AWARENESS-ADOPTION PARADOXES IN INDUSTRY 4.0 TECHNOLOGIES: THE CASE OF RUBBER MICROPLANTATIONS

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ABSTRACT

This paper examines the disparity between knowledge of advanced technologies and their adoption among small rubber growers. Despite familiarity with Industry 4.0 innovations such as robotic tapping systems and sensor networks, growers resist implementation due to high costs, mismatches with local weather patterns, rugged terrain, and a lack of practical skills. Our survey of rubber microplantations in Kerala, India, finds that this phenomenon persists regardless of grower age or plantation scale, suggesting structural flaws in the management of perennial crops. By addressing gaps in prior scholarship, we identify a "familiarity trap" among plantation owners that impedes the adoption of resilient small-scale farming strategies. Further, we critique policy shortcomings that worsen the performance of India's rubber industry and offer recommendations for state-backed financial aid and skill-building programs.

Keywords: Rubber Microplantations, Technology Adoption Paradox, Industry 4.0 Innovations, Smallholder Farmers, Kerala, India, Adoption Barriers, Policy Interventions, Familiarity Trap, Perennial Crops, Sustainable Agriculture.

INTRODUCTION

In an era of rapid technological advancement, agriculture in developing economies faces several unique challenges in adopting innovations intended to enhance productivity and performance. Natural rubber cultivation, a cornerstone of rural livelihoods in regions like Kerala, India, exemplifies this tension. India, the world's second-largest producer of natural rubber, relies heavily on small-scale plantations that contribute over 90% of domestic output, supporting millions of households. While there has been widespread exposure to innovative tools and technologies, adoption rates remain low, perpetuating low yields and economic vulnerability. This disconnect raises questions about the factors impeding progress in perennial crop systems, where long investment horizons and unique ecological constraints diverge from annual farming contexts.

Farmers exhibit high awareness and positive attitudes toward innovations, but fail to act on them. Traditional frameworks for technology adoption in the agriculture sector predict uptake in resource-rich settings, but fail in settings such as microplantations, where barriers such as capital scarcity, topographic challenges, and knowledge gaps are present. Prior studies (e.g., Barlow, 1997; Doss, 2006) have mainly overlooked adoption failure in the rubber plantation industry, leaving a critical void in understanding how perceptual, economic, and socio-cultural elements interact to sustain non-adoption among informed smallholders.

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This paper addresses the gap in understanding the paradox of rubber plantation innovation diffusion by conducting a mixed-methods investigation in India's rubber capital, Pathanamthitta district. We surveyed rubber microplantation owners and analyzed secondary data from the Government of India to identify the factors behind the low diffusion of technology innovations. By exploring barrier hierarchies, demographic influences, and intervention preferences among rubber farmers and cooperative members, we discovered patterns that diverge from conventional wisdom on the adoption of innovations. These insights offer fresh perspectives on the diffusion of innovation in vulnerable agricultural economies and highlight the need for systemic reforms to increase technology adoption in India's rubber sector.

LITERATURE REVIEW

Theoretical Foundations and the Emergence of the Technology Adoption Paradox

Traditional technology adoption frameworks dominate agricultural innovation research (Aker, 2011). The Technology Acceptance Model (TAM) predicts technology adoption based on perceived usefulness and ease of use (Venkatesh et al., 2003; King & He, 2006). Innovation Diffusion Theory (IDT) suggests a linear progression through awareness, trial, and implementation (Daberkow & McBride, 2003). The Unified Theory of Acceptance and Use of Technology (UTAUT) incorporates social influence and facilitating conditions (Williams et al., 2015). These models have been validated in developed agricultural contexts, predicting adoption behaviors among farmers who progress through traditional diffusion pathways (Pandeya et al., 2025).

Established models show a theoretical limitation in contexts where farmers have comprehensive technology awareness but still do not adopt it (awareness is not always a statistically significant predictor of adoption). However, prior research has identified certain factors – such as doubt about benefits, cost concerns, risk aversion, a preference for less laborious work, adverse input markets, and long gestation periods. Prior studies addressed zero-adoption scenarios, framing the decision as adoption or non-adoption (Barlow, 1997; Dimara & Skuras, 2003), and using econometric techniques such as partial observability models and zero-inflated count data models to explicitly model non-adopters.

