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Article

Mediating Effect of Technology Adoption: Agricultural Extension Services Enhances Sustainability of Smallholder Tea Farmers in Sri Lanka

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Abstract: This study examined the role of agricultural extension services in promoting sustainability among smallholder tea farms in Sri Lanka through technology adoption. Using the Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB), it explored how extension services influenced farmers' technology adoption and sustainability practices. Data were collected from 452 smallholder tea farmers in Kandy and Badulla districts using a structured questionnaire. The analysis, conducted via PLS-SEM, revealed that extension services significantly enhanced technology adoption, positively impacting farm sustainability. Findings confirmed that technology adoption mediated the relationship between extension services and sustainability, improving productivity, environmental practices, and social outcomes. The study emphasized a comprehensive sustainability approach integrating extension services, social factors, and economic support. Key recommendations included increasing investment in extension services, addressing financial constraints, and expanding training and resource access. Policymakers and practitioners should strategically support technology adoption initiatives to enhance sustainability in Sri Lanka's smallholder tea sector. Focused extension programs and novel approaches, such as farmer organizations and farmer field schools, should be developed to promote sustainable tea technologies. Strengthening extension services is crucial for the sector's long-term viability. Investments in extension services, educational campaigns, and financial support systems will encourage technology adoption, leading to increased productivity, higher incomes, and sustainable growth for smallholder tea farmers in Sri Lanka.

Keywords: Technology adoption; sustainability; agricultural extension services; smallholder tea farmers; Sri Lanka

Introduction

Sri Lanka is renowned for its tea, grown in small holdings across the country. These farms play a crucial role in rural development and tea production, strengthening Sri Lanka's global reputation. Despite 150 years in the industry, challenges persist. While traditionally dominated by large estates, smallholder farms, mainly in mid and low-country regions, now contribute 75% of the country's tea output despite occupying only 60% of tea-growing land (Tea Small Holdiing Authority, 2022).

However, sustainability concerns threaten these farms. Productivity remains low, as Sri Lanka's yield per unit area lags behind Kenya, Malawi, and India (International Tea Committee (2022). The Tea Research

Institute of Sri Lanka (TRISL) recommends Good Agricultural Practices (GAPs) to maintain productivity, but smallholders, facing low yields, struggle financially (Mahaliyanarachchi, 1996). Additional challenges include land fragmentation, high costs, and dependence on chemical fertilisers (Jeewanthi & Shantha, 2021).

Sustainable Development Goals (SDGs) highlight the need to improve smallholder yields and reduce poverty. A key issue is farmers' limited adoption of recommended technologies, often due to low awareness (Mahaliyanarachchi, 1996). However, technology adoption has been linked to better incomes and economic outcomes (Chandio & Jiang, 2018). Barriers include slow adoption rates, geographical remoteness, and restricted access to extension services (Ntume et al., 2015). Notably, Sri Lankan smallholders could boost production without increasing inputs (Jeewanthi & Shantha, 2021), reinforcing the potential of technology-led development.

This study examines the relationship between agricultural extension services, technology adoption, and smallholder tea farmers' sustainability. It also investigates whether technology adoption mediates the link between extension services and farmer sustainability.

Literature Review

The tea smallholding sub-sector is crucial to Sri Lanka's rural economy and tea production. According to the Tea Control Act, these farms, which hold less than 10 acres, significantly contribute to the industry and economy (Tea Small Holdiing Authority, 2022). Despite their large collective land area and production, smallholders face challenges such as low productivity, declining yields, poor technology adoption, high production costs, low household income, soil fertility decline, labor shortages, low green leaf prices, and inadequate infrastructure (Mahindapala, 2020). Additionally, family farm divisions reduce farm sizes, complicating effective management. In 2022, the sector's average productivity was 1,200 kg of manufactured tea per hectare, which was 8% lower than in 2021 (Tea Small Holdiing Authority, 2022).

Technology is essential for agricultural development (Chandio & Jiang, 2018). Martey et al. (2020) highlighted the effectiveness of climate-smart practices, such as improved crop varieties and water management, in increasing yields and resource efficiency. Additionally, Integrated Pest Management (IPM) reduces pesticide use, promoting soil health and biodiversity (Pretty, 2003). Studies show a strong link between technology and economic sustainability, benefiting smallholders by enhancing income and production (Akter & Gathala, 2014; Chandio & Jiang, 2018). However, barriers to technology adoption include limited access to information, lack of capital, and socio-cultural constraints.

