funding: The study was funded by the National Science Foundation. Sri Lanka. Grant Number; NTRP/217/CC&ND/TA-04/P-02/01.

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