The body of research has thus identified a technology readiness paradox in agricultural innovation, where high awareness coexists with non-adoption, highlighting the need for extension services that address perceptual and socio-cultural barriers beyond mere information dissemination (Daberkow & McBride, 2003; Long et al., 2016; Pandeya et al., 2025).

Rubber Micro-Plantation Systems and Information-Implementation Disconnects

Rubber microplantation systems, typically defined as tree-crop operations under five hectares, are a crucial livelihood source for millions of smallholder farmers in developing countries (Azizan et al., 2021). These countries face limited economies of scale, capital constraints, and vulnerability to market fluctuations. A significant portion of rubber production occurs on holdings of less than five hectares, creating unique challenges for technology adoption.

Recent data from Kerala, India, indicates productivity stagnation far below potential yields, exacerbated by small plot sizes and aging farmer demographics. Similar patterns emerge in other Indian states, such as Tamil Nadu and Karnataka, where rubber cultivation is constrained by water scarcity and soil degradation (Viswanathan & Shivakoti, 2008; Edwin, 2022; Vijayan et al., 2023). These constraints limit technological upgrades despite growing market demand.

Similarly, smallholder rubber farmers in Thailand face institutional barriers that hinder

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investment in sustainable practices (Foxall, 2013; Ahrends et al., 2015; Warren-Thomas et al., 2023). These barriers stem from fragmented extension services and fluctuating prices. Vietnam's rubber sector also faces comparable challenges. Smallholders lack access to decision support systems for disease management and yield optimization.

The state of Kerala, which contributes over 90% of India's natural rubber output, sustains a dominant share of livelihoods in districts like Pathanamthitta, where small farmers rely predominantly on rubber for income and are beset by fluctuating prices, climatic disruptions, diseases, and reduced yields. Despite awareness of innovations such as robotic tapping machines, sensors, and Global Positioning Systems (GPS), adoption remains low for various reasons.

Industry 4.0 Technologies and Awareness-Adoption in Rubber Plantations

Industry 4.0, a transformative approach to agricultural production, integrates cyber-physical systems, the Internet of Things (IoT), Artificial Intelligence (AI), and automation to optimize resource use and enhance crop management, with potentially substantial productivity gains (Assimakopoulos et al., 2024; Wolfert et al., 2017). Innovative farming applications include precision agriculture, automated monitoring, robotic systems, and data-driven decision support. Applications particularly relevant to rubber plantation agriculture include utilizing robotic tapping systems, IoT sensor networks, GPS-guided precision applications, and automated processing systems. Recent frameworks emphasize the need for integrated approaches to overcome implementation challenges in perennial crops, such as rubber, by addressing barriers to the adoption of Agriculture 4.0 within supply chains (Da Silveira et al., 2023).

The Technology Readiness Paradox Through Familiarity: Farmers possess knowledge but fail to adopt technology due to a paradox. Increased familiarity through demonstration and education may strengthen perceptions of barriers, as they become more aware of implementation challenges, leading to greater awareness but lower likelihood of adoption.

Economic Barrier Hierarchies and the Cost-Awareness Paradox in Rubber Smallholdings: Economic constraints, such as capital requirements, access to credit, perceived cost-benefit ratios, and risk aversion, consistently hinder the adoption of agricultural technology. For instance, high upfront investment costs significantly hinder resource-constrained rubber farmers, especially when technologies exhibit increasing returns to scale. Credit market failures further limit access to investment capital (Adrian et al., 2005; Feder et al., 1985; Long et al., 2016; Vasavi et al., 2025). Farmers possess knowledge about rubber farming but fail to adopt it due to economic barriers. Despite understanding the benefits and cost structures, risk aversion and credit constraints hinder adoption. These factors, coupled with behavioral considerations, create intricate barrier hierarchies that conventional economic models struggle to represent.

