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Constraints Affecting the Adoption of Low-Carbon Agricultural Technologies in Kerala

Sudhakaran Anupama[1]*, K. G. Sangeetha[2] and Allan Thomas[3]

[1]Ph.D. Scholar, [2]Assistant Professor, [3]Professor, Department of Agricultural Extension Education, College of Agriculture, Vellayani, Thiruvananthapuram-695522, Kerala, India
*Corresponding author email id: anupama.s@kau.in

HIGHLIGHTS

- Unpredictable weather, labour shortages, and high input costs emerged as significant constraints to the adoption of low-carbon agricultural technologies.
- Economic and market constraints surpassed awareness-related barriers.
- Locale-specific extension strategies, highlighting district-level customisation, are essential to overcoming barriers to the adoption of low-carbon agricultural technologies.

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ABSTRACT

The study was conducted during 2025 in the three districts of Kerala, viz., Thiruvananthapuram, Ernakulam, and Kasaragod, to identify the most critical constraints to farmers' adoption of low-carbon agricultural technologies (LCAT). A descriptive research design was administered for data collection, and 270 farmers were selected using random sampling technique. The Garrett ranking technique was applied to quantify the severity of ten predetermined constraints influencing adoption. The results revealed that unpredictable weather, labour shortage, and high input costs were the most severe constraints limiting adoption. Economic and market-related barriers, including the lack of marketing facilities and inputs, also restricted farmers' willingness to adopt low-carbon agricultural technologies. Knowledge-related constraints, including limited awareness of climate change and low-carbon technologies, were ranked lower, indicating that awareness alone was inadequate to drive adoption without tackling structural and financial barriers. Spearman's rank correlation revealed the district-wise variation in the severity of constraints, emphasising the need for location-specific extension strategies, within a broader state-level policy framework to promote Kerala's transition towards carbon-neutral agriculture.

INTRODUCTION

Agricultural practices significantly impact the carbon balance, underscoring agriculture's dual role as both a source of emissions and a carbon sink. (Chen et al., 2020). In this context, how well carbon sequestration and low-carbon agricultural technologies such as reduced tillage, optimized fertilizer and pesticide usage, managing manure and waste, addition of biochar, etc., are increasingly recognized as essential for mitigating climate change while sustaining agricultural productivity (Ozlu et al., 2022).

Since 2018, Kerala has actively been exploring pathways to promote carbon-neutral farming practices, in line with both national climate action objectives and the global agenda for sustainable agriculture. A noticeable milestone is the designation of Meenangadi Panchayath in Wayanad district as India's first carbon-neutral village, which introduces the concept of a "carbon-neutral community",

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emphasizing zero-carbon development and grassroots-level food and energy self-sufficiency (Jayakumar et al., 2018). Complementing this, the State Seed Farm, Aluva, has been declared the first carbon-neutral farm in India, demonstrating the feasibility of low-carbon agricultural technologies at a farm scale (Mani, 2022). The successful implementation of these models positions Kerala to pursue the broader goal of achieving Net Zero status by 2050 through the "Net Zero Carbon Keralam through People Campaign" under the Navakeralam Karmapadhathi, which seeks to integrate community participation with sustainable development initiatives.

Despite these initiatives, the low-carbon agricultural techniques are yet to gain widespread adoption among homestead farms across the state. As reported by Singh et al. (2022), low-carbon agricultural technologies remain insufficiently adopted and scientifically validated. Accordingly, the study aims to identify the significant constraints that hinder farmers from implementing such practices at the household level. As noted by Momenpour et al. (2024), understanding the constraints is essential for policymakers and stakeholders to design targeted, more successful interventions.

METHODOLOGY

Three districts in Kerala, *viz.,* Thiruvananthapuram, Ernakulam, and Kasaragod, which were purposefully selected to represent the state's Southern, Central, and Northern regions, respectively, for the study. A total of 270 farmers were randomly selected for the study, comprising 202 males and 68 females. The study followed a descriptive research design to identify the key constraints to farmers' adoption of low-carbon agricultural technologies.

The Garrett ranking technique was applied to quantify the severity of these constraints perceived by the farmers. On a scale of 1 (most severe) to 10 (least severe), respondents were asked to rank ten pre-identified constraints, derived from the existing literature and focus group discussions with stakeholders. The ranks assigned by each respondent were converted into per cent positions and corresponding Garrett scores. The total and mean Garrett scores of each constraint were calculated, and constraints were then arranged in descending order of their mean scores to establish their relative ranking. Furthermore, the Garrett ranking for the three districts was calculated separately.

