

Smart Vertical Hydroponic Tower (HyDRA-T): An Exploratory Study on User Acceptance and Technical Feasibility for Urban Home Farming

Ida Syafiza Md Isa^{1*}, Kong Yong Keng¹, M.Aiman Azhar¹, Lim Jing Wen¹, M.Syahmi Afiq Mohd Roszalan¹, Vaineswari Krishnarajah¹, Nur Latif Azyze Mohd Shaari Azyze²

¹Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia

²Fakulti Teknologi Kejuruteraan Elektrik, Universiti Teknikal Malaysia Melaka, Melaka Malaysia

*Corresponding Author

DOI: <https://doi.org/10.47772/IJRISS.2026.100900239>

Received: 09 September 2026; Accepted: 14 September 2026; Published: 07 October 2026

ABSTRACT

Rapid urbanization, limited residential space, and busy daily routines present significant barriers to urban home food production. This study presents an exploratory evaluation of the Smart Vertical Hydroponic Tower (HyDRA-T), an IoT-enabled prototype designed to mitigate manual labor in home hydroponics. HyDRA-T integrates an ESP32 microcontroller, environmental sensors, automated irrigation, grow-light control, and Blynk-based remote monitoring. To evaluate preliminary user acceptance and practical constraints, an exploratory survey of 110 university respondents was conducted. The findings indicate that key barriers include a lack of daily maintenance time (87.3%), fear of crop failure (69.1%), and spatial constraints (62.7%). While 90% of respondents expressed conditional purchase intention under a hypothetical 50% reduction in manual labor, this represents stated preference rather than confirmed market demand. Technical bench testing demonstrated high short-term functional reliability (96%–100%) across sensing and telemetry modules. Overall, the study offers preliminary insights into how automated vertical farming can potentially contribute to Sustainable Development Goals (SDGs 2, 11, and 12), while highlighting the need for extended field testing and comprehensive financial analysis prior to commercialization.

Keywords: Internet of Things (IoT), Smart Farming, Socio-Economic Feasibility, Sustainable Development Goals (SDGs), Technology Adoption, Urban Agriculture.

INTRODUCTION

Many urban households are interested in fresh and self-grown food, but growing food at home is not always practical. Limited land, high living costs, and demanding work schedules can reduce the time and space available for regular gardening. Urban agriculture has therefore received increasing attention as a way to improve local food access and household resilience, particularly in densely populated areas [1] - [3]. Vertical hydroponics is well suited to this setting because crops can be grown without soil and arranged in a compact structure. Even so, conventional hydroponic systems still require users to monitor water level, pH, temperature, humidity, and lighting conditions. For inexperienced users, this routine can be difficult to maintain and may increase the risk of poor crop growth or failure [4] - [6].

Smart Vertical Hydroponic Tower (HyDRA-T) was developed as a Service-Learning project in response to these practical issues. The system combines an ESP32 microcontroller [7], several environmental sensors, automated irrigation and grow-light control, and the Blynk IoT platform [8]. Users can check the system through a smartphone or laptop instead of relying only on manual observation. In this study, the technology is treated as a practical intervention rather than as the main outcome. The main interest is whether automation can make home farming more manageable for people who have limited time, limited space, or little gardening

experience. This focus is also relevant to several Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production) [9].

The issue addressed in this study is not simply whether a hydroponic system can be automated. A more important question is whether automation can make home food cultivation easier for people who may otherwise avoid it. Potential users may be discouraged by the need for daily care, uncertainty about crop survival, limited knowledge, or a lack of suitable space. Existing hydroponic systems can still require regular manual attention, which may reduce their appeal to first-time users [5]. This study therefore considers both the technical operation of HyDRA-T and the social and economic factors that may influence its acceptance.

Accordingly, this study aims to identify the practical and psychological barriers to home food cultivation., develop an automated, IoT-enabled vertical hydroponic system that responds to these barriers, examine user acceptance, perceived usefulness, feature preferences, purchase intention, and price sensitivity through a structured survey, and confirm that the automation functions are reliable enough to support user confidence in the system.