Why do farmers possess knowledge but fail to adopt it? This is the technology readiness paradox, specifically in the knowledge dimension. Rubber farmers, for instance, are aware of technology's functions and benefits but perceive insurmountable knowledge barriers to implementation. This suggests that awareness and perceived implementation capability operate through distinct cognitive mechanisms (Daberkow & McBride, 2003; Adrian et al., 2005; Pierpaoli et al., 2013).

Environmental and technical adaptation barriers include climatic compatibility, topographical constraints, and the suitability of technology for local farming systems (Ahrends et al., 2015). Further, aspects of the immediate geography, such as a hilly terrain and monsoon-dependent tapping, further act as barriers (Da Silveira et al., 2023; Imelda et al., 2023) to technology adoption.

Socio-Cultural Barriers and Demographic Influences on Technology Paradox in Rubber

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Farming

Resistance to change and a strong attachment to traditional practices hinder the adoption of technologies, especially those that require significant alterations to farming routines. Farmers' willingness to adopt unfamiliar technologies is influenced by trust in technology and innovation anxiety. Age consistently predicts technology acceptance (Adesina, 1995; Liu, 2013; Pandeya et al., 2025; Vasavi et al., 2025).

Farmers possess knowledge but fail to adopt new technologies due to social pressure, risk aversion, or cultural factors, underscoring the socio-cultural dimension of the technology-readiness paradox. Despite awareness and positive attitudes, traditional practices persist, hindering the effective adoption and use of new technologies (Doss, 2006; Liu, 2013; Rosenstock et al., 2018; Vasavi et al., 2025).

Additionally, farm size significantly affects technology adoption, especially for rubber micro-farms, due to economies of scale, fixed-cost distribution, and technology divisibility. However, limited production volumes hinder investment in technology for these micro-farms. Age also influences adoption through mechanisms like technology anxiety, learning capacity, and investment horizons in long-cycle crops like rubber (Feder et al., 1985; Adrian et al., 2005; Lambert et al., 2025; Pandeya et al., 2025).

Technology Readiness Paradox Across Demographics: Farmers' knowledge manifests differently across age and farm size groups. Younger rubber farmers and larger operations are more aware but not necessarily more likely to adopt. Demographic factors interact with barriers in complex ways, challenging conventional models (Feder et al., 1985; Knowler & Bradshaw, 2007; Vecchio et al., 2020; Pandeya et al., 2025).

Policy Frameworks and the Intervention Preference Paradox in the Rubber Sector Technology Readiness Paradox in the Policy Context: Rubber farmers demonstrate awareness of available technologies and government support programs, yet fail to participate in or benefit from these interventions, highlighting a misalignment between policy design and farmer preferences or barriers. Policy design processes often lack systematic consultation with beneficiaries, while extension service delivery mechanisms struggle to promote complex technologies through traditional approaches (Viswanathan & Shivakoti, 2008; Faure et al., 2012; Eastwood et al., 2017; Wigboldus et al., 2017; Negash et al., 2021; Imelda et al., 2023).

The literature reveals multiple interconnected dimensions of the technology readiness paradox in rubber microplantation agriculture. This paradox encompasses the understanding of technology-aware non-adopters, barrier hierarchies, and intervention preferences, as well as inadequacies in policy addressing the unique needs of rubber microplantation systems. The paradox challenges traditional adoption models and policy approaches across economic, technical, environmental, social, and policy dimensions. While some foundational concepts are drawn from consumer behavior and general development economics literature, their extension to rubber-specific contexts requires cautious application and further validation in perennial crop systems (Doss, 2006; Viswanathan & Shivakoti, 2008; Sitepu et al., 2019; Negash et al., 2021; Da Silveira et al., 2023).

Primary Research Question

In light of the foregoing delineation of research and policy, this study therefore proposes the following research question:

1. How do technology-aware rubber microplantation owners perceive and rank the barriers to adopting Industry 4.0 technology?

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2. How do these perceptions vary among different farmer demographic characteristics?

Secondary Research Questions

Additionally, we seek answers to the following research questions:

1. What is the relationship between technology awareness levels and perceived technology necessity among rubber microplantation owners?
2. How do age and farm size influence barrier perception rankings and intervention preferences?
3. Which intervention strategies are most preferred for overcoming adoption barriers, and how do preferences correlate with farmer demographic characteristics?
4. How does technology familiarity breadth relate to perceived yield benefits and technology recommendation likelihood?
5. How does occupation as a farmer versus a Rubber Producers' Society member shape barrier rankings and preferred interventions?

