Humanizing Agricultural Robotics: A Constructivist Grounded Theory of Farmers' Perspectives on Adopting Chili Harvesting Robot in Fertigation Farming

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.92800015

Received: 08 November 2025; Accepted: 14 November 2025; Published: 18 December 2025

ABSTRACT

The integration of robotics into agriculture offers opportunities to increase efficiency and address labour shortages, yet its adoption is strongly shaped by farmers' perceptions and lived realities. This study explores how smallholder chili farmers perceive the adoption of a chili harvesting robot within fertigation farming, with a particular focus on humanising agricultural robotics to ensure alignment with farmers' social and economic needs. Guided by a Constructivist Grounded Theory (CGT) approach, semi-structured focus group interviews were conducted with five smallholder farmers from Kulai, Johor, Malaysia. The analysis generated five interrelated domains that influence technology acceptance: (i) socio-needs of chili farmers, (ii) harvesting practices, (iii) labour and human resource issues, (iv) farming economics, and (v) robotic handling. Together, these domains capture the complex realities of farming and the conditions under which robotics may be accepted. The study contributes by extending grounded insights into how agricultural robotics can be humanised through the integration of farmer perspectives across these five domains, offering practical implications for innovators, policymakers, and agritech developers aiming to design sustainable and farmer-centred smart farming systems.

Keywords: Human-Centred Robotics, Smart Farming, Technology Adoption, Chili Harvesting, Constructivist Grounded Theory.

INTRODUCTION

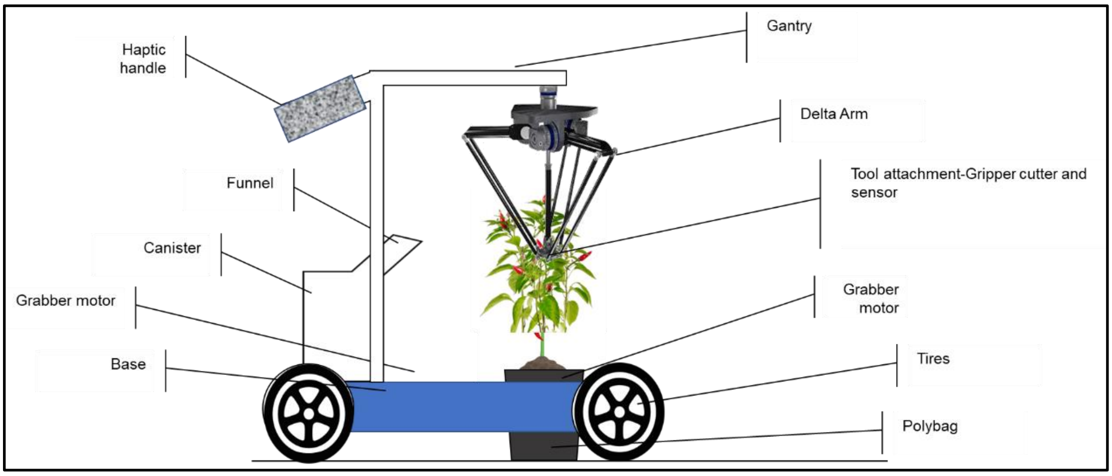
The integration of robotics into agriculture has been widely promoted as a solution to labour shortages, efficiency demands, and sustainability challenges in food production systems (Bechar & Vigneault, 2016; Liakos et al., 2018). Within the broader agenda of smart farming, robotic solutions such as automated harvesting systems have gained traction, particularly in high-value crops like chili, where labour-intensive practices limit productivity (Shamshiri et al., 2018; Tzounis et al., 2017). In Malaysia, fertigation-based chili farming has become increasingly significant in supporting food security and rural livelihoods (Rahman et al., 2020). However, despite technological advancements, the successful adoption of agricultural robotics depends not only on technical performance but also on how innovations are perceived, accepted, and integrated by farmers in their daily practices (Eastwood et al., 2019; Klerkx & Rose, 2020).

Much of the existing research on agricultural robotics has prioritised technical optimisation, engineering design, and cost efficiency (Bechar & Vigneault, 2017; Bac et al., 2014). Considerably less attention has been devoted to the human dimension of adoption, particularly the perspectives, expectations, and lived realities of farmers. Yet, end-users ultimately determine whether new technologies succeed or fail (Lajoie-O'Malley et al., 2020). This gap is especially critical in the context of smart farming adoption in Southeast Asia, where socio-economic diversity, labour constraints, and cultural practices strongly influence farmers' willingness to engage with technological innovations (Hafeez et al., 2022). Without integrating farmers' voices into the innovation process, robotic systems risk misalignment with the practical and social realities of agricultural communities (Klerkx, Jakku, & Labarthe, 2019).

This study addresses this gap by adopting a Constructivist Grounded Theory (CGT) approach (Charmaz, 2014) to explore chili farmers' perspectives on adopting a chili harvesting robot in fertigation farming (refer Figure 1).

CGT enables the co-construction of theory from participants' experiences, making it well-suited for investigating how farmers articulate concerns and expectations about robotic technologies (Bryant & Charmaz, 2007). Semi-structured focus group interviews were conducted with chili farmers in Johor, Malaysia, and the analysis generated five interrelated themes: (i) socio-needs of farmers, (ii) harvesting practices, (iii) labour considerations, (iv) farming economics, and (v) robotic handling.

