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RESEARCH ARTICLE

Insights of sustainable horticultural practices for hill vegetables from the organic district of Tamil Nadu

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Abstract

Hill horticulture faces numerous constraints, including soil erosion, landslides, water scarcity, unique cropping seasons andlimited access to extension services and technologies. The Nilgiris, labelled as the "Organic District of Tamil Nadu", serves as an ideal setting to assess farmers' awareness, adoption and challenges related to Sustainable Horticultural Practices (SHP). This study focused on 320 farmers across four blocks: Coonoor, Ooty, Gudalur and Kothagiri, with an emphasis on hill-top vegetables such as potato, carrot, cabbage and cauliflower. The findings present a mixed scenario. While most farmers were aware of SHP, only 55.00 % adopted erosion control measures and 60.63 % practiced integrated pest, disease, nutrient and irrigation management. Some practices, such as improved filtration runoff (69.37 %) and animal waste management (66.25 %), were more widely adopted. However, significant challenges were noted, including limited time to track market trends for hill vegetables (68.00 %) and high transportation costs (67.00 %). The leading source of contamination was wild animal intrusion (94.38 %), followed by improper animal waste decomposition (81.56 %). Workers' hygiene was identified as a contamination risk by 73.13 % of respondents, while transport containers and biosecurity breaches were reported by 65.63 % and 64.69 %, respectively. This study underscores the necessity to promote SHP adoption to address thesenumerous constraints. Enhancing farmers' knowledge and practices can significantly improve horticultural sustainability and foster development in the hilly regions.

Keywords: awareness; contamination source; good agricultural practices; hill vegetable growers; Nilgiris

Introduction

In 2022, an article published by The Economic Times (ET) magazine titled "Policy on Good Agriculture Practice (GAPs) Soon" highlighted the global concerns regarding sustainable agriculture, GAPs and environmental issues (1). This prompted a study to examine the knowledge of farmers about Sustainable Horticultural Practices in the Nilgiris district. According to the Food and Agriculture Organization of the United Nations, 2016, GAPs involve a set of guidelines designed to ensure the safety and quality of both food and non-food agricultural products, while also taking into account economic, social and environmental sustainability (2). The United States Department of Agriculture (USDA) created GAPs as food safety assessments to evaluate farm management practices and recommend improvements (3). It is estimated that foodborne pathogens cause approximately 48 million illnesses and 3000 deaths each year in the United States (4). However, the situation in India differs, as many rural farmers lack access to critical agricultural information, modern technologies and best practices. Enhancing knowledge exchange, providing affordable modern technologies and bridging the digital divide can significantly improve GAPs in India (5).

In recent years, the consumption of fresh produce in India has increased significantly, highlighting a rising trend of direct consumer purchases from small-scale farmers (6). Direct sales of fresh produce from producers to consumers have risen sharply, with farmers' markets emerging as popular locations for these exchanges (7).

Good Agricultural Practices (GAPs) are essential for enhancing the agricultural system's ability to produce safe, high-quality food while being environmentally sustainable(8). The growing demand for safe and nutritious food in both domestic and international markets highlights the importance of implementing GAPs throughout the entire agricultural value chain. GAPs encompass practices from production to post-harvest handling, packaging, transportation, storage and marketing (9). The FAO identifies four fundamental supports of GAP: financial capability, ecological sustainability, societal suitability and ensuring safety in food standards (10). Implementing GAP standards can improve smallholder farmers' access to markets, promote sustainable farming practices and ensure the well-being of farmers and consumers. GAPs help farmers use natural resources responsibly, enhance soil fertility, preserve biodiversity and build resilience against agricultural challenges. Additionally, GAPs address social aspects by preventing the misuse of agrochemicals and ensuring fair wages (11). By adopting GAPs, smallholder farmers in Tamil Nadu can reduce foodborne diseases and enhance food safety.

Good Agricultural Practices (GAP) are essential for meeting the current needs of farming households while ensuring their capacity to sustainably produce food for a growing population in the future (12). GAP offers sustainable approaches that enable farmers to manage natural resources and agricultural inputs responsibly, improve soil fertility, protect biodiversity and bolster the resilience of farming households against external agricultural challenges (13). By adopting GAP, smallholder farmers in Tamil Nadu can efficiently use inputs, improve soil fertility and preserve natural resources, contributing to the sustainability of agriculture.