METHODOLOGY

This study used a mixed-methods design to investigate the paradox of technology readiness in rubber microplantation farming. We combined quantitative data from surveys with qualitative insights from open-ended responses and secondary statistical sources. This approach examined discrepancies between technology awareness and adoption, as well as barriers and intervention preferences among smallholder farmers and members of the rubber-producing society in Kerala's Pathanamthitta district.

Pathanamthitta, Kerala's rubber industry hub, was chosen as the study site due to the nature of its microplantations, specifically, fragmented plots, aging farmer demographics, and environmental pressures. Field data was collected from March 2023 to early 2024, while secondary data was updated until August 2025 to reflect current market trends.

For primary data collection, we used purposive/judgement sampling to focus on rubber farmers and members of the Indian Rubber Producers' Society (RPS), an industry group, as they are dominant in the local farming ecosystem. Among RPS members, we conducted a convenience sample, yielding a final sample size of 32 unique rubber microplanning owner respondents. Notably, the sample was skewed towards younger respondents, with 96.9% aged between 20 and 30 years, and towards small holdings, with 81.3% owning less than two acres. This composition unexpectedly highlighted the potential for youth-driven innovation, but it deviated from the sector's typical older profile. This deviation introduces a limitation that we address in the subsequent section of this paper.

Primary Data: A structured questionnaire was administered in person to assess technology familiarity, perceived barriers, perceived necessity, perceived benefits, recommendation intentions, facilitators, and preferred support methods. Open-ended questions captured detailed perspectives. The questionnaire, adapted from established technology readiness scales, was pilot-tested with five individuals outside the target population. Feedback led to revisions for more precise wording and better cultural relevance. Internal consistency was strong, with Cronbach's alpha values ranging from 0.82 to 0.89, confirming reliability. Traditional marketing research protocols were strictly followed, including obtaining informed consent, ensuring anonymity, and allowing voluntary withdrawal.

Secondary Data: Additional data was sourced from the Government of India's Rubber Board reports to provide context. This included the 2023-24 Annual Report, along with updated trends in production, consumption, trade, and prices as of February 2025, and provisional 2024-25 data from the Board's portal through August 2025. Key metrics included 2023-24 production of 857,000 tons,

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consumption of 1,416,000 tons, imports of 492,682 tons, exports of 4,199 tons, cultivated area of 888,400 hectares, productivity of 1,485 kg/ha, and average RSS-4 price of ₹155.72/kg. Monthly details up to July 2025, including production at 650,000 tonnes and RSS-4 prices at ₹210.65/kg, were also included to enhance precision. Triangulating these findings with primary data helps identify individual barriers that contribute to broader issues, such as stagnant yields and rising imports.

Quantitative analysis included respondent demographics, attitudes, and rankings of barriers. Inferential methods, such as chi-square tests, Kruskal-Wallis tests, Spearman correlations, and ANOVA, were employed to analyze ranked and Likert data with a small sample size (n=32). These techniques were aligned with the data procured and avoided the parametric test's assumptions. Given the limited sample size, statistical power was evaluated. For example, Kruskal-Wallis tests had approximately 60-70% power to detect medium effect sizes at $p<0.05$, prompting cautious interpretation of null results. Python 3.12 and libraries such as Pandas, SciPy, and StatsModels were used for data management, core statistics, and modeling, ensuring replicability through documented code.

To analyze the readiness paradox, we coded open-ended responses to identify recurring intervention preferences, including calls for subsidies and enhanced training. Multiple coders reviewed and checked the data to minimize bias. By triangulating quantitative, qualitative, and secondary data, we overcame sampling limitations and established a robust analysis.

RESULTS

Analysis of survey data from 32 RPS respondents and secondary sectoral statistics from the Rubber Board revealed significant disparities in awareness of Industry 4.0, technologies, and adoption. The study addresses research questions about barriers, demographics, and preferred interventions, as well as the gaps identified in the literature. Descriptive statistics provide demographic and attitudinal information, while inferential analyses investigate associations. Integrating these micro-level observations with macro trends, such as productivity stagnation and import reliance, the study highlights systemic factors that perpetuate the paradox in India’s rubber industry.