Agricultural extension services bridge research institutions and farmers, providing training and support for technology adoption (Syarifuddin et al., 2023, 2024; Wulandari, 2015). Their effectiveness depends on factors such as farmer participation, training quality, and agent availability (Maffioli et al., 2013). Moreover, institutions like the Tea Small Holding Development Authority (TSHDA) support smallholders through training and loan facilitation (Tea Small Holding Authority, 2022). However, the relationship between extension services, technology adoption, and farm sustainability remains underexplored.

This study addresses this gap by examining four key areas. The first research question focuses on the role of extension services in the sustainability of small tea farmers in Sri Lanka. The second examines the connection between extension services and technology. The third explores the impact of technology on the sustainability of smallholder tea farms. The fourth investigates the mediating role of technology adoption in the relationship between extension services and farmer sustainability. By exploring these aspects, this research aims to provide insights into strengthening smallholder tea farming through effective extension services and technology integration.

This study employs two theories to analyze the conceptual framework: Innovation Diffusion Theory (IDT) and the Theory of Planned Behaviour (TPB). According to IDT, extension agents play a crucial role in farmers' adoption of technologies by introducing eco-friendly methods and generating interest in new techniques. They identify agricultural challenges and provide solutions to meet farmers' needs (Rogers, 2003). Acting as intermediaries, they connect farmers to research information, educational resources, funding, and expert advice, ensuring a smooth adoption process. They also guide farmers on what, when, and how to implement innovations (Rogers, 2003).

Extension agents facilitate innovation transfer, bridging researchers and implementers. IDT emphasizes social learning, communication, and flexible strategies to prepare farmers for change. Sustainable agricultural practices require a gradual, well-supported transition (Rogers, 2003; Ugochukwu & Phillips, 2018). Understanding adopter categories, innovation attributes, and the innovation-decision process aids in disseminating sustainable tea farming practices. Agents may encourage information exchange on positive outcomes, improve communication, simplify complex processes, and raise awareness of new technologies. This approach reduces the gap between research and practice, fostering broader adoption of sustainable farming methods.

The Theory of Planned Behaviour (Ajzen, 1991) assesses farmers' decision-making regarding technology adoption. It examines beliefs and attitudes toward new technologies, subjective norms regarding perceived pressure to adopt them, and perceived behavioral control—farmers' confidence in using specific technology. While behavioral intention is not measured directly, adoption-related responses provide insights into farmers' motivation for technology adoption.

Methodology

This study examined the smallholder tea sub-sector in Sri Lanka's mid-country region, where growers face unique challenges. TSHDA and Tea Board records indicate mid-country tea growers are less productive and earn lower green leaf prices than those in low and up-country regions. The survey covered Kandy and Badulla districts, home to about 95% of mid-country tea growers. A key objective was to explore technology adoption's mediating role between agricultural extension services and smallholder tea farmers' sustainability. Four hypotheses were tested in this paper:

H1: Agriculture extension services positively correlate with sustainability among smallholder tea farmers in Sri Lanka.

H2: Technology adoption and sustainability is positively correlated among smallholder tea farmers in Sri Lanka.

H3: Agricultural extension service is positively related to the adoption of technology by smallholder tea farmers in Sri Lanka.

H4: Technology adoption mediates the effect of the role of agricultural extension services on the sustainability of smallholder tea farmers in Sri Lanka.

1. Research Design

This study employed a quantitative research design using a cross-sectional survey method to investigate the relationship between agricultural extension services, technology adoption, and sustainability among smallholder tea farmers in Sri Lanka. Data were collected through a structured questionnaire, which measured key constructs such as agricultural extension services, technology adoption, and sustainability (economic, social, and environmental aspects).

2. Participants

The study involved 452 smallholder tea farmers from the Kandy and Badulla districts in Sri Lanka. A multi-stage stratified random sampling technique was employed to select participants from the Tea Small Holding Development Authority (TSHDA) records, ensuring proportional representation across Divisional Secretariat (DS) divisions. The selected sample represents a crucial segment of Sri Lanka's tea industry, providing insights into the adoption of sustainable agricultural practices through extension services.