The social dimension of GAP plays a vital role in protecting the well-being of farmers by preventing the misuse of agrochemicals and ensuring fair wages for their labor (14). Proper education is essential for farmers to manage and apply hazardous substances correctly (15). Adopting GAP among smallholder farmers in Tamil Nadu can improve the safety and health of farmers and consumers, support local and traditional food production knowledge and boost the availability of safe agricultural products. Foodborne microorganisms, including bacteria, viruses and parasites, pose significant biological hazards as they can transmit pathogens to humans, leading to foodborne illnesses. Chemical hazards arise from poor production and handling practices, including improper pesticide application, untreated manure, contaminated water and unsanitary handling methods, all of which can adversely affect the health of agricultural workers and consumers. Physical hazards, such as foreign objects like wood or metal packaging, residual soil and stones in fruits and vegetables, can also lead to illnesses and injuries (16). Adopting GAP by smallholder farmers and other participants in Tamil Nadu's agricultural value chain can reduce foodborne diseases and promote food safety and well-being.

GAP audits are optional assessments that examine the cultivation, packing, handling and storage of fruits and vegetables to reduce microbiological food safety risks (17). These audits verify adherence to the guidelines specified in the United States Food and Drug Administration's "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables" as well as industry-standard food safety procedures. In 2021, the USDA performed GAP audits in all 50 states, Puerto Rico and Canada, encompassing more than 90 commodities (18). Certification of Good Agricultural Practices involves an independent certifying body verifying that agricultural methods or products meet specified GAP criteria. While certification is not mandatory, it is often requested by buyers such as fruit distributors and supermarkets. The USDA's main GAP program offers Good Agricultural Practices certification, which requires farmers to pass a USDA GAP audit, demonstrating compliance with both Good Agricultural Practices and Good Handling Practices as outlined in the USFDA's guidelines for reducing microbial food safety risks in fresh produce (19). The current food safety practices and safety awareness among hill vegetable growers of Nilgiris district are not well-documented. This study aims to assess the current Sustainable Horticultural Practices adopted by hill vegetable growers of Nilgiris District and evaluate their knowledge and adoption towards food safety and investigate their awareness of contamination sources on their farms. Good Agricultural Practices (GAPs) ensure safe and sustainable food production. They include soil management, pest control and safe handling practices, ensuring food safety from farm to table (20). Good Agricultural Practices not only improve farm productivity but also mitigate environmental impact and enhance food safety standards.

Materials and Methods

A field survey was conducted across Nilgiris District to assess the adoption and implementation of Sustainable Horticultural Practices (s) among hill vegetable growers. The study sought to assess food safety knowledge, existing farming practices, perceived obstacles to certification and attitudes toward food safety.

Construction of questionnaire

The survey tool included 31 questions divided into four primary sections:

Socio-profile characters

This section collected data on gender, education level, birth year, farm size, producer profile and district of residence.

Current practices and requirements

Questions focused on irrigation sources, types of crops cultivated, sales methods and past or current involvement in GAP audits.

Barriers and drivers for GAP adoption

Explored farmers' experiences and attitudes towards GAPs, identifying obstacles to meeting food safety standards and obtaining certification.

Interest in future GAP-related training

Assessed participants' willingness and interest in future educational opportunities related to GAPs.

Questionnaire validation

The questionnaire was developed and validated at Tamil Nadu Agricultural University (TNAU). Prior to data collection, a pre-test was conducted at two blocks in Nilgiris districts, viz., Conoor and Kothagiri to ensure clarity and comprehensibility. Feedback from professionals, horticultural extension officials and academic faculty was incorporated to refine the questionnaire.

Data collection

Data collection took place from October 2023 to April 2024, targeting a diverse range of hill vegetable growers across Nilgiris district. The sampling strategy aimed for representation across revenue block (e.g., Cudalor), medium-sized blocks (e.g., Conoor and Kothagiri), smaller blocks (e.g., Ooty). This purposive sampling approach ensured a comprehensive representation of farmers across all the blocks of the Nilgiris District.

Participant consent and data analysis

Participants were informed about the voluntary and anonymous nature of the survey, with the option to withdraw at any time. Data analysis was conducted using SPSS software, with descriptive statistics such as means and standard deviations calculated for each variable.

Standard Deviation

$$\sigma = \sqrt{\frac{\sum(xi - \mu)^2}{N}} \quad \text{(Eqn. 1)}$$

Where, σ = Standard Deviation of Population, N = Population Size, xi = Population Value and μ = Mean Population.

The Chi-Square test was employed to examine relationships between categorical variables, assessing differences in demographic factors and farming practices among farmers utilizing s versus those not utilizing s.

$$X^2\,(df) = X,\ p = Y \quad \text{(Eqn. 2)}$$

Where, X^2 is written using the Greek letter chi (X) and superscript ^{2},.df represents degrees of freedom (italicized in APA), X is the chi-square value and p is the p-value.