LITERATURE REVIEW

Previous work has shown that IoT-based monitoring can improve the management of hydroponic and vertical farming systems. Ibrahim and Audah [4], for example, demonstrated real-time monitoring of a vertical hydroponic setup using ESP32 and Blynk, while Jain and Kaur [5] showed that automated control of electrical conductivity and pH can improve the consistency of nutrient management. Austria et al. [6] also integrated several environmental parameters into an IoT-enabled greenhouse system. These studies show that the technical components required for automated cultivation are already well established. However, most of this work focuses on system performance rather than on how ordinary users respond to the technology.

For this reason, user acceptance is important when evaluating a system intended for household use. The Technology Acceptance Model (TAM) explains adoption in terms of perceived usefulness and perceived ease of use [10]. UTAUT broadens this view by considering performance expectancy, effort expectancy, social influence, and facilitating conditions [11]. These ideas are useful for understanding smart-farming adoption because a technically capable system may still be rejected if users find it difficult, unnecessary, expensive, or unsuitable for their living environment. Recent Malaysian studies have similarly highlighted behavioural intention and user-related factors in the adoption of smart-farming technologies [12] - [13].

Urban farming studies also point to the importance of housing conditions, experience, affordability, and perceived benefit. Marzouk et al. [14] found that social acceptance of urban agricultural systems is shaped by user preferences and the surrounding residential context. Yuniarsih et al. [15] reported that adoption of urban-farming technology is influenced by several individual and situational factors, while Wang [16] discussed the role of technology in improving the sustainability of urban and peri-urban food systems. Other studies have linked urban agriculture with household food security [3] and with the use of compact smart-gardening solutions in high-rise environments [17]. Taken together, the literature suggests a gap between technical feasibility and user adoption. HyDRA-T was therefore evaluated not only as an engineering prototype, but also as a possible home-farming solution from the perspective of potential users.

METHODOLOGY

System Development Overview

HyDRA-T uses a 3D-printed vertical tower with a recirculating nutrient reservoir, a submersible water pump, and five sensing modules, as shown in the block diagram in Figure 1. The sensing modules include a DHT22 sensor for ambient temperature and humidity, a PH4502C sensor for nutrient-solution acidity, a DS18B20 sensor for water temperature, an LDR 5528 sensor for light intensity, and a resistive water-level sensor. The completed prototype is shown in Figure 2. An ESP32 microcontroller [7] reads the sensors and applies threshold-based control to the water pump and grow lamp. The sensor readings are also transmitted to the

Blynk dashboard [8], which can be accessed through a smartphone or web browser, as shown in Figure 3.