3. Data Collection

A multi-stage stratified random sampling procedure was used to capture a proportional sample from the population. The study used a cross-sectional survey of farmers identified from the Tea Small Holding Authority (TSHDA) records, stratified by the Divisional Secretariat (DS) divisions until the 452 subject sample was achieved. The questionnaires were provided in the participants' local language, Sinhala. The data was collected through structured and unstructured questions (Bryman, 2016). The questionnaire was adopted following previous studies with a reliability coefficient of more than 0.7 (Pallant, 2001). A 16-item questionnaire used by Rogers (2003), Shah et al. (2013) and Al-Zahrani et al. (2016) was used to assess the agricultural extension services. A self-administered questionnaire of 11 items developed based on the most utilised measurement instrument by (Ajzen (1991) was used to establish the level of technology adoption. A 24-item survey was conducted based on Haq and Boz (2018), Ibrahim and Alola (2020), Palihakkara et al. (2015), and Waarts et al. (2012) to come up with the composite sustainability score. The data collection took place from September 2023 up to April 2024.

4. Data Analysis

The Partial Least Square Structural Equation Modelling (PLS-SEM) technique was used for hypothesis testing and employed SmartPLS 4 software. This approach is especially relevant for this study because it aims to capture the maximum amount of variance (R^2) between the exogenous variable (agricultural extension services), mediating variable (technology adoption), and endogenous variable (sustainability) constructs (Hair et al., 2022b).

Assessment of Measurement Model

The construct and measurement models for factor loadings, validity, reliability, and multicollinearity were assessed. The current study evaluated the multicollinearity using variance inflation factor (VIF); results of less than 5 indicated no severe multicollinearity problem (Hair et al., 2022b). The ideal values with factor loadings are above 0.70; any value higher than 0.4 can be acceptable if the composite reliability is greater than 0.7 (Hair et al., 2022b). The current study established internal consistency using composite reliability (CR), superior to Cronbach's alpha in SEM analysis (Hair et al., 2022b). Convergent validity was tested using average variance extracted (AVE), and AVE values greater than 0.5 are favoured (Hair et al., 2022b). However, Lam (2012) suggested that an AVE value of 0.31 or higher can be acceptable if CR is above 0.6. Discriminant validity was evaluated by Heterotrait-Monotrait (HTMT) analysis to ensure that the constructs were not too closely related (Henseler et al., 2015) and that all constructs were distinct.

Structural Model Assessment

Path coefficients were estimated to determine the degree of strength and significance of agricultural extension services, technology adoption, and farmer sustainability. The bootstrapping analysis was used to evaluate the proportion of the variance in technology adoption that mediates the relationship between the exogenous latent variable agricultural extension service and the endogenous latent variable sustainability.

Results and Discussion

This section discusses the respondents' profile, descriptive analysis, measurement model, and hypothesis testing.

1. Respondent Profile

The data set was collected from 452 smallholder tea farmers in the Mid Country of Sri Lanka. Participants included 65.7% males, and the mean age of the farmers was 56.6 years old. Out of them, 66.7% of farmers are over 50 years old. All the respondents were married, and their average family size was 3.92. The average defenders in a family were 2.62.

Many respondents were members of the Tea Smallholding Development Society (TSHDS). Many farmers had more than 20 years of farming experience and an education level of GCE O/L based on their status. Most of them, with an average monthly tea yield of 241.39 kg per acre, had no more than one acre of tea land extent. Most farmers had less income & savings and limited credit possibilities. Most farmers engaged in full-time farming and monocropping.

2. Descriptive Statistics of Measurement Items

The findings of the descriptive statistics study are presented in three dimensions: agricultural extension services, technology adoption, and sustainability.

Agricultural Extension Service (AES)

Four significant dimensions were used in this study to evaluate how small tea growers perceived extension services: Change Catalyst, Problem Solver, Resource Linker, and Process Helper. This study also provides descriptive data for the measuring items in Table 1 (Rogers, 2003; Shah et al., 2013).