Figure 1: Proposed Chilli Padi Harvesting Robot



The study contributes to the literature in three ways. Theoretically, it extends technology adoption research by grounding adoption factors in farmers' lived experiences through CGT, offering a more nuanced understanding of human–robot interaction in agriculture (Rose et al., 2021). Practically, it provides insights for innovators and agritech developers to design farmer-centred robotic solutions that are contextually relevant and socially acceptable. At the policy level, the findings highlight the importance of incorporating farmers' voices into Malaysia's smart farming strategies to ensure inclusive and sustainable agricultural innovation (Food and Agriculture Organization [FAO], 2022).

Scope of the Study

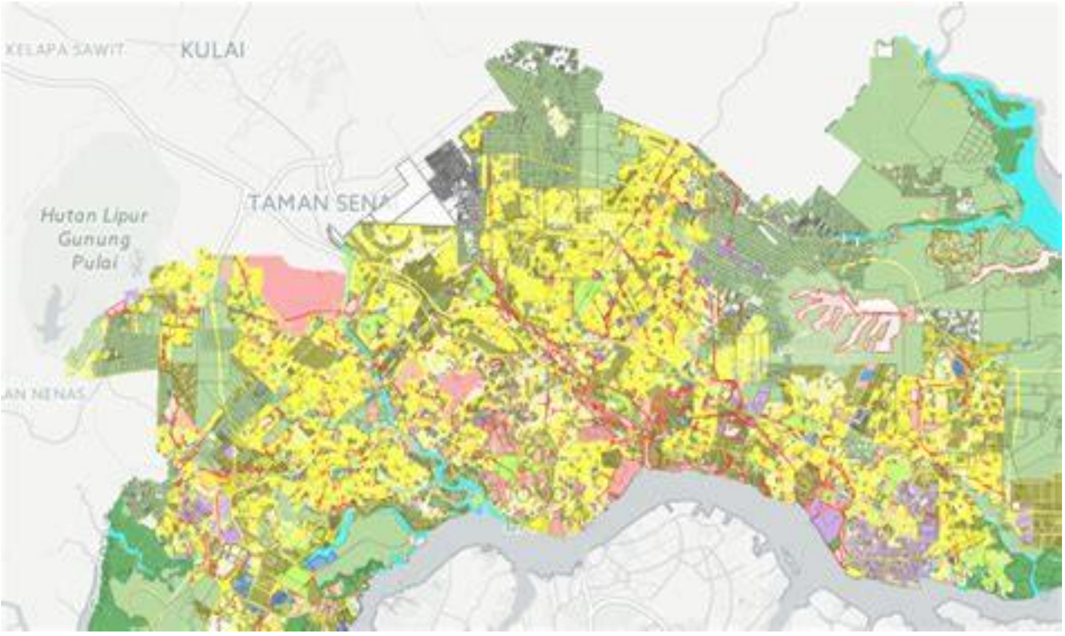
Johor is one of Malaysia's leading agricultural states, with crop production contributing significantly to its agricultural output. In 2023, Johor recorded RM27.2 billion in agricultural sales, of which RM20.9 billion came from crops, underscoring the state's strong reliance on small and medium-scale cultivation (The Sun, 2024). While oil palm dominates, Johor's agricultural landscape is also shaped by smallholders engaged in vegetables, fruits, and high-value crops such as chillies, often on a part-time basis to supplement household income. These smallholder contributions are crucial, as they ensure the diversity and resilience of the local food system, in line with findings that small-scale farmers remain central to sustaining agricultural productivity in Southeast Asia (FAO, 2022).

In addition, institutional support in Johor reflects the growing recognition of vegetable and chilli farming as viable income sources. For instance, the Johor state government has allocated over RM5 million to support young farmers, particularly in chilli cultivation and vegetable projects (The Star, 2023). Peri-urban districts such as Kulai have become hubs for smallholder vegetable and chilli farming, where access to markets and infrastructure facilitates part-time and community-based production. This context makes Johor—and specifically areas around Kulai—a highly relevant research site to explore the experiences of smallholder farmers. Furthermore, as Klerkx and Rose (2020) emphasize, understanding smallholder perspectives is critical in the era of Agriculture 4.0, where new technologies and practices must align with local realities to ensure equitable and sustainable adoption

Academic recent work also backs up the importance of agrifood smallholders in Malaysia broadly. The Khazanah Research Institute's Understanding the Landscape of Agrifood Smallholders in Malaysia: Climate Risks, Sustainable Standards, and Gender Gap (2024) provides evidence that many smallholder farms are involved in vegetable, fruit, and local food crop production; these farms often operate on smaller plots and combine farming with other income sources. Thus Kulai, being close to urban centers while still retaining agricultural land, is a strategic location to study smallholders' practices and challenges in technology adoption (like chilli robot).