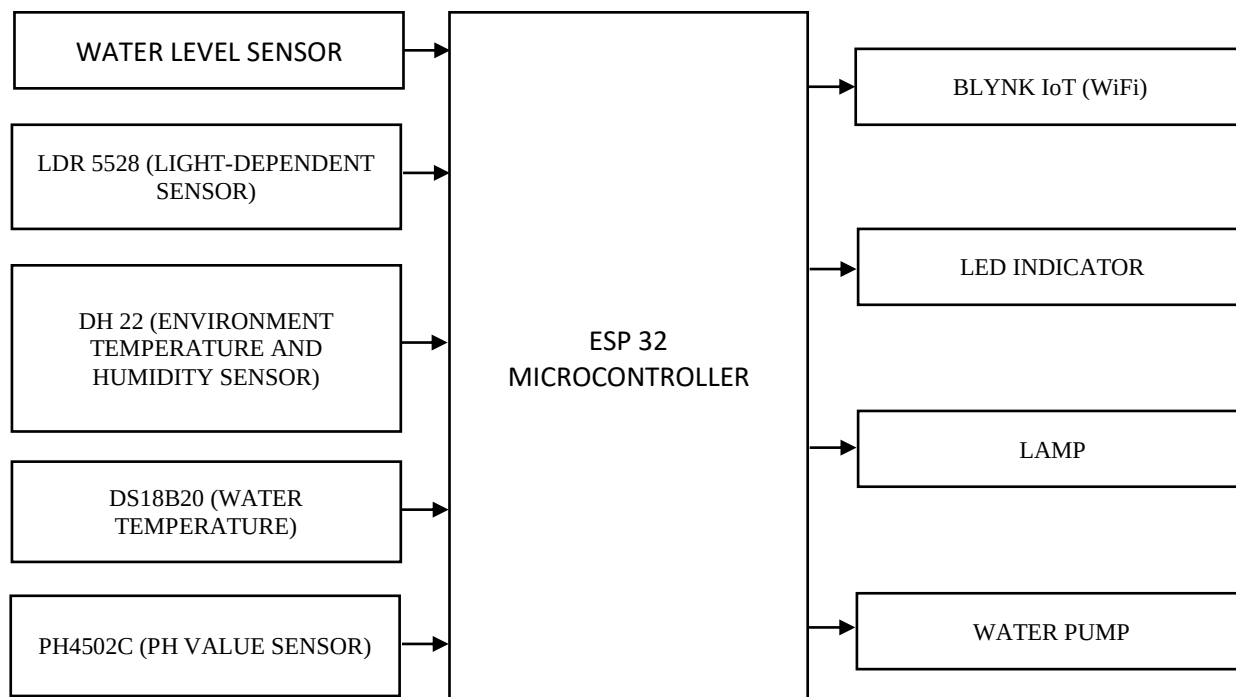


Figure 1. HyDRA-T system block diagram.



Figure 2. Completed HyDRA-T prototype.

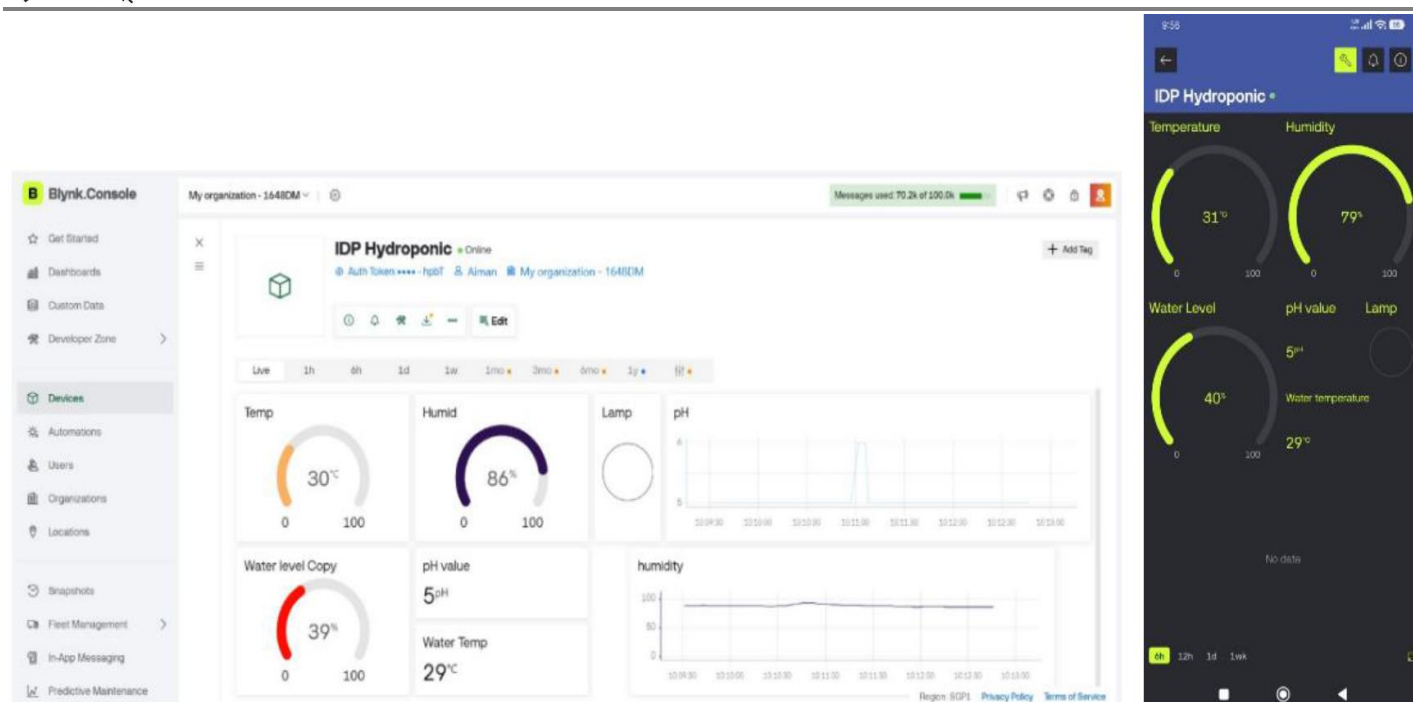


Figure 3. Blynk dashboard on laptop and smartphone.