Table 1. Descriptive statistics of extension service measurement items

No.	Statement	Mean	Standard Deviation
Change of Catalyst			
1	Technical knowledge is empowering the tea smallholder community.	4.038	0.985
2	Your extension agent has a positive attitude toward the work and organisation of development agencies.	3.810	1.043
3	Your extension agent encourages you to adopt new technologies.	3.613	1.144
4	Your extension agent points out the advantages of using new technologies.	3.597	1.135
Problem Solver			
5	Your extension agent has extensive knowledge and experience related to work and social life matters.	3.770	1.109
6	Your extension agents will always be a reference source for the tea smallholder community.	3.562	1.199
7	Your extension agent encourages you to try agricultural innovation despite facing high risks.	3.336	1.291
8	Your extension worker discusses your problem and helps with solutions whenever you request	3.699	1.144
Resource Linker			
9	Your extension agent has a vast network of contacts with agricultural agencies.	3.608	1.080
10	Your extension agent exhibits friendly behaviour during the development and technology transfer process.	3.701	1.098
11	Your extension agents help you get agricultural loans.	3.004	1.365
12	Connecting tea farmers for resource sharing	3.577	1.194
Process Helper			
13	Your extension agent has the qualities of a diligent and dedicated mentor.	3.723	1.162
14	Your extension agent is confident in the capabilities demonstrated by the tea smallholder community.	3.770	1.022
15	Your extension agent always encourages the tea smallholder community to achieve the highest innovation progress.	3.876	1.030
16	Your extension agent has a high level of patience when developing agriculture.	3.996	0.938

Note: Mean scores are based on the Likert scale 1 to 5 (low to high). (Likert & Roslow, 1934)

The extent to which extension agents persuade farmers to adopt new technologies and practices is called the ‘Change of Catalyst’ role. Farmers rate AES as quite effective in driving innovation, with a mean score of 3.76. While many see AES as a vehicle for change, opinions vary, as shown by a standard deviation of 0.84. The ‘Problem Solver’ sub-construct reflects AES’s role in helping farmers address challenges. Farmers rate AES as relatively efficient, with a mean score of 3.59. However, the standard deviation of 0.85 suggests varied experiences, indicating that not all farmers benefit equally from AES's problem-solving support.

The ‘Resource Linker’ role assesses AES’s ability to connect farmers with essential resources like capital, equipment, and inputs. Farmers find this function less beneficial than others, with a mean score of 3.47. A higher standard deviation of 0.87 suggests service delivery gaps, as some farmers access resources more easily than others. The ‘Process Helper’ factor evaluates AES’s support in understanding and adopting new processes for improved yields and quality. This is considered AES’s strongest function, earning the highest mean score of 3.84. The standard deviation of 0.86 indicates moderate variability, suggesting room for improvement in implementation support. Overall, farmers have a positive view of AES, reflected in a mean score of 3.67 across all dimensions. The lower standard deviation of 0.74 suggests a more stable experience regarding AES's role in technology adoption and sustainability.

Technology Adoption

Based on the Theory of Planned Behaviour (TPB), the research highlights three dimensions: attitude, subjective norms, and perceived behavioural control (Beedell & Rehman, 2000). A self-structured questionnaire containing eleven statements determined the farmers' perceptions of technology adoption.

Table 2. Descriptive statistics of farmer technology adoption measurement items

No.	Statement	Mean	Standard Deviation
Attitude			
1	I believe following the recommended technology in tea cultivation will produce high-quality tea.	4.473	0.65
2	Adopting new technology in my tea farming will improve yields and productivity."	3.823	0.764
3	Using technology in tea farming feels more advantageous than sticking to traditional methods.	4.184	0.778
4	I feel optimistic about the potential benefits of technological advances in tea cultivation.	4.035	0.838
Subjective Norms			
5	The opinions of tea cultivation experts and experienced farmers significantly influenced my decision to adopt the tea technologies.	3.885	0.938
6	I often seek advice and recommendations from other farmers who have successfully implemented recommended technologies in their tea cultivation practices.	3.92	0.986
7	My peers and family would support and appreciate my decision to incorporate technology in my tea farming."	3.735	1.127
Perceived Behavioural Control			
8	I have the necessary resources, skills, and knowledge to adopt and implement recommended technologies in my tea cultivation effectively.	3.715	1.018
9	I believe that I have control over the process of integrating recommended technologies into my tea cultivation practices.	3.819	0.949
10	With the proper training, I can overcome challenges in using new technology for tea farming.	4.179	0.896
11	My previous experiences with technology make me confident in adopting new technological advancements in tea farming.	3.927	0.896

Note: Mean scores are based on the Likert scale 1 to 5 (low to high).