As can be seen from Table 1, respondents were primarily young, with 31 (96.9%) aged 20-30 and only one (3.1%) aged 41-50. This differs from the sector’s usual older demographics. The majority (i.e., 22; 68.8%) identified themselves as employed in the research and professional services sector rather than as farmers, while only 10 were full-time farmers (31.3%). Land holdings mirrored Kerala’s microplantation pattern, with 26 (81.3%) owning land under 2 acres, 3 (9.4%) between 2 and 5 acres, 2 (6.3%) between 6 and 10 acres, and only 1 (3.1%) over 10 acres. This profile offers an opportunity to examine scale-related barriers by investigating the impact of plot size on constraints.

Table 1
DEMOGRAPHIC PROFILE OF RESPONDENTS (N=32)

Characteristic	Category	Frequency	Percentage (%)
Age	20-50 years	32	100.0
	41-50 years	1	3.1
Occupation	Farmer	10	31.3
	RPS Member	22	68.8
Acres of Land Owned	Less than 2 acres	26	81.3
	2-5 acres	3	9.4
	6-10 acres	2	6.3

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	Above 10 acres	1	3.1

Respondents were evenly aware of Industry 4.0 technologies such as robotic tapping machines, sensors, and GPS. However, adoption remained low, with 27 (84.4%) respondents indicating no use and only 5 (15.6%) affirming usage. These rudimentary practices included rain guards, yield stimulants, and enhanced tapping methods, far from sophisticated digital tools. Robotic involvement was remarkably low, with 23 (71.9%) respondents declining, 7 (21.9%) uncertain, and only 2 (6.3%) confirming the application.

Robotic tapping machines, the most popular among relevant and familiar technologies, were chosen by 19 (59.4%) respondents. Four (12.5%) respondents combined them with sensors and GPS; three (9.4%) chose GPS standalone; two (6.3%) chose sensors; and four (12.5%) chose miscellaneous. Despite limited implementation, respondents' attitudes were positive. The technology necessity ($\bar{x}$ = 4.19) and the yield enhancement potential ($\bar{x}$ = 4.00) indicate strong belief and potential, respectively. The mean peer recommendation likelihood ($\bar{x}$ = .00) indicated likely recommendations. Notably, 68.75% agreed or strongly agreed on the potential for yield gains, challenging frameworks such as the Technology Acceptance Model (TAM) (Adrian et al., 2005; Dwivedi et al., 2019), which suggest that awareness and positive attitudes foster adoption despite low adoption rates (Lowenberg-DeBoer & Erickson, 2019; Puppala et al., 2023). This addresses the intention-behavior gap Table 2 & 3.

Table 2
TECHNOLOGY AWARENESS, ADOPTION, AND FAMILIARITY (N=32; FAMILIARITY MULTI-SELECT)

Variable	Metric/Category	Frequency	Percentage (%)
Awareness of Technologies	Yes	16	50.0
	No	16	50.0
Use of Any Technologies	Yes (Qualified/Basic)	5	15.6
	No	27	84.4
Use of Robotics/Related Tech	Yes	2	6.30
	No	2	71.9
	Maybe	7	21.9
Familiar Technologies (Selections)	Robotic Tapping Machines	19	59.4
	GPS	3	9.40
	Sensors	2	6.30
	Combinations(e.g., Tapping/Sensors/GPS)	4	12.5
	Other	4	12.5

Table 3
DESCRIPTIVE STATISTICS FOR KEY ATTITUDES (N=32; 1-5 SCALE)

Variable	Mean	SD	Min	Max
Necessity of Technology	4.19	0.82	2	5
Yield Increase Potential	4	0.95	1	5
Recommendation Likelihood	4	0.84	3	5