Survey Instrument and Sampling

To evaluate user perceptions, a structured closed-ended questionnaire was designed and distributed online (via Google Forms) to students and staff within the Universiti Teknikal Malaysia Melaka (UTeM) community. A non-probability convenience sampling method was employed, yielding 110 valid responses. The survey instrument was reviewed for face validity by two academic experts in agricultural technology and social science before deployment.

Although this study does not perform structural equation modelling, the survey questions were operationalized around key constructs from the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT):

- Perceived Usefulness: Operationalized through items assessing perceived labor reduction (50% manual watering effort) and space optimization.
- Perceived Ease of Use: Operationalized through preferences for automated lighting, simplified warning systems (LED indicators vs. app notifications), and user interface complexity.
- Facilitating Conditions & Price Sensitivity: Measured via current residential space, prior gardening experience, and acceptable price threshold (RM).

Technical Reliability Testing Protocol

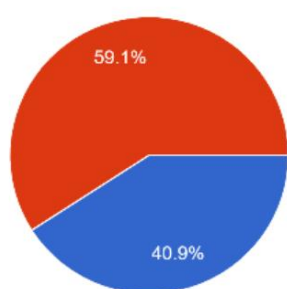
To verify baseline functional viability, the HyDRA-T prototype underwent controlled bench testing over a 14-day continuous observation period. Sensor telemetry accuracy and control actuation were evaluated over 100 discrete automated cycles (N=100) under ambient indoor conditions (25°C–32°C; 60%–85% RH). A test trial was recorded as successful if:

- (1) sensor readings fell within $\pm 5\%$ of standard baseline reference meters,
- (2) automated actuators (pump relay/lamp) triggered within 2 seconds of threshold breach,
- (3) telemetry packets were logged on the Blynk dashboard without packet loss.

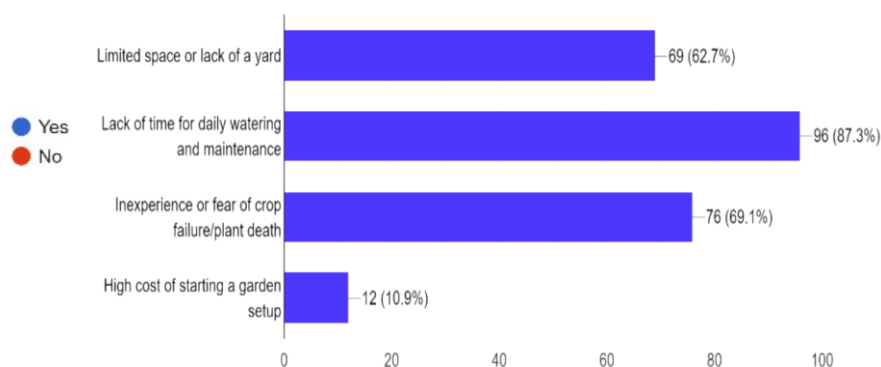
RESULTS AND ANALYSIS

Socio-Economic Barriers to Urban Farming

Based on the survey responses described in the methodology, the main socio-economic barriers to urban home farming were examined. Of the 110 respondents, 59.1% had never tried either traditional or hydroponic home gardening as in Figure 4(a). The responses in Figure 4 (b) show that the main difficulties were lack of time for daily watering and maintenance (87.3%), lack of experience or fear of crop failure (69.1%), and limited space or lack of a yard (62.7%). Only 10.9% selected the cost of setting up a garden as a major barrier. This suggests that, for this group, time, confidence, and living-space constraints were more important than initial cost. Awareness of smart farming was also limited. Only 19.1% reported being very or moderately familiar with smart farming and IoT, while 42.7% had heard of the concept but did not understand how it worked. These findings support the need for a system that is simple to operate and does not assume a high level of technical knowledge.