The 'Attitude' component of farmers' perception of new technologies is either positive or negative. Here, the mean score averaged 4.13, indicating a strong positive perception of technology as beneficial to farming strategies. The standard deviation of 0.61, shown in Table 2, suggests a relatively high level of agreement among respondents. Subjective norms refer to perceived social pressure influencing technology adoption. Farmers felt moderate social influence, with a mean score of 3.85. The standard deviation of 0.76 indicates some variability in how social norms impact farmers, with some being more sensitive to external pressure.

Perceived Behavioural Control assesses farmers' confidence in adopting new technology based on resources and knowledge. The mean score of 3.91 suggests a relatively high perception of capability, though the standard deviation of 0.68 reflects some variation. While farmers recognize challenges, they believe training can help overcome them. The mean score for 'Technology Adoption' is 3.96, indicating a generally favorable attitude toward new technologies, though there is room for improvement. A low standard deviation of 0.56 suggests most farmers share similar experiences and positive perceptions of innovation in tea farming.

Farmer Sustainability

A 24-item survey construct was used in the research to assess various aspects of sustainability: social, economic, and environmental. The standard deviations and the means of the two groups are shown in Table 3. The mean score of farmer sustainability is 3.782.

Table 3. Descriptive statistics of farmer livelihood sustainability measurement items

No.	Statement	Mean	Standard Deviation
Social			
1	I can access essential social services such as healthcare, education, and clean water.	4.069	0.918
2	I engaged in community activities and have a strong sense of social cohesion.	4.177	0.839
3	I have opportunities for skills development and training to enhance my knowledge and capabilities.	3.934	0.962
4	I am satisfied with the balance between tea cultivation work and social life.	4.058	0.834
5	I wish to make decisions with community members on sustainable tea farming activities.	4.241	0.813
6	The community promotes gender equality and provides equal opportunities and support for women in tea farming.	4.173	0.847
7	I have been recognised as a successful farmer in the tea farming community.	4.06	0.841
8	I feel that cultivating tea will save our future.	4.144	0.97
Economic			
9	My tea factories or leaf collectors are given mostly reasonable prices for green leaves.	3.591	0.956
10	I am willing to increase my yield further by adopting sustainable agricultural practices.	4.374	0.755
11	I can access financial services and credit facilities to invest in my farms and businesses.	2.861	1.424
12	I can access affordable, high-quality inputs, such as fertilisers and new tea varieties.	3.117	1.287
13	I receive training and support to improve my farming practices and increase productivity.	3.071	1.3
14	I am willing to spend money on all the agricultural practices required to increase the yield.	3.67	1.093
15	My yield has been improving over the years.	2.785	1.083
16	I am actively involved in decision-making processes related to my economic activities and have a say in market development initiatives.	4.018	0.982
Environmental			
17	My tea farming community actively conserves and protects biodiversity in and around tea farms.	3.695	1.024
18	I adopt and promote soil conservation practices, such as terracing or cover cropping, to prevent soil erosion on tea farms.	4.004	0.833
19	I adopt climate-smart agriculture techniques (e.g. proper shade management, light plucking in the dry season, and using drought-resistant or disease-resistant varieties).	3.863	0.822
20	I practice organic or agroecological farming methods to minimise the use of synthetic pesticides and fertilisers.	3.179	0.944
21	I ensure that I am not contributing to adding chemicals to typical water streams or water sources.	3.212	0.769
22	I have implemented sustainable waste management practices such as composting and recycling in my tea land.	3.741	0.739
23	I use pesticides as recommended and carefully to maintain pesticide residues.	4.412	0.716
24	I wish to get environmental certification for my tea land and proceed accordingly. (e.g. Rainforest Alliance (RA) certificate)	4.325	0.766

Note: Mean scores are based on the Likert scale 1 to 5 (low to high). (Likert & Roslow, 1934)

3. Social Sustainability

The social aspect of sustainability is the most developed among farmers, with an average of 4.107. This high ranking suggests good access to social services and strong social cohesion. Key contributing factors include social integration and community participation (mean = 4.177), indicating high social capital among tea growers. Farmers also have reasonable access to skill enhancement opportunities and a good work-life balance (mean = 3.934 and 4.058, respectively). Interest in cooperative decision-making is the highest (4.241), reflecting a strong commitment to inclusivity. Social well-being is linked to gender equality (mean = 4.173) and financial status (mean = 4.06). However, variations exist, such as in social service access (coefficient of variation = 0.918), suggesting differing experiences of social sustainability.