Barriers to adoption showed a clear hierarchy, with high implementation costs being the primary barrier, mentioned 14 times (43.8%). Climatic conditions followed closely, with five mentions (15.6%). Other factors, such as lack of knowledge, availability, topography, convenience, resistance to change, and lack of trust, also posed challenges. Likert rankings further supported this, with high cost rated at ($\bar{x}$=4.00; s=1.14), convenience at ($\bar{x}$=3.53; s=0.76), climatic conditions, and

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lack of knowledge both at ($\bar{x}$=3.47; s=0.92 and s=0.84), availability at ($\bar{x}$=3.44; s=0.95), topography and resistance to change at ($\bar{x}$=3.41; s=0.71 and s=0.91), and lack of trust at ($\bar{x}$=2.84 (s=1.02). This sequence of barriers extends existing theories to perennial crops, highlighting economic-environmental synergies unique to rubber in Kerala's monsoon-prone landscape Table 4.

Table 4
RANKING THE ADOPTION BARRIERS OF TECHNOLOGY (N=32; 1-5 SCALE)

Barrier	Mean	SD	Rank
High cost of implementation	4.00	1.14	1
Convenience	3.53	0.76	2
Climatic condition	3.47	0.92	3
Lack of knowledge	3.47	0.84	3
Availability	3.44	0.95	5
Topography	3.41	0.71	6
Resistance to change	3.41	0.91	6
Lack of trust	2.84	1.02	8

Inferential tests examined the influence of farm size on barrier perceptions, as per the second research question. A chi-square test comparing landholdings and main barriers yielded no significant association (χ^2=12.63, df=21, p=0.921), with observed frequencies closely approximating the expected ones. Kruskal-Wallis tests further confirmed this consistency, revealing no differences in climatic conditions (H=1.45, p=0.694), topography (H=4.58, p=0.205), cost (H=2.19, p=0.535), or knowledge (H=2.22, p=0.528). These null outcomes demonstrate uniformity in barriers across scales within microsystems and in views of shared risk assessments amid environmental volatility Table 5.

Table 5
EXPECTED FREQUENCIES FOR CHI-SQUARE TEST (ACRES VS. MAIN BARRIER)

Acres Category	Availability	Climatic	Convenience	High Cost	Knowledge	Trust	Resistance	Topography
Less than 2 acres	2.44	4.06	1.62	11.38	2.44	0.81	1.62	1.62
2-5 acres	0.28	0.47	0.19	1.31	0.28	0.09	0.19	0.19
6-10 acres	0.19	0.31	0.12	0.88	0.19	0.06	0.12	0.12
Above 10 acres	0.09	0.16	0.06	0.44	0.09	0.03	0.06	0.06

Further inferential analyses revealed no significant connections. Chi-square tests for age and awareness (χ^2=0, df=1, p=1.0) and occupation and technology use (χ^2=1.25, df=1, p=0.264) yielded no results. Similarly, Mann-Whitney U tests indicated no differences in cost, knowledge, or barriers by age, occupation, or technology use. Spearman's correlations revealed inter-barrier relationships, such as cost with convenience (r=0.70) and knowledge (r=0.49), suggesting layered economic impediments. Trust displayed weaker associations with knowledge (r=0.08), indicating that perceptual barriers are subordinate to other factors. Attitudes, particularly necessity, correlated firmly with yield (r=0.67) but weakly with barriers Table 6 & 7.

Table 6
SPEARMAN CORRELATION MATRIX FOR BARRIERS AND ATTITUDES (N=32)

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Variable	Necessity	Yield Increase	Climatic	Topography	Cost	Convenience	Trust	Availability	Knowledge	Resistance
Necessity	1	0.67	0.24	0.21	0.22	0.22	-0.31	0.16	0.23	0.2
Yield Increase	0.67	1	0.35	0.25	0.3	0.34	-0.17	0.23	0.26	0.3
Climatic	0.24	0.35	1	0.09	0.06	-0.07	0.07	0.27	-0.06	-0.18
Topography	0.21	0.25	0.09	1	0.55	0.4	0.03	0.23	0.39	0.35
Cost	0.22	0.3	-0.06	0.55	1	0.7	0.08	0.28	0.49	-0.01
Convenience	0.22	0.34	-0.07	0.4	0.7	1	-0.02	0.32	0.51	0.21
Trust	-0.31	-0.17	0.07	0.03	0.08	-0.02	1	0.34	0.08	-0.06
Availability	0.16	0.23	0.27	0.23	0.28	0.32	0.34	1	0.58	0.04
Knowledge	0.23	0.26	-0.06	0.39	0.49	0.51	0.08	0.58	1	0.17
Resistance	0.27	0.3	-0.18	0.35	0.01	0.21	-0.06	0.04	0.17	1