(a)

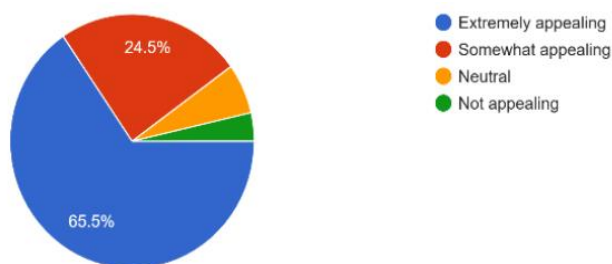


(b)

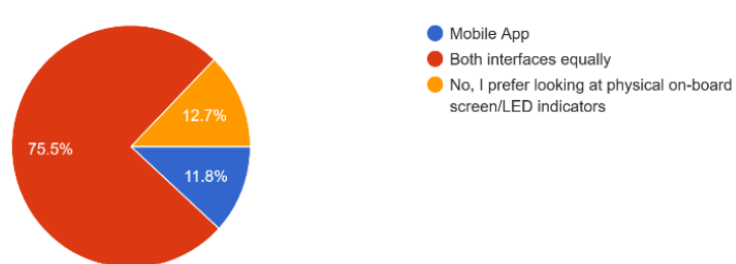
Figure 4. Survey findings on home gardening experience and barriers: (a) respondents' previous experience with home gardening; (b) main barriers to home plant cultivation (n = 110).

Consumer Acceptance and Feature Preferences

The survey responses also showed a generally positive reaction to the automated vertical concept. A total of 65.5% of respondents rated the system as extremely appealing while 24.5% rated it as somewhat appealing, giving a combined positive response of 90% as shown in Figure 5(a). For remote monitoring, Figure 5(b) shows 75.5% preferred access through both a mobile application and a laptop or web dashboard. This suggests that users value flexibility in how they interact with the system. For warning methods, 63.6% preferred a physical light-emitting diode (LED) indicator on the device, while others favoured a combination of local and smartphone-based alerts, as in Figure 5(c). In addition, Figure 5(d) shows that 59.1% considered the automated grow lamp to be very important for indoor planting. Overall, these responses suggest that respondents were not only interested in automation itself, but also in features that make the system easier to monitor and use in everyday settings.



(a)



(b)