Figure 1 below illustrates the land use and agricultural zoning in Kulai District and its surrounding areas. The green-colored zones represent designated agricultural land, which includes areas cultivated by smallholders for crops such as vegetables and chilli. These green areas highlight the concentration of peri-urban farming activities, reflecting the importance of small-scale agriculture in Johor's food supply chain. Meanwhile, the yellow-colored zones indicate residential or mixed-use settlements that often border farming areas, allowing farmers to combine part-time agricultural activities with other livelihood sources. This spatial proximity of settlements (yellow) to farmlands (green) provides a unique context in which smallholders and part-time farmers, such as those cultivating chilli, operate within a semi-urban agricultural landscape. The co-existence of settlement and agricultural land-use supports the choice of Johor, particularly Kulai and its surroundings, as a relevant study location for smallholder chilli farmers (Department of Agriculture Malaysia, 2023).

Figure 2: Land use and agricultural zoning in Kulai District and surrounding areas, Johor.



LITERATURE REVIEW

Smart Farming and Agricultural Robotics

The adoption of smart farming technologies—including robotics, automation, and precision agriculture—has been promoted as a pathway to improve efficiency, sustainability, and resilience in agriculture (Liakos et al., 2018; Tzounis et al., 2017). Robotics in particular has received increasing attention due to its potential to alleviate labour shortages, improve harvesting accuracy, and reduce production costs (Bechar & Vigneault, 2016; Shamshiri et al., 2018). High-value crops, such as chili (Capsicum frutescens), demand intensive manual labour for harvesting, creating an urgent need for robotic solutions in countries like Malaysia, where fertigation farming is widely practised (Rahman et al., 2020). However, while technological development is advancing rapidly, adoption has remained uneven, with farmers' perceptions and socio-economic conditions playing a crucial role in shaping acceptance (Eastwood et al., 2019; Klerkx & Rose, 2020).

Humanising Agricultural Technology

The concept of humanising technology refers to designing innovations that are not only technically functional but also aligned with human needs, abilities, and socio-economic realities (Clarkson, Coleman, Keates, & Lebbon, 2013). In agriculture, humanising innovation involves ensuring that new technologies are user-friendly, economically viable, and adaptable to farmers' working conditions. Research has shown that human abilities such as concentration, decision-making, and spatial perception are crucial for effective agricultural operations (Macdonald, 2013). Yet, many agricultural machines are designed without fully accounting for the variability of human skills, leading to usability challenges and low adoption rates (Häggström, 2015). Humanising agricultural robotics also requires attention to environmental stressors—such as noise, dust, and ergonomic strain—that can affect both system performance and human well-being (Kearnes et al., 2016). If these factors are ignored, new technologies risk rejection by intended users, rendering them ineffective or wasted investments.

Technology Adoption in Agriculture

Technology adoption in agriculture has been extensively studied through models such as the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and innovation diffusion theory (Venkatesh et al., 2003; Davis, 1989; Rogers, 2003). Key factors influencing adoption include perceived usefulness, ease of use, socio-economic conditions, and institutional support (Rose et al., 2021). However, scholars have increasingly argued that adoption cannot be explained solely by functional attributes, as cultural, ethical, and contextual issues also shape decision-making (Klerkx, Jakku, & Labarthe, 2019). In the context of agricultural robotics, adoption depends on whether the technology reduces labour intensity, fits within existing farming practices, and aligns with farmers' values and capacities (Eastwood et al., 2019). Thus, exploring adoption from farmers' perspectives is crucial for designing farmer-centred innovations that go beyond technical performance.

Human–Technology Interaction in Farming

The study of human–technology interaction highlights the interdependencies between technological performance and human operators. As automation increases, the farmer's role is shifting from manual labourer to technology manager, requiring new skills in interpretation, monitoring, and decision-making (Bronson & Knezevic, 2016). Humanising robotic systems in agriculture means recognising farmers not just as end-users but as active co-designers whose insights and concerns must shape innovation pathways (Eastwood et al., 2019). Ignoring the socio-technical interface risks creating "solutions in search of problems" where robots are developed without regard to actual farming contexts (Klerkx & Rose, 2020).

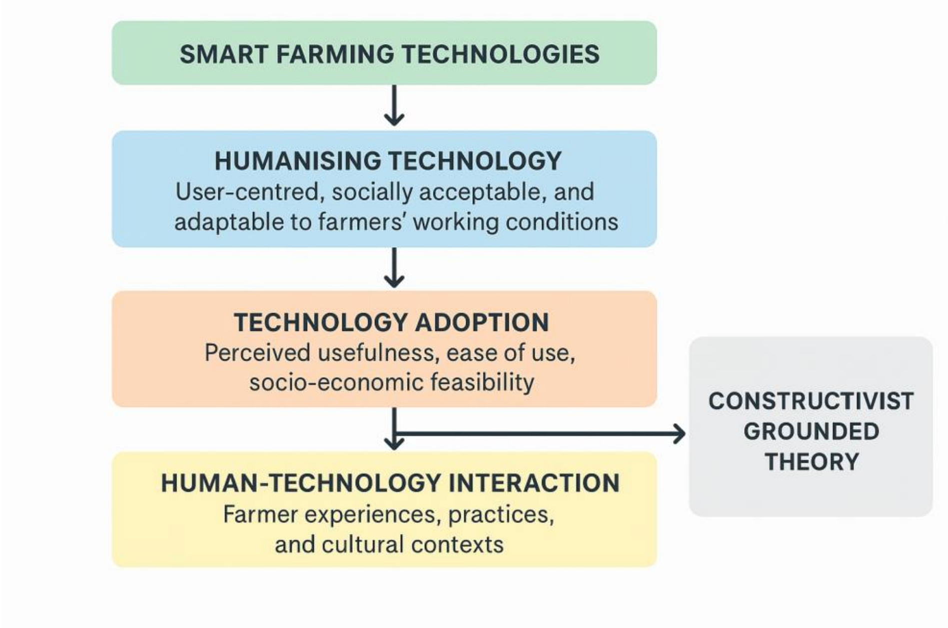
Constructivist Grounded Theory in Agricultural Innovation Research