Spearman's rank (r_s) correlation coefficient was used to assess the degree of similarity in the rankings of constraints across the three districts. Spearman's rank correlation was computed pairwise between Thiruvananthapuram and Ernakulam, Thiruvananthapuram and Kasaragod, and Ernakulam and Kasaragod.

RESULTS

Apart from identifying the priority, the Garrett Ranking Technique also provided insight into the severity and spread of each constraint. A higher Garrett score indicated not only that the constraint was ranked more frequently as important, but also that it was widely experienced across respondents. This means the constraints were consistently perceived as significant, cutting across different situations, contexts, or respondent groups. The constraint means that weighted scores, mean scores, and corresponding ranks of the constraints identified by farmers in adopting low-carbon agricultural technologies are presented in Table 1. The constraints with higher mean scores were interpreted as the most significant barriers to adopting low-carbon technologies, whereas those with lower mean scores were considered less influential.

Table 1. Overall Garrett ranking of constraints in adopting low-carbon agricultural technologies

Codes	Constraints	GMS	Rank
C1	Lack of climate change awareness	48.51	VII
C2	Lack of low carbon agriculture technology awareness	47.82	VIII
C3	Lack of suitable inputs	54.71	V
C4	High input cost	57.44	III
C5	Lack of proper marketing facility fetching premium price	55.30	IV
C6	High labour shortage	60.56	II
C7	Unpredictable weather	63.85	I
C8	Lack of access to timely weather information	54.15	VI
C9	Lack of access to credit facilities	35.27	IX
C10	Limited access to agricultural extension agencies	20.48	X

GMS: Garrett Mean Score

DISCUSSIONS

The Garrett ranking analysis provided critical insights into the challenges farmers faced when implementing low-carbon agricultural technologies. The study provided a solid foundation for addressing the main constraints by identifying a number of limitations that affect the adoption process (Warshini et al., 2025). According to the analysis, the top barriers were unpredictable weather, labour shortages, and high input costs. These results uncovered the multidimensional challenges farmers face in transitioning to sustainable low-carbon agricultural technologies, such as precision agriculture, straw recycling, and soil carbon sequestration methods (Zhao & Zhou, 2021). The most significant constraint farmers identified was unpredictable weather, highlighting the increasing susceptibility of smallholder farmers to climate variability and extreme events. Irregular rainfall, extended dry spells and temperature fluctuations disrupted the cropping patterns, creating production uncertainty and thereby constraining the farmers' willingness to adopt new technologies (Tripathi & Mishra, 2017). Under such conditions of climate risk, low-carbon agriculture practices that require upfront investment become less attractive to farmers, thus constraining their adoption (Issahaku & Abdulai, 2020; Ling et al., 2022). The second significant constraint identified was the shortage of agricultural labour. Daum et al. (2023) found that many low-carbon agricultural techniques required more labour than conventional, mechanised, and input-heavy practices. Tong et al. (2024) suggested that labour intensive practices like mulching, organic manuring and integrated farming systems were not as feasible due to labour scarcity brought on by rural-urban migration and an ageing farming population. This suggested that farmers were frequently pressured to choose labour-saving, but often carbon-intensive alternatives.

The following three ranking constraints of high input cost (III), lack of proper marketing facility fetching premium price (IV) and

Table 2. District wise Garrett ranking of constraints in adopting low-carbon agricultural technologies

Codes	Constraints	District-wise ranking					
		TVM		EKM		KSG	
		GMS	R	GMS	R	GMS	R
C1	Lack of climate change awareness	51.00	VI	44.08	VII	50.46	VI
C2	Lack of low carbon agriculture technology awareness	52.72	V	41.26	VIII	49.43	VII
C3	Lack of suitable inputs	50.18	VIII	62.30	III	51.66	V
C4	High input cost	59.40	II	55.68	V	57.24	IV
C5	Lack of proper marketing facility fetching premium price	50.33	VII	51.99	VI	63.10	I
C6	High labour shortage	56.61	III	63.36	II	61.71	II
C7	Unpredictable weather	64.73	I	65.92	I	60.79	III
C8	Lack of access to timely weather information	54.59	IV	57.54	IV	50.07	VIII
C9	Lack of access to credit facilities	33.60	IX	37.63	IX	35.06	IX
C10	Limited access to agricultural extension agencies	24.83	X	18.24	X	18.49	X

GMS: Garrett Mean Score; TVM: Thiruvananthapuram; EKM: Ernakulam; KSG; Kasaragod; Rank: R

Table 3. Spearman's Rank Correlation Matrix

Correlation	r_s	P value (5%. Level)
TVM – EKM	0.721*	0.019
EKM – KSG	0.685*	0.029
TVM – KSG	0.552	0.098