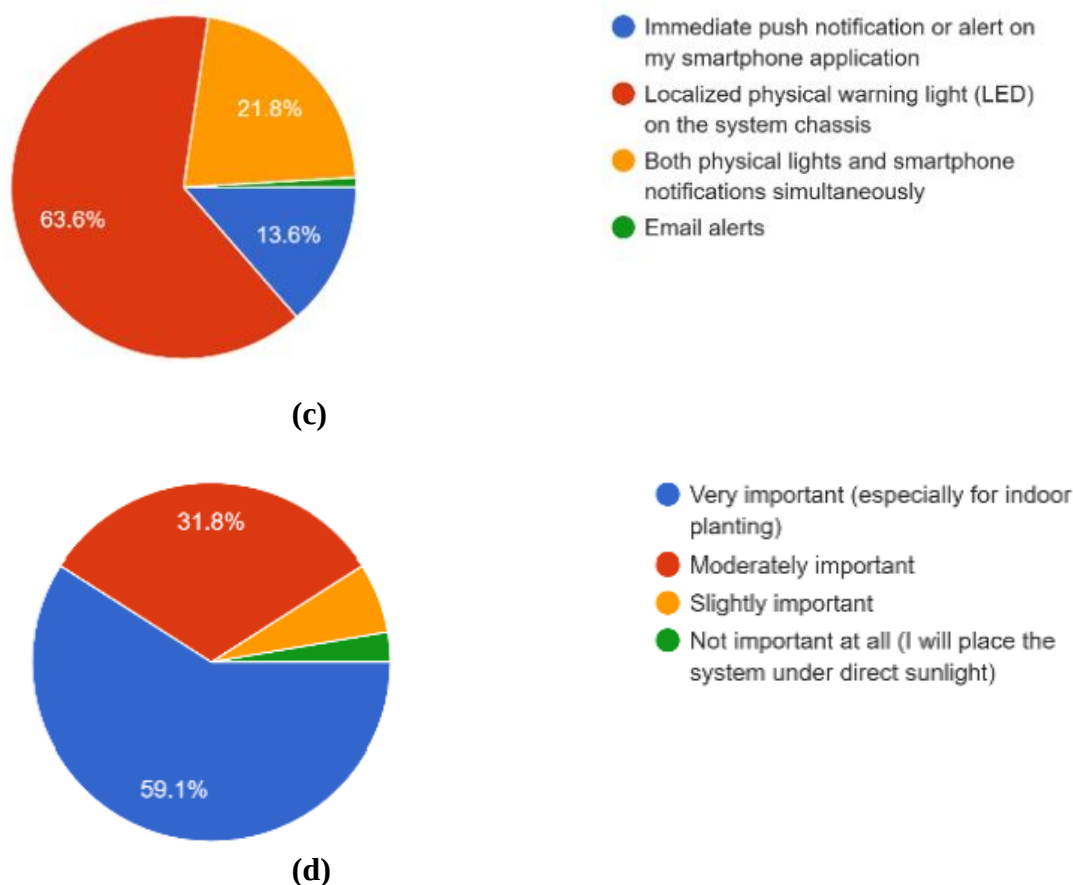


Figure 5. Respondents' views of the automated vertical farming system: (a) system appeal; (b) preferred monitoring interface; (c) preferred warning methods; (d) perceived importance of the automated grow lamp.

Market Viability and Financial Analysis

Purchase intention was evaluated under a explicit operational condition. When respondents were asked how likely they would be to acquire the system if it achieved a 50% reduction in manual watering effort, 60.0% indicated an extremely probable likelihood of purchase, while an additional 30.0% reported a probable likelihood, yielding a combined positive response of 90.0%. However, this high level of interest must be explicitly interpreted as a conditional stated preference rather than evidence of actual market demand or immediate purchasing behavior, as hypothetical survey responses do not account for real-world purchasing constraints. In terms of perceived target audiences, 57.3% of respondents identified high-density city dwellers

living in apartments or flats as the primary end-users, followed by small-scale local farmers (20.0%), educational institutions (15.5%), and commercial food establishments (7.3%). This distribution aligns closely with the compact vertical architecture of the prototype, reinforcing its intended utility for space-constrained residential environments.

Regarding consumer price sensitivity, 59.1% of respondents identified RM301–RM400 as an acceptable price range for a complete household unit, while 19.1% selected RM401–RM500, 10.9% selected RM200–RM300, and smaller proportions selected below RM200 or above RM501. The physical prototype's Bill of Materials (BOM) totalled RM383.36, which falls within the primary price window preferred by potential users. However, establishing true socio-economic feasibility requires distinguishing simple prototype hardware costs from comprehensive commercialization and operating expenditures. The raw BOM cost reflects only immediate component acquisition (such as the ESP32 microcontroller, sensors, relay modules, and 3D-printed structural elements). It does not incorporate essential commercialization overheads, including mass-manufacturing tooling, plastic injection molding, assembly labor, protective packaging, distribution logistics, retail margins, or post-purchase warranty support.

Furthermore, ongoing operational costs must be factored into the user's overall financial commitment. Assuming continuous operation of the 12V submersible pump and automated grow lighting, electrical consumption is estimated at approximately 12.5 kWh per month (translating to ~RM 4.50 monthly at standard domestic electricity rates), while recurring consumables such as liquid hydroponic nutrient solutions and replacement pH/EC calibration fluids add approximately RM 10.00 to RM 15.00 per month. Periodic component replacement due to sensor degradation over long-term fluid exposure also represents a minor recurring cost. Therefore, while the prototype's physical production cost initially aligns with consumer price expectations, full commercial viability will depend on optimizing manufacturing processes to absorb operational and logistics overheads while maintaining target retail price points.

TECHNICAL RELIABILITY AND OPERATIONAL LIMITATIONS

Technical testing was conducted to verify whether the baseline automated functions performed reliably under bench conditions. Across repeated trials, the light-dependent resistor (LDR) based grow-lamp control, humidity-based pump automation, and physical LED warning system each achieved a 100% success rate. The DHT22 humidity sensor achieved 98%, while the resistive water-level sensor achieved 96%. The Blynk dashboard successfully received real-time telemetry in 99% of 100 trials, with minor deviations resulting from brief Wi-Fi delays and fluid movement in the reservoir.

However, these short-term bench metrics do not establish long-term agronomic or hardware reliability under real-world operating conditions. Analogue sensors (such as pH and water-level probes) remain susceptible to calibration drift, oxidation, and bio-fouling over extended immersion periods. Furthermore, testing was limited to functional electronic verification rather than full multi-month crop growth cycles across diverse plant species. Long-term operational reliability under varying environmental conditions requires further investigation through multi-crop field trials.