To capture these complex, context-specific adoption dynamics, Constructivist Grounded Theory (CGT) (Charmaz, 2014) offers a rigorous methodological lens. CGT emphasises the co-construction of knowledge between researchers and participants, allowing theory to emerge from farmers' lived experiences rather than being imposed a priori. This approach is particularly valuable in agriculture, where socio-cultural practices, family dynamics, and local economic constraints strongly influence technology adoption (Bryant & Charmaz, 2007). By applying CGT, researchers can uncover not just barriers and facilitators of adoption but also the deeper meanings farmers attach to innovation, thereby advancing both theoretical understanding and practical guidance for humanising agricultural robotics.

Proposed Conceptual Model

The proposed conceptual model illustrates the interconnected themes that underpin this study. At the foundation, smart farming technologies such as agricultural robotics represent the driving force for innovation, particularly in addressing labour shortages and efficiency challenges. However, successful implementation requires humanising technology, ensuring that robotics are user-centred, socially acceptable, and adaptable to farmers' working conditions. This leads to the critical stage of technology adoption, where farmers' perceptions of usefulness, ease of use, and socio-economic feasibility shape their willingness to adopt innovations. Adoption, in turn, is influenced by human–technology interaction, which recognises farmers not merely as passive users but as active agents whose experiences, practices, and cultural contexts shape innovation outcomes. To capture these complex interdependencies, the study employs Constructivist Grounded Theory (CGT) as a methodological lens, enabling theory to emerge inductively from farmers' perspectives. The model highlights that the pathway from technological innovation to adoption is non-linear and requires attention to socio-technical and human factors to ensure sustainable and meaningful integration of agricultural robotics into farming systems.

Figure 3: Conceptual Model of Agricultural Robotics Adoption



METHODOLOGY

This study applies a qualitative approach, specifically the Constructivist Grounded Theory (CGT) method, to explore farmers' perspectives on the adoption of chili harvesting robots in fertigation farming. The CGT approach aligns with the interpretive research paradigm, which is rooted in the constructivist philosophy of learning. This paradigm posits that individuals construct meaning through their lived experiences and interactions, and thus emphasizes the subjective interpretation of reality rather than objective measurement (Charmaz, 2014; Creswell & Poth, 2018). The choice of CGT allows the researcher to investigate how farmers make sense of agricultural robotics, uncovering the underlying social and psychological processes that influence technology adoption.

Qualitative research is particularly well-suited for this inquiry as it enables the examination of dynamic complexities within agricultural settings and captures the richness of individual experiences (Flick, 2018). Through CGT, the study does not seek to verify pre-existing theories but instead focuses on developing theory grounded in empirical data (Glaser & Strauss, 1967; Charmaz, 2020).