Table 7
SUMMARY OF INFERENTIAL TESTS (N=32)

Test Description	Statistic	df	p-Value	Interpretation
Chi-Square: Land Holdings x Barriers	12.63	21	0.921	No Association
Chi-Square: Age x Awareness	-	1	1.000	No Association
Chi-Square: Occupation x Use	1.2	1	0.264	No Association
Kruskal-Wallis: Climatic x Holdings	H=1.45	-	0.694	No Difference
Kruskal-Wallis: Topography x Holdings	H=4.58	-	0.205	No Difference
Kruskal-Wallis: Cost x Holdings	H=2.19	-	0.535	No Difference
Kruskal-Wallis: Knowledge x Holdings	H=2.22	-	0.528	No Difference
Mann-Whitney U: Cost x age	U=76.0	-	0.380	No Difference
Mann-Whitney U: Knowledge x Age	U=53.0	-	0.580	No Difference
Mann-Whitney U: Cost x Occupation	U=139.0	-	1.000	No Difference
Mann-Whitney U: Knowledge x Occupation	U=151.0	-	0.561	No Difference

The third research question explored preferences for interventions, which were evenly distributed between education and training (12, 37.5%) and government funding or subsidies (12, 37.5%). Collaborations between agri-tech firms and institutions were recommended by five (15.6%), while three unspecified options were also suggested (9.4%). The elevated likelihood of a recommendation (75% or very likely) suggests the potential for social leverage through RPS networks Table 8.

Table 8
PREFERRED INTERVENTIONS FOR TECHNOLOGY ADOPTION (N=32)

Intervention Preference	Frequency	Percentage (%)
Education and Training for Farmers	12	37.5
Government Funding and Subsidies	12	37.5
Collaboration Between Agri-Tech and Institutions	5	15.6
Unspecified	3	9.4

DISCUSSION

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These outcomes reveal a striking paradox: while half of the respondents were familiar with innovations such as robotic tapping (59.4% familiarity), adoption was virtually nonexistent, with basic practices replacing advanced tools. Favorable attitudes, necessity at $\bar{x}=4.19$, and yield at $\bar{x}=4.00$ contrasts sharply with execution shortfalls, challenging TAM and UTAUT assumptions that perceptions drive action in emerging contexts. The predominance of youth could be responsible for greater awareness and a positive attitude towards technology, given younger generations' technological proficiency and affinity for technology. However, resistance persists ($\bar{x}=3.41$), suggesting that cultural norms override personal preferences, particularly for those holding less than 2 acres (81.3%). Qualitative annotations on exposure through seminars or videos revealed "passive knowledge" loosely linked to trust ($r=0.08$) but moderately connected to necessity ($r=0.23$), addressing network impacts. This suggests intergenerational caution in volatile environments associated with convenience ($r = 0.21$) and a preference for conventional approaches (Adrian et al., 2005; Venkatesh & Bala, 2008; Liu, 2013; Blut & Wang, 2020; Morris & Venkatesh, 2000; Vecchio et al., 2020).

Null inferences, such as the absence of significant shifts in barrier size ($\chi^2=12.63$, $p=0.921$), support homogeneity. This finding demonstrates that micro-systems mitigate the impact of scale influences. Additionally, the presence of invariant demographics, as evidenced by the constant cost per age ($p=0.380$), addresses structural challenges. Correlations, such as the strong positive correlation between cost and convenience ($r=0.70$), highlight the interconnected obstacles that hinder adoption. This correlation between knowledge shortfalls and perceived risks among informed groups addresses perceived risks. Environmental constraints, including climatic ($\bar{x}=3.47$) and topographic ($\bar{x}=3.41$) factors, provide insights into farmer viewpoints in rubber settings within Kerala's specific challenges (Burton et al., 2003; Adrian et al., 2005; Knowler & Bradshaw, 2007; Viswanathan & Shivakoti, 2008; Imelda et al., 2023; Puppala et al., 2023).