Furthermore, correlations between socio-economic factors and interest in further -related education were explored.

$$\Upsilon xy = \frac{\sum(xi \cdot yi)}{\sqrt{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right] - \left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}} \quad \text{(Eqn. 3)}$$

Where, n - Size of Sample, ∑(xi.yi) - xi and yi represent different pairs of values for xxx and yyy, Sx^2 - $(Sx)^2$ / n - Aggregate of Squares of x and Sy^2 - $(Sy)^2$ / n - Summation of y Square

Results and Discussions

Profile characteristics of respondents

A survey was conducted across Nilgiris district and 320 Farmers were surveyed with complete response. The findings are summarized in Table 1.

The socio-economic profile of the participants demonstrated considerable diversity across gender, age, education, farm size and farming experience. Most respondents were male (54.37 %) and held college degrees (42.50 %). The age distribution was predominantly middle-aged, with 76.25 % falling between the age range of 35 and 50 years old. Farm sizes varied widely, with 88.74 % of respondents cultivating hill vegetables ranging between less than an acre to 5 acres of land. The largest cohort of farmers reported farming experience ranging from 6 to 10 years (35.00 %).

The demographic profile of the respondents in the study area has been graphically represented as follows in Fig. 1. Participants represented all four blocks of Nilgiris district, with significant concentrations from Gudalur, Ooty and Kothagiri blocks, accounting for more than half of all the hill vegetable growers. Among these, Gudalur and Kothagiri had the highest representation at 35.00 %, followed closely by Ooty at 33.80 %. Coonoor block accounted for just over 31.20 % of the total respondents in this study.

Table 1. Socio-economic profile of the farmers of Nilgiris district

S. No	Profile	N	%
	Sex		
1	Men	174	54.37
	Women	146	45.62
	Educational Status		
2	Below high school	52	16.25
	Diploma / Certification Course	128	40.00
	College Degree	136	42.50
	Age		
3	Young Age 18 – 34 years	16	5.00
	Middle Age 35 – 50 years	244	76.25
	Old Age > 50 years	60	18.75
	Farm Size		
4	<than an acre	40	12.50
	1 to 2 acres	68	21.25
	2.1 to 3 acres	48	15.00
	3.1 to 4 acres	50	15.62
	4.1 to 5 acres	78	24.37
	>than 5 acres	36	11.25
	Farming Experience		
5	Below 5 years	102	31.87
	6 – 10 years	112	35.00
	11 – 20 years	66	20.63
	>20 years	40	12.50

N = 320

Relationship between awareness, property, status of education and present practices in farming

A large majority of respondents (90.00 %) reported being familiar with sustainable horticultural practices. Following this, their awareness of was analyzed in relation to their current farming practices, which is displayed in Table 2.

A strong correlation ($X^2(3)$ = 7.72, p < 0.01) was found between awareness and improved filtration runoff practices, with 69.37 % of -aware participants managing runoff in the hill slope farming zones. In terms of erosion fighting practices, slightly above half (60.00 %) mentioned managing it and approximately 53.75 % adopted crop rotation. Zero tillage was primarily adopted by 51.25 % of the respondents for fighting erosion. Integrated Pest and Disease management practices were adopted by 61.25 % of participants. Integrated Management of nutrients and irrigation water was reported by 60.00 % of the respondents. The most adopted practices were improved filtration runoff (69.37 %) and animal waste management (66.25 %). A comparative assessment of respondents managing and not managing practices in their farms is represented graphically in Fig. 2.

Among those aware of s, a noteworthy statistical association (P < 0.001; X^2 (1) = 19.1) was observed between the portion of property allocated for practices and the oversight of farmers health and hygiene represented in Table 3.

The correlation between and adoption of zero tillage (X^2 = 19.1) was found widely among respondents dedicating 3.1 - 4 acres of land (26.25 %). Additionally, a significant association (X^2 = 15.8) was found between land allocation for adopting and the management of pest and diseases, with the highest adherence on 1.1 - 2 acres (26.25 %). Respondents using 4.1-5 acres were significantly adopting crop rotation (X^2 = 12.7). The portion of land allocated for performing Sustainable Horticultural Practices as plotted from the responses of the farmers were graphically represented below in Fig. 3.