4. Economic Sustainability

The economic sustainability aspect is the lowest rated, with a mean score of 3.436. Farmers reported difficulties in accessing credit facilities and financial services (mean = 2.861) and affordable, quality inputs (mean = 3.117). Despite challenges, significant adoption of sustainable practices (mean = 4.374) reflects farmers' willingness to progress. The mean price of tea leaves is 3.591, considered reasonable, though more evidence is needed to confirm an improved outcome (mean = 2.785). Farmers viewed themselves as purchasers of appropriate goods and services (mean = 4.018). These findings indicate their involvement in economic development but highlight the need for better funding to sustain farming. The relatively high standard deviation (1.424) for financial services suggests disparities in farmers' economic status, reflecting inequality in access to services and financial support.

5. Environmental Sustainability

The study recognizes agricultural practices related to resource conservation and environmental management, reflected in the above-average environment score (3.804). Pesticide management (mean = 4.412) is well-established, with farmers adhering to recommended usage. Climate-smart agriculture (mean = 3.863) and soil conservation (mean = 4.004) indicate a solid grasp of sustainable farming. The high interest in environmental certification (mean = 4.325) suggests farmers seek eco-friendly recognition.

However, weaknesses exist in organic farming (mean = 3.179) and preventing water pollution (mean = 3.212), highlighting the need for greater effort and knowledge. Social sustainability among smallholder tea producers in Sri Lanka is strong, driven by gender balance, community engagement, and participatory decision-making. Economic sustainability faces challenges like low yields and limited access to improved inputs and finance. Despite strong environmental standards, improvements are needed in water management and ecological development. Agricultural extension services and technology adoption could bridge these gaps, enhancing sustainability.

6. Measurement Model Results: Reliability and Validity

The quality of the measurement model was assessed using internal consistency and convergent validity tests, factor loading assessment, and collinearity diagnostics. The average VIFs of all constructs were less than five (Hair et al., 2022b), meaning that multicollinearity is not likely to be a problem in the proceed to analysis data.

Following Hair et al. (2022), only the items with factor loadings of less than 0.4 were excluded from the analysis (n=3). However, those with factor loadings of 0.4 – 0.7 were kept if they had a Cronbach's Alpha of > 0.70 and Average Variance Extracted (AVE) of > 0.33. All constructs were reliable, with Cronbach's Alpha coefficients greater than 0.728 and convergent validity with AVE higher than 0.333 (Lam, 2012). For this reason, due to the Composite Reliability (CR) and Cronbach's Alpha coefficients, the convergent validity of the constructs can be considered appropriate (Table 5). HTMT ratio analysis was used to assess discriminant validity, and all the values were below the cutoff level of 0.85 (Henseler et al., 2015) (see Table 6).

Table 4. Collinearity results

Model Variables	**Collinearity Statistics VIF**
Extension service	2.092
Technology Adoption	2.599
Farmer sustainability	

Table 5. Reliability and convergent validity of constructs

	Cronbach Alpha	Composite Reliability	Average Variance Extraction (AVE)
Extension service	0.915	0.926	0.446
Technology Adoption	0.835	0.867	0.333
Sustainability	0.848	0.879	0.403

Table 6. HTMT discriminant validity result

	Extension Service	Sustainability	Technology Adoption
Extension Service		0.750	0.718
Sustainability	0.750		0.848
Technology Adoption	0.718	0.848	

7. Structural Model Results: Hypothesis Testing

This study examined the role of agricultural extension services, technology adoption, and sustainability among smallholder tea farmers in Sri Lanka using Partial Least Squares Modeling (PLS-SEM) to test four hypotheses (H1, H2, H3, H4). H1 proposes that agricultural extension services positively impact sustainability, H2 explores the link between technology adoption and sustainability, H3 examines the relationship between extension services and technology adoption, and H4 assesses technology adoption's mediating role between extension services and sustainability.

Figure 1 presents the path analysis model, confirming a significant positive influence of agricultural extension services on farmer sustainability (β = 0.382, p<0.01). The strongest determinant was extension services on technology adoption (β = 0.664, p<0.01), followed by technology adoption on sustainability (β = 0.514, p<0.01). Additionally, AES and TA explained 67% of the variance in farmer sustainability, while AES accounted for 44.1% of the variance in TA. These results were computed using Smart PLS Algorithm analysis. The following section presents the structural model of the study's mediating effect.