*significant at 5% level ($p < 0.05$)

lack of suitable inputs (V) collectively indicated significant economic and marketing barriers. Many LCATs, including biofertilizers, renewable energy-based irrigation systems, or improved composting units, require higher initial investments, posing a significant challenge for small and marginal farmers (Autio et al., 2021; Roy & Ghosh, 2022; Sabu & Roy, 2024). According to the study by Jiang et al. (2022), farmers were likely to prioritise short-term cost reduction over long-term sustainability benefits, when sufficient subsidies or financial incentives were not offered. Additionally, even when farmers adopted such practices, the lack of differentiated markets and reward mechanisms that offer premium prices for low-carbon products limits their economic motivation to continue these efforts.

Even with adequate awareness, adoption remained unlikely due to the absence of supportive structural and economic barriers, as indicated by the lower ranking of the knowledge and awareness-related constraints, such as lack of access to timely weather information (VI), lack of climate change awareness (VII) and lack of low-carbon agriculture technology awareness (VIII). These findings challenged a predictive model introduced by Kuehne et al. (2017), which focused on knowledge, awareness and learning as key factors influencing adoption decisions. The result also emphasized that merely providing information was insufficient to induce behavioral change, as farmers prioritized financial viability and risk management. Nonetheless, the comparatively higher ranking of inadequate access to timely weather information highlighted the importance of actionable, real-time data as a risk-mitigation tool, valued more by farmers than general climate awareness. Accordingly, extension efforts should prioritize the dissemination of location-specific, real-time information rather than focusing solely on general climate education (Mabhaudhi et al., 2025; Sattar et al., 2025).

According to the comparatively lower rankings of lack of access to credit facilities (IX) and limited access to agricultural extension agencies (X), either financial and institutional links were relatively functional among the farmers surveyed, or farmers were not fully aware of the mechanisms available to them. In the latter instance, limited awareness of credit schemes, subsidies and extension services may restrict farmers' ability to take advantage of institutional resources that could otherwise facilitate the shift to sustainable, low-carbon agricultural technologies. Raza et al. (2023) stated that inadequate access to credit constrains farmers' capacity to meet the initial expenses of low-carbon technologies, while weak linkage with the extension agencies limits their exposure to new technologies, best practices, and risk-mitigation techniques.

In view of the observed variations in the rankings of the constraints (Table 2), Spearman's rank correlation analysis was performed. The results (Table 3) revealed that the perceived severity of constraints related to the adoption of low-carbon agricultural technologies was not uniform across all districts. There was a strong and statistically significant correlation between Thiruvananthapuram and Ernakulam as well as Ernakulam and Kasaragod, implying that farmers in Ernakulam district experienced and prioritized the constraints similarly to the other districts. As reported by Devadas & Ushadevi (2018), this similarity may be attributed to the shared agro-ecological environment, possibly due to similar production risks and resource needs, as well as the sound and consistent market linkages and exposure to technology.

In contrast, Thiruvananthapuram and Kasaragod exhibited a non-significant correlation suggesting differences in cropping pattern, resource mobilization, structural and institutional networks access, and socio-economic characteristics of the farm households. Farmers in Kasaragod districts followed more traditional farming practices, faced more structural challenges, primarily related to market facilities. Meanwhile, Thiruvananthapuram is closer to policy institutions and had stronger institutional access, which may therefore lead it to rank knowledge-related constraints higher (Preethi et al., 2022).

CONCLUSION

The study affirms that farmers' adoption of low-carbon agricultural technologies in Kerala is shaped less by awareness deficits and more by perceived risk, economic feasibility, and structural conditions within smallholder farming systems. This highlights the need to move beyond information-centric approaches and adopt policy frameworks that actively reduce climate and market-related uncertainties faced by farmers. The transition towards carbon-neutral agriculture in Kerala will therefore depend on integrated interventions that align financial incentives, climate-resilient infrastructure and institutional support mechanisms with farmers' risk management priorities. Moreover, Spearman's rank correlation results highlight the importance of complementing the state level strategies with the decentralized, context-specific implementation pathways. These inferences highlight that Kerala's transition to carbon-neutral agriculture and the state's broader objective of net-zero emissions by 2050 require coordinated policy interventions that incorporate financial incentives, weather-based advisories, and proper institutional linkages.

DECLARATIONS

Ethical approval and informed consent: Informed consent was sought from the selected 270 farmers during the course of the research.

Conflict of interest: The authors declare that research was conducted in the absence of any commercial or financial relationship that could as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The author takes full responsibility for the final content of this publication.

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