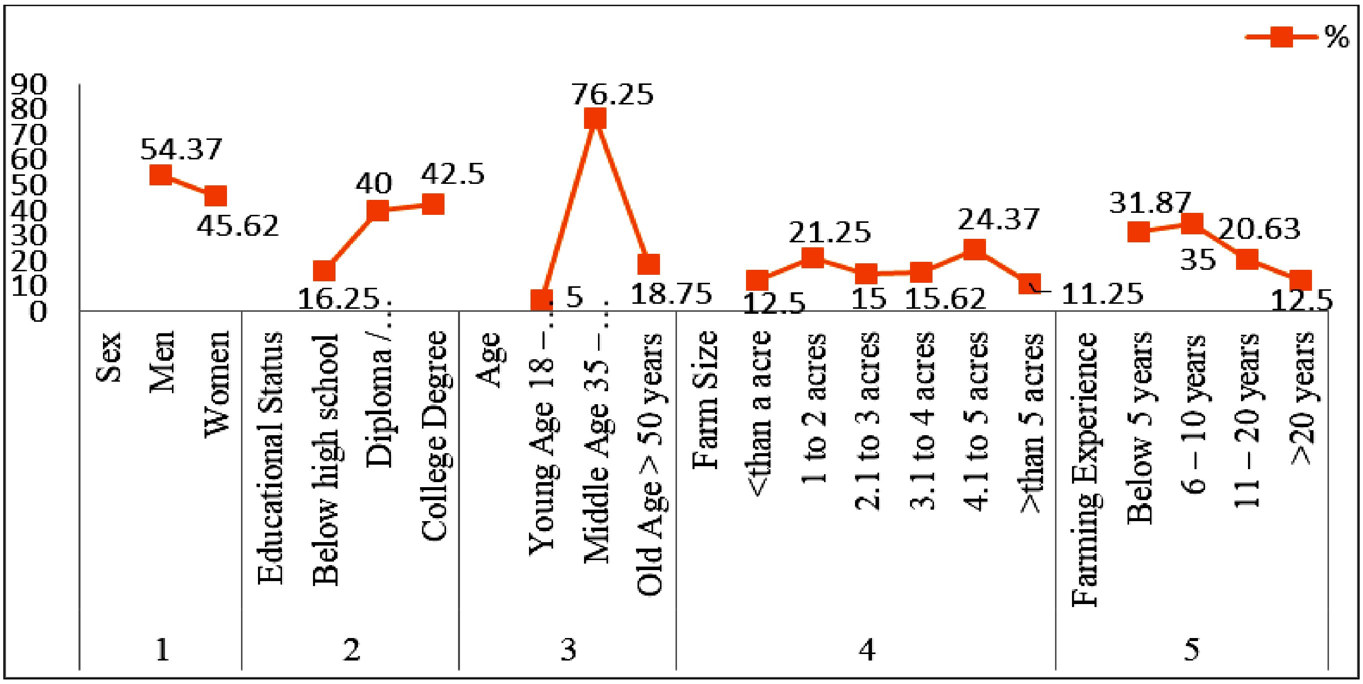

Fig. 1. Profile characteristics of the hill vegetable growers of Nilgiris district.

Table 2. Relationship between awareness of farmers and present practices in farming

S. No.	Practices	Managing Current Practices		Not Managing Current Practices		X^2
		N	(%)	N	(%)	
	Erosion Fighting Practices					
1	Cover crops	192	60.00	128	40.00	0.13
2	Crop Rotation	172	53.75	148	46.25	2.50
3	Zero tillage	164	51.25	156	48.75	2.40
	Water Friendly Management Practices					
4	Integrated Pest & Disease Management	196	61.25	124	38.75	2.42
5	Integrated Nutrient & Irrigation Management	192	60.00	128	40.00	0.13
	Animal Waste Management					
6	Scheduled and timely grazing, waste storage and management	212	66.25	108	33.75	2.22
	Runoff Reduction Practices					
7	Improved filtration runoff	222	69.37	98	30.63	7.72**
	Non-adoption of Practices					
8	I don't opt	54	16.87	266	83.13	1.85

**1 % Level of Significance.

Table 3. Correlation between the land area dedicated to local crop cultivation and the implementation of Sustainable Horticultural Practices (s)

S. No	Practices	Land allocated for adopting s in the farm (n = 320)						
		<1 ac	1.1-2 ac	2.1-3 ac	3.1-4 ac	4.1-5 ac	>5ac	X^2
1	Cover crops	30 (9.37)	60 (18.75)	70 (21.87)	60 (18.75)	70 (21.87)	24 (7.50)	4.23
2	Crop Rotation	27 (8.43)	33 (10.31)	92 (28.75)	48 (15.00)	105 (32.81)	15 (4.68)	12.7*
3	Zero tillage	14 (4.37)	52 (16.25)	77 (24.06)	84 (26.25)	73 (22.81)	20 (6.25)	19.1***
4	Integrated Pest and Disease Management	16 (5.00)	84 (26.25)	67 (20.93)	68 (21.25)	64 (20.00)	21 (6.56)	15.8**
5	Integrated Nutrient and Irrigation Management	29 (9.06)	67 (20.93)	70 (21.87)	67 (20.93)	60 (18.75)	27 (8.43)	4.4
6	Scheduled and timely grazing, waste storage and management	28 (8.75)	56 (17.50)	62 (19.37)	71 (22.18)	71 (22.18)	32 (10.00)	10.6
7	Improved filtration runoff	28 (8.75)	43 (13.43)	51 (15.93)	59 (18.43)	79 (24.68)	60 (18.75)	9.3
8	I don't adopt	148 (46.25)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	121 (0.00)	4.5