Research Design and Sampling

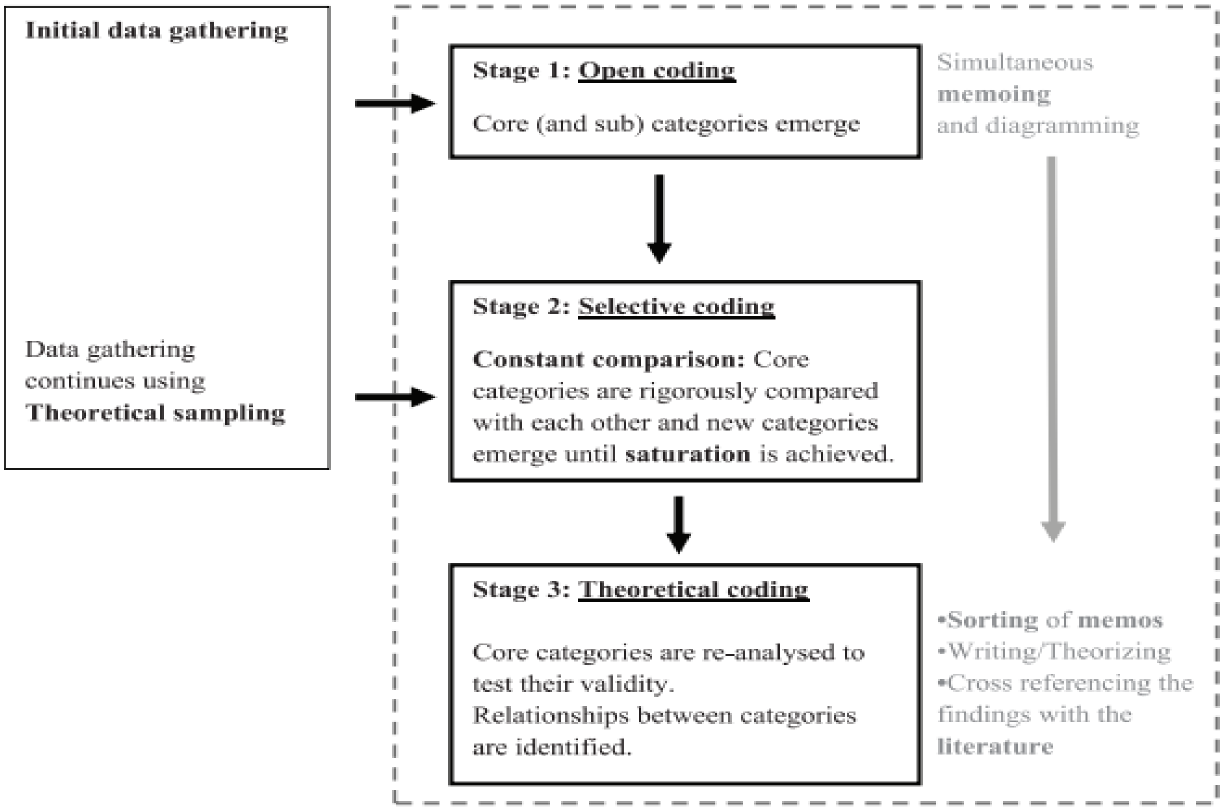
Constructivist Grounded Theory (CGT), pioneered by Charmaz, emphasizes the co-construction of knowledge between researcher and participants, recognizing the interpretive nature of data analysis (Charmaz & Thornberg, 2021). It offers a systematic yet flexible process to build theory from lived experiences and contextual meanings.

The process begins with open coding, where initial categories emerge from data such as interviews, observations, or documents. This is followed by selective coding, in which categories are compared, refined, and integrated through a constant comparison process until saturation is achieved. In the final stage, theoretical coding revisits and connects core categories, enabling the development of a coherent theoretical framework that explains both actions and meanings.

A central feature of this framework is theoretical sampling, where participants are selected not randomly but for their potential to contribute to emerging categories and concepts. This iterative process—driven by ongoing analysis—ensures that data collection continues until theoretical saturation is reached, when no new insights appear (Corbin & Strauss, 2015; Saunders et al., 2018). Throughout these stages, memoing and diagramming capture the researcher's reflections, guide analysis, and bridge the transition from coding to writing the final theory.

ISSN: 2454-6186 | DOI: 10.47772/IJRISS
Special Issue | Volume IX Issue XXVIII November 2025

Figure 4: Constructivist Grounded Theory Framework



In this study, participants were farmers actively engaged in chili fertigation farming, particularly those with exposure to or interest in agricultural automation and robotics. A total of 5 participants were interviewed, comprising smallholder farmers from areas in Pontian Johor. This range of participants was chosen to ensure diversity of perspectives across farm size, technical competence, and organizational structure.

Data Collection

Data were collected through semi-structured interviews and document analysis. The interviews allowed participants to articulate their experiences, motivations, and concerns in adopting robotic harvesting technologies. This approach also enabled the researcher to follow emergent leads and explore unexpected insights raised by participants (Charmaz, 2014; Given, 2016). Interviews were conducted face-to-face and via online platforms when necessary, with each lasting between 45–90 minutes. All interviews were audio-recorded with consent and transcribed verbatim.

Document analysis included reports from agricultural agencies, robotics development initiatives, and policy documents related to smart farming and automation in Malaysia. These secondary sources provided contextual understanding and complemented farmers' narratives (Bowen, 2009; O'Leary, 2021).

Data Analysis

Data analysis followed the Constructivist Grounded Theory coding procedures outlined by Charmaz (2014, 2020). This involved three stages:

1. Initial Coding – line-by-line coding to identify significant actions, meanings, and processes in farmers' accounts.
2. Focused Coding – clustering the most significant and frequent initial codes into broader conceptual categories.
3. Theoretical Coding – integrating and refining categories into a coherent framework that explains farmers' perspectives on adopting chili harvesting robots.

Throughout the process, constant comparative analysis was employed, whereby data were continually compared across interviews to refine categories and develop emerging theory (Bryant & Charmaz, 2019). Memos were written throughout to capture analytic insights and guide further data collection.

Trustworthiness and Ethical Considerations

To enhance the trustworthiness of the study, several strategies were adopted. Credibility was ensured through member checking, where selected participants reviewed their transcripts and emerging interpretations (Lincoln & Guba, 1985; Nowell et al., 2017). Transferability was addressed by providing rich, thick descriptions of the research context. Dependability and confirmability were supported by maintaining an audit trail of analytic decisions and reflexive memos (Tracy, 2020).

Ethical approval was obtained from the host university's ethics committee. Participants were provided with an informed consent form explaining the study's purpose, voluntary participation, and confidentiality of their responses. Pseudonyms were used in reporting to protect participants' identities.