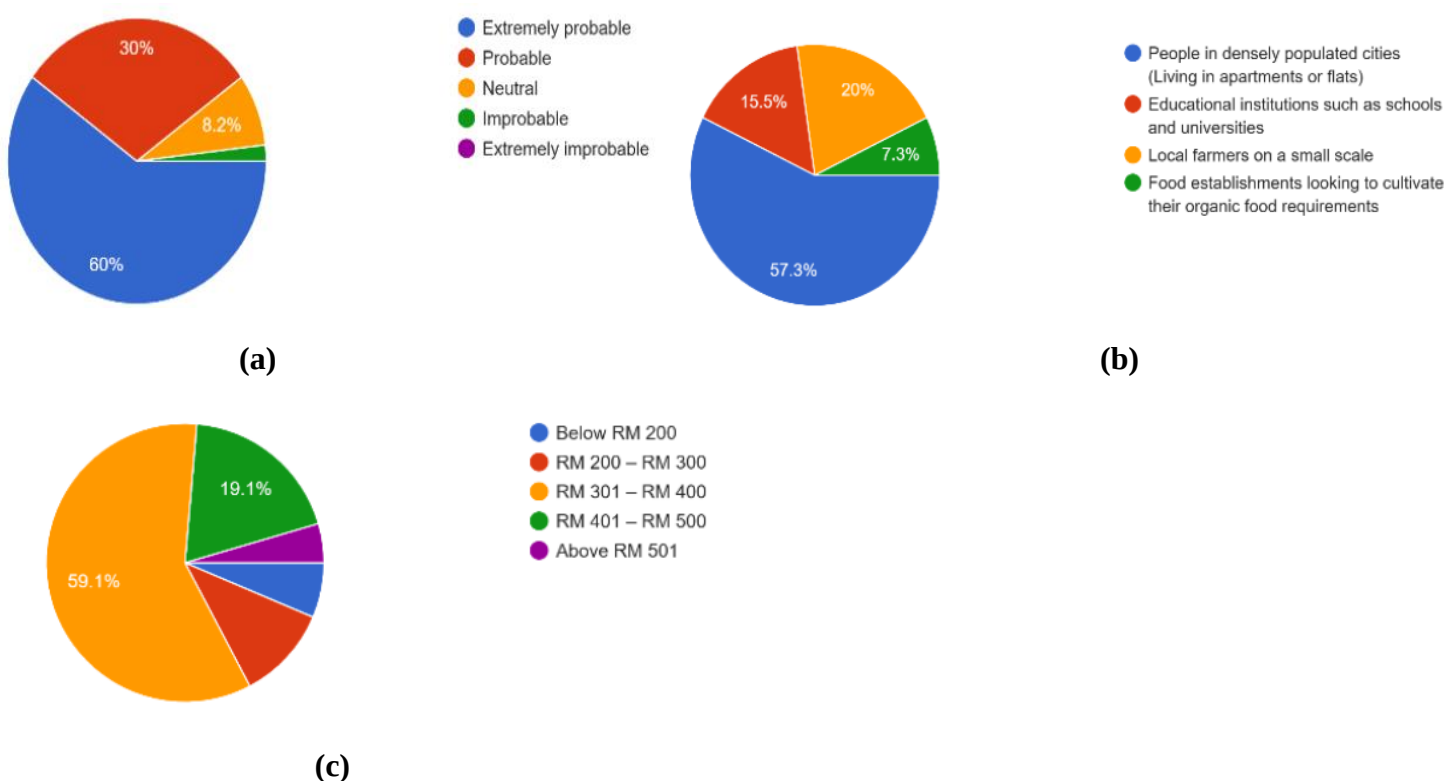


Figure 6. Market-related responses toward HyDRA-T: (a) purchase probability based on 50% labour reduction; (b) primary target audience for system adoption; (c) acceptable consumer price range.

CONCLUSION

This exploratory study investigated the technical functionality and initial user acceptance of the HyDRA-T smart vertical hydroponic tower. Findings from the 110 university-based respondents confirm that daily

maintenance time, lack of gardening experience, and spatial limitations represent the primary obstacles to urban home food production. System automation directly addresses these concerns by providing localized alerts, automated growth cycles, and remote monitoring. While the survey indicates high conditional interest (90%) and acceptable price alignment near the prototype BOM cost (RM383.36), these results must be interpreted within the boundaries of an exploratory sample. Stated purchase intentions cannot be equated with confirmed market demand or long-term technology adoption. Furthermore, HyDRA-T demonstrates potential alignment with Sustainable Development Goals (SDG 2: Zero Hunger, SDG 11: Sustainable Cities, and SDG 12: Responsible Consumption) by facilitating localized urban farming, though demonstrated socio-economic impact requires broader longitudinal verification. In future work, this study focus on expanding field deployments to diverse urban households beyond academic environments, conducting rigorous cost-benefit analyses including crop yield evaluation and payback period calculations, and testing long-term sensor calibration stability and biological crop viability across multiple growth cycles.