*5 % Level of Significance; **1 % Level of Significance; ***Less than 1 % level of significance

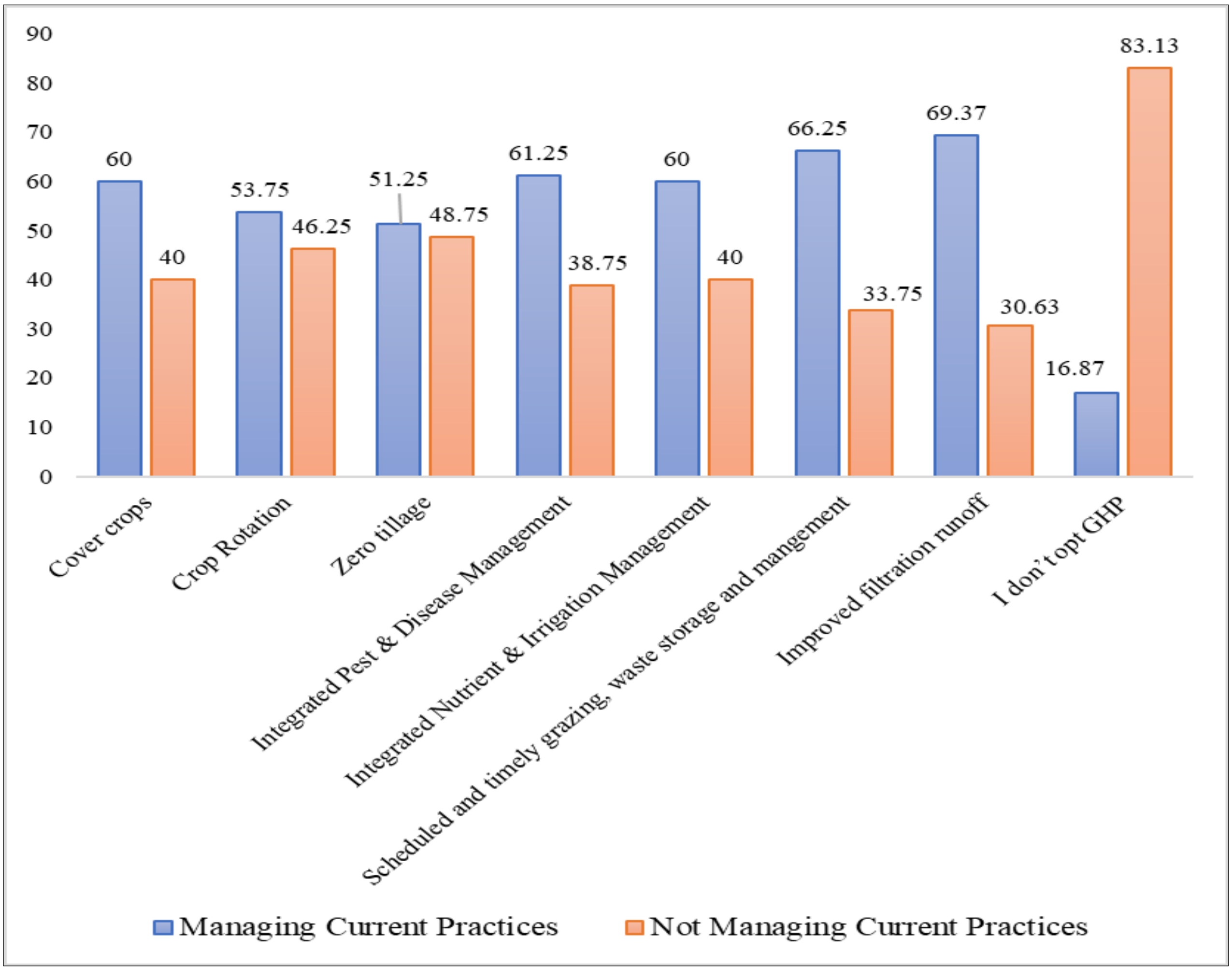

Fig. 2. Comparative assessment of Nilgiris farmers managing and not managing practices in their hill farms.