RESULTS AND DISCUSSION

The Chili Padi Farm

Findings from the study indicate that most participating farmers cultivate chilies on a part-time basis, often balancing farming with other sources of income. The farms studied were largely leased plots ranging from 1 to 5 acres, reflecting small-scale agricultural practices that cater to farmers' socio-economic needs.

Leasing land was found to be both a practical and strategic choice for farmers. It provides access to farmland without requiring substantial upfront capital investment, thereby lowering entry barriers for smallholders. For some, leased land also functions as a space for short-term experimentation and expansion, especially in testing new techniques such as fertigation or mechanized harvesting. However, reliance on leased land also means farmers face insecurity and limited autonomy over long-term planning, particularly when landlords restrict modifications to land use.

The small-scale size of farms (1–5 acres) offers several advantages such as lower operating costs, closer monitoring of crops, and flexible management practices. Yet, these farms also face structural challenges, including limited access to formal financing, bargaining power in markets, and economies of scale. These constraints often influence the farmers' risk appetite in adopting new technologies like chili harvesting robots.

Another notable feature of these farms is their location on uneven terrain, which complicates irrigation, fertigation, and mechanization. Despite this challenge, uneven land also presents opportunities for the adoption of sustainable farming practices, including contour farming, terracing, or integration of agroforestry systems. Indeed, many farms in this study displayed a diverse arrangement of trees and intercropping systems, suggesting that farmers already employ forms of agroecological practices. These systems not only support soil fertility and pest regulation but also increase farm resilience against climate variability.

Taken together, the results suggest that cili padi farming in the study context is characterized by small-scale, leased, and unevenly structured plots that rely on multi-cropping or agroforestry systems. Such farm characteristics present both opportunities (low entry cost, ecological diversity) and constraints (market access, land tenure insecurity, and mechanization challenges) that shape how farmers perceive and respond to agricultural innovations, including robotic harvesting technologies.

Harvesting Process

The second theme identified from the study concerns the harvesting process, which is a labor-intensive and recurrent activity. Farmers reported that chilies are typically harvested once or twice a week, depending on crop maturity and market demand. Harvesting is usually performed either by the farm owners themselves or by hired laborers, often at relatively low cost.

The process of harvesting, as described by participants, involves a series of interrelated tasks:

- Chili ripeness assessment – Farm workers evaluate the maturity of chilies, identifying those ready for harvest while leaving others to ripen. This manual assessment requires skill and experience, particularly as premature harvesting can reduce quality and market value.
- Damage inspection – Workers examine both chilies and plants for pest damage, disease symptoms, or physical injury, which could affect overall yield and post-harvest quality.
- Weeding management – Weeds are removed during harvesting rounds to prevent competition for nutrients, water, and light.
- Input application – Fertilizers and pesticides are sometimes applied concurrently with harvesting activities, ensuring crop health and mitigating pest infestations.
- Transportation (Move) – Harvested chilies are gathered and moved to designated collection areas for temporary storage or further processing.
- Grading and sorting – Chilies are graded based on size, shape, color, and overall quality, which directly influences their market price. Farmers emphasized that grading is a crucial step in maintaining buyer trust and accessing higher-value markets.

This multi-step process highlights that harvesting is not merely the act of collecting chilies but an integrated management activity involving monitoring, maintenance, and quality control. Importantly, farmers acknowledged that while the process is repetitive, it demands considerable labor input and attention to detail, making it one of the most resource-intensive aspects of chili production.

The findings suggest that any attempt to introduce robotic harvesting technologies must take into account these fine-grained and multi-dimensional tasks. For instance, automated systems must be capable not only of identifying ripeness but also of detecting damaged produce, navigating uneven terrain, and integrating seamlessly with existing grading practices. Farmers' perspectives indicate both recognition of the potential labor savings from robotics and skepticism about whether machines can effectively replicate the nuanced judgments involved in chili harvesting.

Human Resource

The dataset describes human resource practices in small-scale chili and rice farming. Figure 4 illustrates the Human Resource keywords and Themes Extraction.

Figure 5: Human Resource – Keywords and Theme Extraction

Keywords / Phrases from Interviewees	Initial Coding (Researcher Notes)	Extracted Theme
"We usually pay workers by the kilo they harvest, cheaper that way" / "Payment is based on how many kilos of chillies or rice they can collect"	Piece-rate payment; l inking wage to output rather than hours	Low-cost labor system
"We don't hire full-time workers, only when needed" / "Most of them come part-time, especially during harvesting season"	Flexibility in contracts; temporary workforce	Part-time employment
"Harvesting is only on weekends" / "Sometimes we call them every two weeks depending on the crop"	Seasonal work; intermittent scheduling	Irregular labor scheduling
"Workers must know how to fertilize, spray poison, and weed properly" / "If they don't	Technical knowledge expected;	Skilled labor

have experience, they slow down the work"	limited training offered	necessity
"Those who have planted chillies and rice before are better" / "We prefer experienced people who can do mapping themselves"	Reliance on past farming expertise	Experience-based recruitment