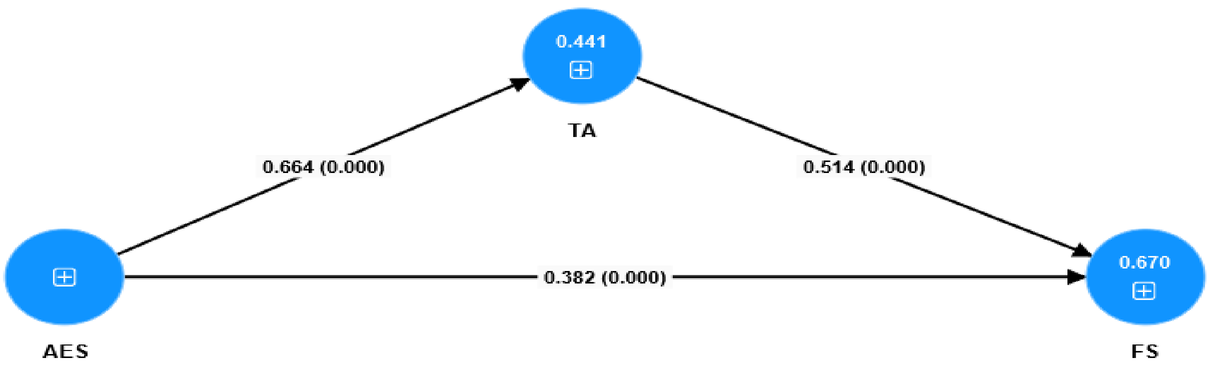

Figure 1. Structural model of Bootstrapping – Mediation effect of Technology Adoption (TA) between Agricultural Extension Service (AES) and Farmer Sustainability (FS) (Hair et al., 2022)

The direct effects of agricultural extension services and technology adoption on farmer sustainability are indicated in Table 7, while the mediating effect of technology adoption is shown in Table 8.

Table 7. Path coefficients for technology adoption and sustainability

Relationship	Std. Beta	Std. Deviation	Std. Error	T Value	P Value	Results
AES -> FS	0.382	0.04	0.001	9.661	0.000	** significant
AES -> TA	0.664	0.028	0.001	23.504	0.000	** significant
TA -> FS	0.514	0.041	0.002	12.645	0.000	** significant

AES -Agricultural Extension Service, TA – Technology Adoption, FS- Farmer Sustainability
*** Significant 0.01 level*

Table 8. The mediation effect of TA on the relationship between AES and FS

Relationship	Indirect Effect	Std. error	t- value	p-value	CI		Result
					LL (2.5%)	UL (97.5%)	
AES -> TA -> FS	0.341	0.001	11.258	0.000	0.304	0.458	Significant**

Note: AES – Agricultural Extension Service, TA- Technology Adoption, FS- Farmer Sustainability

H1: There is a significant relationship between agriculture extension services and sustainability among smallholder tea farmers in Sri Lanka.

According to the path coefficients, the positive relationship between agricultural extension services and sustainability is statistically significant (H1: β= 0.382, p = 0.000), supporting H1. The findings substantiate the hypothesis that farmers' engagement in agricultural extension services positively and significantly impacts the sustainability of smallholder tea farmers in Sri Lanka. Extension services translate research into practical applications, benefiting farmers through knowledge dissemination, capacity building, and technology adoption.

As noted by Hameed and Sawicka (2023), extension agents transfer research findings on tea harvesting, soil conservation, and water conservation to promote sustainable farming. Extension programs also educate farmers to adopt sustainable measures (Pretty, 2003) and encourage innovations such as precision agriculture and efficient resource use (Westermann et al., 2018).

H2: There is a significant relationship between technology adoption and sustainability among smallholder tea farmers in Sri Lanka.

The relationship between technology adoption and farmer sustainability was significant at the 0.01 level (H2: β=0.514, p=0.000), supporting H2 and indicating that technology adoption enhances farmer sustainability. Farmer sustainability and technological adoption are often linked. A recent review by Shariff et al. (2022) on Asian farmers' technology adoption identified key factors influencing usage and sustainability outcomes. These findings show that technology and sustainability are intertwined, with specific technologies and adoption contexts playing a role. Additionally, technology adoption improves agricultural sustainability by boosting resource productivity, yield, and quality.