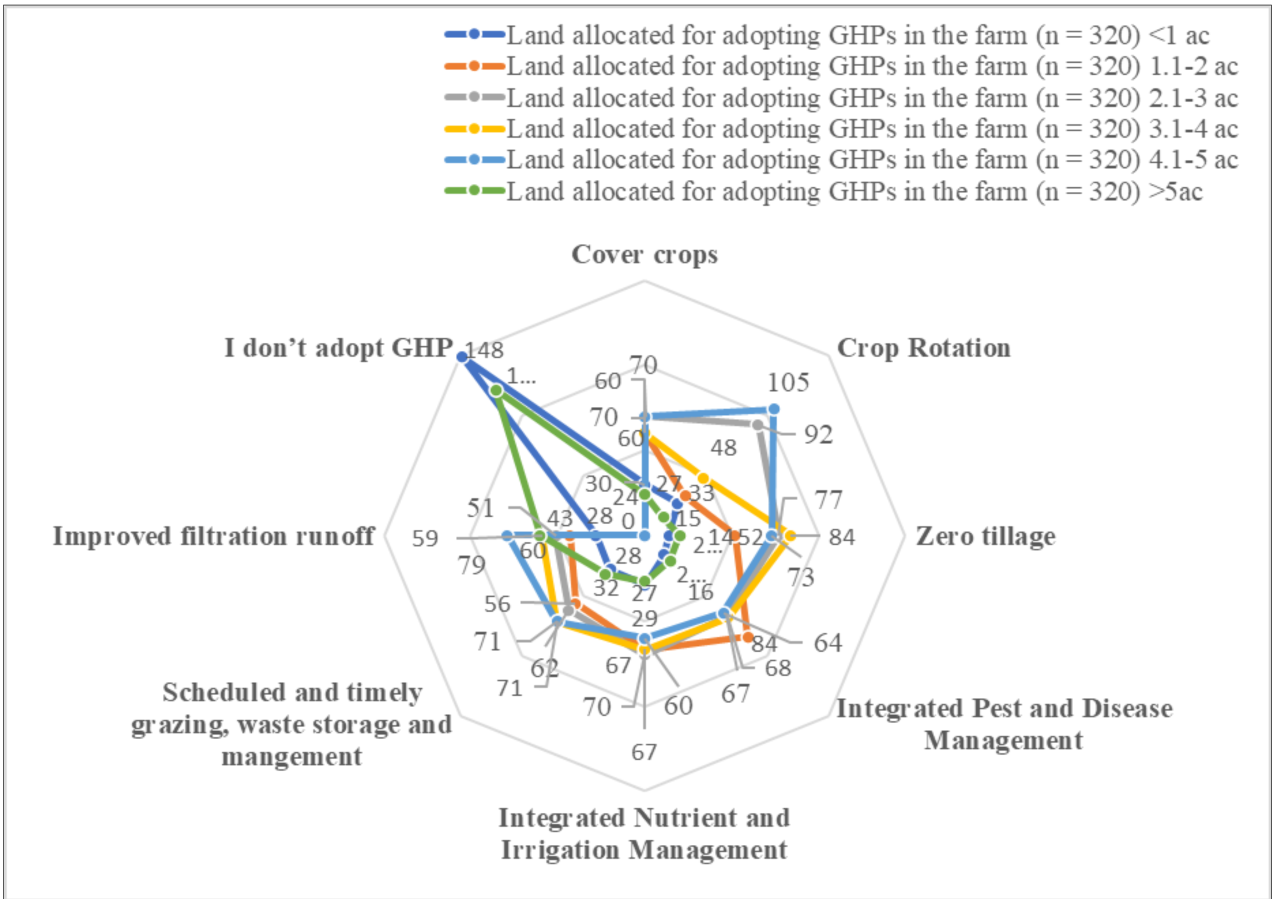

Fig. 3. Non-comparable radar marker representing the portion of land for performing SHP by the farmers of Nilgiris.

Table 4 illustrates the link between respondents' educational levels and their engagement. A significant relationship (X^2 = 8.15) was found between educational attainment and the runoff reduction practices. Approximately 41.93 % of the respondents with education level of Degree and Above were found to be adopting improved filtration runoff, compared to 54.00 % with education level of Diploma and Certificate holders. Those with a high school education had a low rate of runoff filtration practices adoption (18.27 %).

Evaluating farmers' awareness of contamination sources

Respondents were presented with a list of potential contamination sources and asked to identify those they perceived as risks to their farms. Each source corresponds to factors identified in the World Bank report titled '47 countries make 67 reforms to help farmers grow their business (21). Ideally, respondents should have selected all items on the list, but the survey revealed varying perceptions of these contamination sources among participants, presented in Table 5.

The study found that wild animal intrusion onto farms was the most commonly cited contamination source, identified by 94.38 % of respondents. Following closely, improper decomposition of animal waste was acknowledged as a risk by 81.56 % of respondents. In contrast, 73.13 % recognized workers' hygiene as a potential contamination source. Transport containers were identified as fourth major source of contamination by 65.63 % of the respondents, while drenching and biosecurity breach during storage or preparation shared the fifth spot with 64.69 % of the respondents considering it as potential vectors. Slightly above half of the respondents believed packing material (56.25), inadequate or over dose of fertilizer (55.31 %), machineries and farm implements (52.50 %) and topsoil (52.50 %) could contribute to contamination. A minority of (45.00 %) indicated washing and rinsing produce after harvesting as a potential source and even fewer (32.81 %) suggested contamination could arise from cold storage.