- Labor is hired at a cheap price per kilo of chilies and rice: Farm owners commonly pay harvest workers on a piece-rate basis (payment by weight/output), i.e., workers are remunerated according to the quantity (kilograms) they harvest. This piece-rate arrangement reduces fixed wage commitments for farm owners and links pay to productivity, but may also create income insecurity for laborers and incentivize speed over quality.
- Labor on a part-time basis: Most labor engaged on these farms is not permanent; workers are hired on a part-time or casual basis to perform seasonal or task-specific work (e.g., harvesting rounds, weeding, fertigation rounds). This arrangement gives farmers flexibility to match labor input to crop cycles but limits continuity of employment and on-the-job skill development for workers.
- Harvesting is on weekends and every two weeks: Harvest schedules are intermittent: many farms conduct harvesting primarily on weekends and follow a roughly bi-weekly harvesting rhythm, reflecting labour availability, crop maturity cycles, and market timing. Such scheduling minimises regular wage commitments but can create bottlenecks when multiple plots mature simultaneously or when labour becomes scarce. (This pattern was reported directly by participants in the field data.)
- Laborers need to be experienced with planting chillies and rice to be able to map the chillies that need to be fertilized, harvested, insecticides applied, weeded and so on: Farmers emphasised that labourers must possess practical, tacit knowledge of chilli and rice cultivation — the ability to "read" the field, identify which patches need fertiliser or pesticide, distinguish ripeness stages, and prioritise which rows to harvest. This experienced judgement is critical to operational efficiency and crop quality, and is not easily replaced by short-term casual labour. The literature on tacit knowledge in agriculture supports the importance of these local, experiential skills in farm decision-making.

These HR practices point to a labour system that is flexible and low-cost for farm owners yet dependent on skilled, experienced casual workers. For technology adoption (e.g., harvesting robots), such labour arrangements imply that farmers will evaluate robots not only for cost savings but also for their ability to replicate or complement the tacit decision-making that experienced workers provide.

Costing and Financial

Participants described the financial setup and cost structure of small-scale chili padi farming as follows:

- Self-financing by entrepreneurs: Most farmers reported that they finance their chili padi operations from personal savings, household income, or informal sources rather than formal bank loans. This reliance on self-finance limits scale-up options and explains a cautious approach to high-cost investments. Studies on smallholder finance show many farmers depend on personal or informal finance because formal credit access is limited.
- Small capital: Entrepreneurs stated that establishing and running a chili padi farm requires relatively small initial capital compared with many other agricultural enterprises. Start-up costs focus on inputs (seedlings, media, fertiliser), basic irrigation/fertigation setup, and small equipment. Because capital outlay is modest, chilli farming is attractive to smallholders seeking fast entry into horticulture. This aligns with horticulture/value-chain literature which notes that short-duration vegetable/horticulture crops often require lower entry capital and can be feasible for smallholders.
- Expect a quick return on capital: Farmers expect short payback periods due to fast crop cycles and regular harvests (weeks to months rather than years). This quick-return expectation shapes investment decisions: farmers favour inputs or technologies with rapid payback and are cautious about high-cost items that

promise long-term but uncertain returns. Research on smallholder vegetable/horticulture systems similarly documents the attraction of short-cycle crops for improving cash flow.

- Electricity bill, maintenance bill, etc.: Participants listed recurring operating expenses—particularly electricity for pumps and fertigation systems, maintenance of equipment (drip lines, pumps, shade nets), and replacement of inputs—as ongoing costs that must be budgeted. Studies of micro-irrigation and smallholder technologies show that energy/electricity and maintenance are significant recurring costs influencing technology adoption decisions.
- Labor costs, sales profit: Profitability was described as a balance between labour expenditure (piece-rate or part-time wages) and sales revenue. Farmers monitor market prices closely because fluctuations in chilli market prices directly affect profit margins. Maintaining low labour costs helps margins, but labour shortages or rising wages can quickly erode profitability. Evidence from vegetable profitability studies supports the centrality of labour and market channels to farm income.

Financial constraints and short payback expectations mean farmers favour low-capital, quick-return innovations. For robotic solutions to be attractive, they must either (a) be low-cost or scalable in stages, (b) demonstrably shorten payback periods, or (c) be subsidised/financed via accessible credit or value-chain arrangements.

Chili Padi Robot Issues

The findings reveal that while robotics in agriculture presents promising opportunities for efficiency and labour reduction, smallholder farmers encounter multiple barriers and risks in adopting this technology. The issues are summarised below:

- Cost of buying a robot: Robots are capital-intensive, often requiring substantial upfront investment that is prohibitive for small-scale farmers. The high acquisition cost makes affordability a central barrier to adoption, especially for self-financed farmers who expect short payback cycles. Studies confirm that high capital requirements limit technology adoption in smallholder contexts.
- Maintenance (spare parts, oil, and others): Robots require consistent maintenance, including access to spare parts, lubricants, and technical servicing. For rural or remote farms, the availability and cost of such services can pose significant challenges. The literature highlights that maintenance and after-sales service infrastructure are often overlooked barriers in agri-tech adoption.