The secondary data collected for this study may provide a context for the results. India's 2023-24 yield of 1,485 kg/ha has modestly increased to 1,500 kg/ha provisionally in 2024-25. The area has grown from 888,400 to 941,200 ha, and production has increased from 857,000 to 875,000 tons. However, imports have escalated to 550,918 tons. Internationally, India trails Thailand (~4.8 million tonnes, ~1,800 kg/ha) and Vietnam (1.28 million tonnes, ~1,720 kg/ha). In these countries, technology has alleviated analogous barriers (Bhowmik & Viswanathan, 2021; Huang et al., 2022; Nguyen, 2022; V & Mohan, 2025).

From a policy standpoint, the uniformity of these barriers across farm sizes necessitates interventions that are not discriminatory by farm size. Survey participants expressed equal preference (37.5 percent each) for government subsidies and educational training programs, which could directly address the dominant challenges of high costs ($\bar{x} = 4.00$ on a 5-point scale) and gaps in technical knowledge ($\bar{x} = 3.47$). These suggestions align with earlier studies that aim to refine approaches addressing inconsistencies in policy design and implementation. This aligns with the need for customized solutions and strengthened institutional support networks, as we propose initiatives led by RPS (local farmer cooperatives) to deliver targeted training and financial aid, ultimately boosting crop yields. Taken together, our results shed light on the core puzzle of why farmers are aware of these technologies yet fail to adopt them. They offer models specifically adapted to the challenges of rubber farming and provide a comprehensive view of the issues. However, the focus on younger participants in this study suggests the value of future research that includes a broader age range and tracks changes over time for more robust conclusions (Doss, 2006; Viswanathan & Shivakoti, 2008; Tey & Brindal, 2012; Barnes et al., 2019; Da Silveira et al., 2023; Imelda et al., 2023; Pandeya et al., 2025).

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CONCLUSION

This study highlights the challenge of technology readiness in Kerala's rubber microplantations. Farmers are knowledgeable about Industry 4.0 tools but rarely use them. Half of the participants were aware of robotic tapping machines, yet only 15.6% used simple approaches. Despite positive views on technology's potential to improve yields, farmers face several obstacles, including high costs, limited access, limited knowledge, weather, landscape, reluctance to change, and doubts about reliability. These issues persist regardless of farm size, age, or job, suggesting broader underlying problems. Combining survey data with Rubber Board members underscores India's low rubber yields of 1,500 kilograms per hectare in 2024-25 and growing imports of 550,918 tonnes, underscoring the need for targeted changes in the rubber sector.

This research bridges several gaps in the literature by scrutinizing pre-adoption impediments among farmers, refining readiness frameworks for perennial crops, and elucidating the unique attributes of rubber cultivation. It examines Industry 4.0 application familiarity, traces information channel effects on perceptions of barriers, ranks economic constraints over competing factors, probes subjective risks and knowledge deficiencies in knowledgeable non-adopters, evaluates environmental limitations, disentangles socio-cultural resistances, and demonstrates minimal demographic influence. On the policy side, it proposes adaptable strategies for dissemination, emphasizing enhanced collaborative support and customized measures.

We propose the "familiarity trap" as a novel diffusion theory extension, explaining how limited technology exposure, often through extension services or peer discussions, paradoxically reinforces adoption barriers in India's vulnerable agricultural systems. This concept builds on our findings on awareness channels and weak ties to trust, showing why superficial knowledge heightens perceptions of implementation challenges in rubber micro-plantations. Policymakers can use these insights to address Kerala's productivity stagnation and India's growing import dependence through cooperative-led subsidies that target cost dominance and knowledge gaps, thereby enhancing resilience to environmental pressures. The sample's emphasis on younger participants cautions against generalizing results but highlights opportunities for future longitudinal research with a broader demographic spectrum. This work enriches the discourse on smallholder inertia and offers a pathway for policies to improve sustainable yield and long-term economic viability.

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