The study found no significant relationship between respondents' awareness of contamination sources and their educational level, shown in Table 6.

While respondents with a college degree tended to identify contamination sources more frequently than those with a high school education or less, the difference was not statistically significant. Notably, a minority of respondents recognized contamination risks across all categories. These findings, consistent with Table 6, underscore the ongoing need for enhanced awareness among farmers regarding potential contamination risks in their farming operations.

Constraints in implementing GAPs

Respondents were surveyed regarding the challenges they face in adopting Good Agricultural Practices (GAPs), as depicted in Fig. 4.

The most significant perceived barriers included lack of time to access market trends for hill vegetables in the plains (68.00 %) and concerns about the high transportation cost (67.00 %). Approximately 40 % of respondents expressed skepticism regarding the return on investment from, while 35.00 % cited limited access to training and educational opportunities on s as potential obstacles. Just over a quarter of respondents (27.00 %) believed that uncertainty in prioritizing s would hinder the market, whereas 26.00 % identified a lack of guidance in the audit. It's noteworthy that a relatively smaller proportion of respondents (17.00 %) viewed a lack of knowledge about s as a hindrance to certification.

The study revealed a nuanced understanding of contamination awareness among farmers in Nilgiris District.

Table 5. Source of contamination on the farm identified by the respondents

S. No.	Sources	n	%	Rank
1	Topsoil	168	52.50	
2	Drenching	207	64.69	V
3	Improper decomposition of animal waste	261	81.56	II
4	Inadequate/overdose of fertilizers	177	55.31	
5	Wild animal damage	302	94.38	I
6	Workers hygiene	234	73.13	III
7	Machineries and farm implements	168	52.50	
8	Transportation containers	210	65.63	IV
9	Washing and Rinsing of Produce after harvesting	144	45.00	
10	Cold storage	105	32.81	
11	Packing material	180	56.25	
12	Biosecurity breach during storage	207	64.69	V

*Respondents were allowed to give multiple responses.

Table 4. Correlation between educational status and management

S. No	Practices	<High School	Diploma / Certificate	Degree & Above	Total	X^2
1	Cover crops	8 (25.80)	10 (32.25)	13 (41.93)	31 (9.68)	0.54
2	Crop Rotation	6 (20.68)	9 (31.03)	14 (48.27)	29 (9.06)	0.93
3	Zero tillage	8 (25.80)	12 (33.33)	16 (44.44)	36 (11.25)	2.31
4	Integrated Pest and Disease Management	15 (17.24)	21 (24.13)	51 (58.62)	87 (27.18)	5.35
5	Integrated Nutrient and Irrigation Management	1 (7.69)	5 (38.46)	7 (53.84)	13 (4.06)	1.59
6	Scheduled and timely grazing, waste storage and management	3 (10.71)	11 (39.28)	14 (50.00)	28 (8.75)	0.45
7	Improved filtration runoff	17 (18.27)	37 (39.78)	39 (41.93)	93 (29.06)	8.15*
8	I don't adopt	2 (66.66)	1 (33.33)	0 (0.00)	3 (0.93)	4.37

*5% Level of Significance.

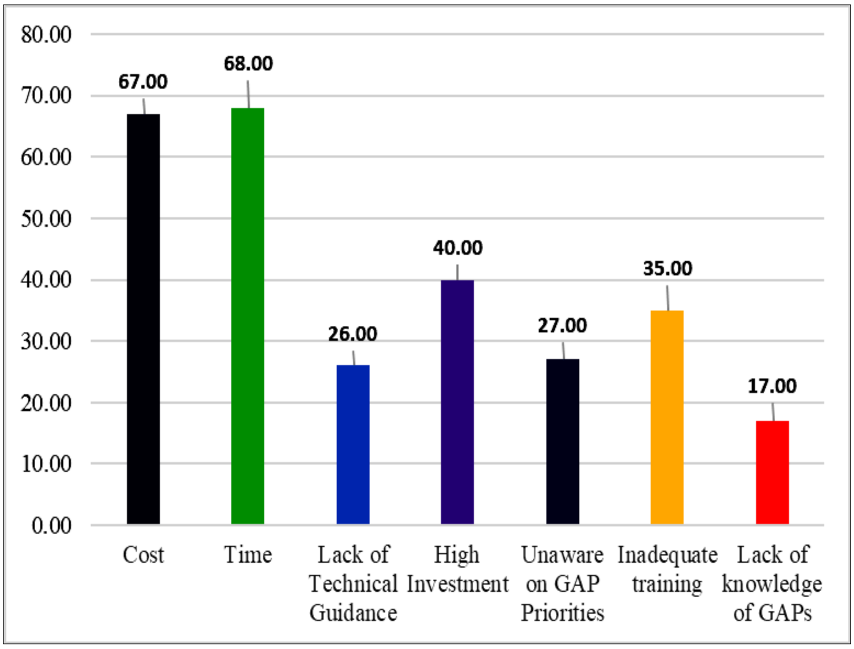

Fig. 4. Constraints faced by the farmers in implementing GAP in their farms.