Figure 6: Chili Padi Robot Issues – Keywords and Theme Extraction

Keywords / Phrases from Interviewees	Initial Coding (Researcher Notes)	Extracted Theme
"The robot is too expensive for us small farmers" / "How can we buy it when the price is higher than our yearly income?"	High upfront cost; affordability as a barrier	Cost of acquisition
"If it breaks down, where do we get spare parts?" / "Maintenance like oil and servicing will be costly"	Continuous servicing; lack of local spare parts	Maintenance challenges
"We cannot keep the robot in our house, it might get stolen" / "It needs a proper place for storage away from rain and people"	Need for secure, weather-proof storage	Storage and security
"We need proper training to know how to use it" / "Older farmers may not understand the system without courses"	Training requirement; generational skill gap	Training requirement
"The machine is too complicated to operate" /	Perception of complexity; fear of	Technological

"If it is not user-friendly, farmers will avoid it"	misuse	complexity
"Our farm has no strong internet connection" / "Without stable internet, we cannot operate the robot properly"	Digital infrastructure as prerequisite	Connectivity issues
"What happens if the battery runs out?" / "Electricity costs and charging are another burden"	Energy source dependency; limited rural electricity	Power dependency
"It's not easy to move the robot around the farm" / "Transporting between plots will be troublesome"	Limited portability; heavy design	Robot mobility
"Our land is uneven; the wheels might not work here" / "Robots may not suit the rough terrain we have"	Terrain-related limitations	Terrain compatibility

- Storage and security (away from the farm operator's residence): Farmers expressed concern over safely storing robots when not in use. Since robots are high-value assets, risks of theft, vandalism, or weather-related damage require proper storage infrastructure, which smallholder farms often lack. Security concerns are frequently cited as deterrents to mechanisation in rural settings.
- Training for use: Effective use of agricultural robots requires farmers to undergo training to acquire new technical skills. This involves additional time, cost, and willingness to learn, which can be a barrier for older or less tech-savvy farmers. Evidence shows that inadequate training is one of the main reasons for under-utilisation of agricultural technologies.
- Complexity of using robots: Farmers highlighted that robots may be technically complex, requiring higher digital and mechanical literacy compared with traditional tools. This creates a steep learning curve and may discourage adoption unless simplified interfaces and farmer support are provided.
- Internet access: Many robots rely on connectivity for data collection, monitoring, or remote control. In rural farming contexts, limited or unreliable internet access poses a significant challenge. Research indicates that digital infrastructure is a precondition for precision agriculture and robotics adoption.
- Power for the robot (battery or the like): Reliable power sources (e.g., rechargeable batteries, solar charging stations) are essential for operating robots. Farms in areas with inconsistent electricity supply face additional costs in securing reliable power. Sustainable energy solutions are therefore critical for long-term viability.
- Mobility of the robot: Farmers stressed the importance of moving robots easily across plots or between farm sites. Bulky or poorly designed robots can create logistical challenges for small farms. Mobility considerations are often underreported in robotics literature but are crucial for user acceptance.
- Robot wheels and terrain compatibility: Given that chilli farms often sit on uneven terrain, wheel design and overall terrain compatibility are key concerns. Robots designed for flat, uniform fields may struggle in such environments, limiting their usefulness. Recent studies on agricultural robots emphasise the importance of adaptable designs that account for diverse field conditions.

These findings demonstrate that adoption of robotic solutions in small-scale chilli farming is not only a matter of cost but also of technical, infrastructural, and socio-cultural readiness. For successful diffusion, robot developers must consider affordability, durability, ease of training, and adaptability to uneven terrains typical of smallholder farms. Policies that improve internet access, provide farmer training, and subsidise initial investments could help overcome these barriers.

CONCLUSION

This study demonstrates that farming is not only a technical process but a deeply human-centered activity where cultivation practices, financial considerations, and labor management intersect with technological change. Farmers' lived experiences reveal that any attempt to introduce chili padi harvesting robots in fertigation farming must go beyond technical efficiency and explicitly address usability, affordability, and adaptability to local contexts.

The findings highlight that humanising agricultural robotics requires a holistic integration of five key domains. First, human resource management, where robots must complement the skills of hired labor rather than replace them abruptly. Second, costing and financial planning, since affordability and return on investment are critical for farmers operating on tight margins. Third, chili padi robot issues, where design must consider ease of use, maintenance, and durability in farm conditions. Fourth, chili padi farming practices, such as fertigation systems, soil and water management, and pest control, which must align with robotic functions. Finally, the harvesting process, where robots must handle delicate chili padi fruits without compromising speed, accuracy, or quality.

From a constructivist grounded theory perspective, this study contributes by framing robot adoption not only as a technological shift but as a socio-economic and cultural process shaped by these five domains. For innovators, the lesson is clear: successful chili padi robots must be designed with farmers, not just for them. Prototyping must integrate farmer feedback, cost models must reflect farmers' financing realities, and training must empower users to adopt robots confidently and sustainably.

Ultimately, this research moves the discussion beyond feasibility and into the realm of practical implementation, offering critical insights for policymakers, technology developers, and researchers. By listening to and prioritising farmers' voices, innovation in chili padi fertigation farming can be humanised—ensuring that robotics supports, rather than disrupts, the biological, financial, and social fabric of farming communities.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for the financial support provided through the Short-Term Research Grant. Appreciation is also extended to the Faculty of Technology Management and Technopreneurship (FPTT), UTeM, for their continuous support and encouragement throughout this study.

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