H3: There is a significant relationship between agricultural extension services and technology adoption among smallholder tea farmers in Sri Lanka.

As shown in Table 7, the results confirm a significant positive relationship between agricultural extension services and technology adoption among tea farmers (H3: β= 0.664, p=0.000). These findings align with earlier studies highlighting extension services' role in information dissemination, overcoming adoption constraints, and encouraging technology adoption (Feder et al., 2004). Extension agents provide essential information, training, and demonstrations to help farmers decide on changing their practices.

H4: Technology adoption mediates the relationship between the role of agricultural extension services and the sustainability of smallholder tea farmers in Sri Lanka.

Path coefficients, R-square values, T-values, confidence interval levels and significance levels offer an understanding of how technology adoption mediates between agricultural extension services and farmer sustainability, including technology adoption as a mediator significantly enhanced the model, with the indirect effect of AES towards FS was positive (H4: β= 0.341, p=0.000). The bootstrap confidence interval (LL = 0.304, UL = 0.458) was not inclusively zero, thus supporting the mediation role of TA. Therefore, hypothesis

H4 received support, confirming that technology adoption is essential in the mediating relationship between agricultural extension services and farmer sustainability.

Recent studies highlight the vital role of extension services in linking technology to farmers. According to Gao et al. (2020), understanding how information spreads among farmers is crucial for technology adoption, particularly ensuring that small-scale and elderly farmers receive relevant knowledge. Extension services facilitate adoption by informing farmers about new technologies through agents who bridge the gap between researchers and farmers. Research shows a strong correlation between extension services, technology adoption, productivity, and farmer sustainability. For instance, Walisinghe et al. (2017) found that public agricultural extension programs positively influenced technology adoption among rice farmers in Sri Lanka. Similarly, Ali and Rahut (2013) reported that farmers in Pakistan who received extension support had higher yields and incomes. Pan et al. (2018) also found that Ugandan women farmers involved in extension programs achieved higher yields, more savings, and increased wages. These findings align with the innovation diffusion theory, which suggests that access to information drives technology adoption, leading to improved production and income. Therefore, extension officers, particularly in the tea sector, can significantly boost technology uptake and sustainability among Sri Lankan smallholder farmers.

To enhance agricultural extension services, policymakers and agricultural agencies should invest more in extension agents, financial resources, and the application of new technologies. This includes improved education for extension agents, better communication tools, and stronger ties with financial institutions. Tailored extension programs for smallholder farmers should address challenges such as credit access and risk management. Further research is needed to identify constraints limiting smallholder farmers' adoption of risky innovations, particularly examining financial literacy and credit availability. Longitudinal studies should assess the long-term impact of technology use and agricultural extension on farm management practices. Comparative studies across different regions and crops would help identify the most effective extension strategies. Using qualitative methods such as interviews and focus group discussions could provide deeper insights into farmers' perspectives, complementing quantitative data. Understanding why farmers choose to innovate can aid in designing targeted extension programs. Assessing the long-term effects of these technologies on farmers' well-being and the environment is also essential for ensuring sustainability. Addressing these research gaps will help policymakers and practitioners develop effective strategies to enhance agricultural extension services, ensuring smallholder farmers adopt suitable technologies for sustainable farming.

Conclusion

This study examined the link between extension services, technology adoption, and smallholder tea farmers' sustainability in Sri Lanka. It also supports extension services in promoting technology adoption to enhance sustainability. Extension agents, who act as change agents, problem solvers, resource linkers, and process helpers, play a key role in technology adoption among farmers. The study confirmed a positive relationship between extension services and technology adoption, highlighting the importance of quality services in bridging information gaps and promoting better practices.

As hypothesized, technology adoption mediated the relationship between extension services and farmer sustainability. It significantly impacts smallholder tea farmers by increasing production, supporting environmentally friendly practices, and improving resource efficiency. However, while technology adoption is crucial, other factors also affect farmer sustainability, reinforcing the need for a comprehensive approach that considers social, economic, and environmental aspects.

This research provides empirical evidence supporting the interaction between extension services and technology adoption in smallholder tea farming sustainability. It also confirms that technology adoption mediates the relationship between agricultural extension services and farmer sustainability. The study recommends increased investment in quality extension services and technology adoption to ensure the sustainable development of Sri Lanka's tea sub-sector.

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