Table 6. Relationship between identification of contamination source and education qualification of the respondents

S. No.	GAP Practices	<High School	Diploma / Certificate	Degree & Above	Total	X^2
1	Topsoil	30 (17.86)	57 (33.93)	81 (48.21)	168 (52.50)	1.48
2	Drenching	27 (13.04)	84 (40.58)	96 (46.38)	207 (64.69)	0.40
3	Improper decomposition of animal waste	39 (14.94)	108 (41.38)	114 (43.68)	261 (81.56)	0.39
4	Inadequate/overdose of fertilizers	21 (11.86)	78 (44.07)	78 (44.07)	177 (55.31)	1.21
5	Wild animal damage	36 (11.92)	111 (36.75)	153 (50.66)	302 (94.38)	5.51
6	Workers hygiene	24 (10.26)	96 (41.03)	114 (48.72)	234 (73.13)	3.25
7	Machineries and farm implements	18 (10.71)	72 (42.86)	78 (46.43)	168 (52.50)	1.43
8	Transportation containers	18 (8.57)	93 (44.29)	99 (47.14)	210 (65.63)	4.88
9	Washing and Rinsing of Produce after harvesting	9 (6.25)	57 (39.58)	78 (54.17)	144 (45.00)	5.00
10	Cold storage	9 (8.57)	42 (40.00)	54 (51.43)	105 (32.81)	1.65
11	Packing material	12 (6.67)	45 (25.00)	57 (31.67)	180 (56.25)	0.92
12	Biosecurity breach during storage	15 (7.25)	81 (39.13)	84 (40.58)	207 (64.69)	4.01

*No significant differences were found at $P < .05$.

While 12 categories of potential contamination sources were assessed, only six were recognized by a majority of respondents. Particularly concerning were wild animals intruding into the farm. Given that hilly vegetables are often grown in subtropical highland climate susceptible to chemical and microbiological hazards, addressing this knowledge gap is critical.

Interestingly, cold storage was identified as the least reported source of microbiological contamination. This finding aligns with prior research emphasizing the significance of managing wild boar populations to mitigate agricultural damage (22). Growers' perceptions of wild animal intrusion often reflect challenges such as perceived powerlessness or economic disincentives to effectively address these issues on their farms.

Respondents highlighted lack of time to access market trend for hill vegetables in the plains and high transportation cost as significant barriers to Sustainable Horticultural Practices (s), consistent with findings from previous studies (23). This contrasts with surveys where lack of knowledge about s as a hindrance to certification, underscoring the need for targeted education on the benefits of GAP certification. Moreover, the respondents expressed interest towards learning through trainings and workshops. These findings emphasize the demand for educational materials and practical training programs tailored to producers, especially those directly engaging with consumers, to improve the safety standards of farmers practicing s.

Although this study offers valuable insights, it is important to recognize its limitations. The relatively low overall response rate and non-probability sampling method may restrict the generalizability of the findings. However, the purposive sampling strategy enabled the examination of diverse farmer population across various blocks in Nilgiris district, offering rich data for analysis. This geographical diversity enhanced the study's scope by including hill vegetable growers from different backgrounds and regions, contributing to a more comprehensive understanding of implementation challenges and practices in Tamil Nadu.

Conclusion

This study revealed a diverse range of food safety practices and adoption among Farmers in the Nilgiris district, highlighting significant gaps in knowledge and implementation. The findings indicate partial understanding of the respondents about microbial behavior in high altitudes and potential contamination sources such as soil, water and manure. The adoption of Good Agricultural Practices (GAPs) was found to be relatively low, with critical deficiencies in water management and soil safety practices. The primary barriers identified were cost and time constraints, which hinder Nilgiris vegetable farmers from pursuing certification. Addressing these barriers is essential for promoting greater acceptance of s within the farming community, especially in the regions which are vulnerable to soil erosion and landslides. The study underscores the need for targeted educational outreach to enhance food safety knowledge and practices among Nilgiris farmers. Such efforts are crucial to ensuring the safety of fresh produce throughout the farm-to-home supply chain in the region.

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Authors' contributions

PJ conceived the study, served as the research investigator and collected both secondary and primary data. PR provided critical information regarding soil and food-borne microbes and pathogens, coordinated the study and served as the corresponding author. MV contributed to the literature review and performed analytical evaluations. RS from the Department of Sericulture, provided additional insights and support. BVK an entomologist, contributed expertise on pest-related aspects, while ST a soil scientist, provided technical inputs on soil-related factors. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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