ACKNOWLEDGMENT

This study is funded by the Universiti Teknikal Malaysia Melaka, through the UTeM Short Term Perspektif Grant No: PJP/2025/FTKE/PERSPEKTIF/SA0086 and PJP/2025/FTKEK/PERSPEKTIF/SA0084. The Authors would also like to thank Universiti Teknikal Malaysia Melaka (UTeM) for all the support.

REFERENCES

1. FAO, IFAD, UNICEF, WFP and WHO, The State of Food Security and Nutrition in the World 2024: Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms. Rome, Italy: FAO, 2024.
2. S. Oh and C. Lu (2023). Vertical farming - smart urban agriculture for enhancing resilience and sustainability in food security. *The Journal of Horticultural Science and Biotechnology*, vol. 98, no. 2, pp. 133-140, 2023, doi: 10.1080/14620316.2022.2141666.
3. F. D. Alene and M. A. Aga (2025). The roles of urban agriculture to household food security: a case study in Kirkos sub-city, Addis Ababa city, Ethiopia. *Frontiers in Sustainable Food Systems*, vol. 9, p. 1444320, 2025, doi: 10.3389/fsufs.2025.1444320.
4. D. A. Ibrahim and L. H. M. Audah (2023). Vertical Hydroponic Monitoring System Using Internet of Things. *Evolution in Electrical and Electronic Engineering*, vol. 4, no. 2, pp. 766-773, 2023, doi: 10.30880/eeee.2023.04.02.092.
5. S. Jain and M. Kaur (2024). Design and Implementation of an IoT-based automated EC and pH Control System in an NFT-based Hydroponic Farm. *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 13078-13081, 2024, doi: 10.48084/etasr.6393.
6. A. C. H. Austria, J. S. Fabros, K. R. G. Sumilang, J. Bernardino, and A. C. Doctor (2023). Development of IoT Smart Greenhouse System for Hydroponic Gardens. *International Journal of Computing Sciences Research*, vol. 7, pp. 2111-2136, 2023, doi: 10.25147/ijcsr.2017.001.1.149.
7. Espressif Systems (2026). ESP32 Series Datasheet. Espressif Systems [Online]. Available: <https://www.espressif.com/>. [Accessed: Sep. 8, 2026].
8. Blynk (2026). Blynk Documentation: Introduction. Blynk IoT Platform Documentation. [Online]. Available: <https://docs.blynk.io/>. [Accessed: Sep. 8, 2026].
9. United Nations Department of Economic and Social Affairs (2026). Sustainable Development Goals. United Nations. [Online]. Available: <https://sdgs.un.org/goals>. [Accessed: Sep. 8, 2026].
10. Marikyan, D. & Papagiannidis, S. (2026). Technology Acceptance Model: A review. *TheoryHub Book*, S. Papagiannidis, Ed. [Online]. Available: <https://open.ncl.ac.uk>. ISBN: 9781739604400.
11. V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis (2023). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, vol. 27, no. 3, pp. 425-478, 2003, doi: 10.2307/30036540.
12. Y. Ravindran, N. B. M. Haris, J. A. Shah, and W. F. F. Ilahi (2024). UTAUT Model Insights on the Adoption of Smart Farming Technologies (SFTs) in Malaysia. *International Journal of Research and Innovation in Social Science*, 2024, doi: 10.47772/IJRISS.2024.8080301.
13. N. F. Azmi, A. A. Rashid, and A. Hanif (2024). A Systematic Review of Behavioural Intentions Influencing Data Analytics Adoption among Malaysian Crop Farmers. *International Journal of*

Research and Innovation in Social Science, 2024, doi: 10.47772/IJRISS.2024.8110105.

14. M. A. Marzouk, M. A. Salheen, and L. K. Fischer (2024). Towards sustainable urbanization in new cities: Social acceptance and preferences of agricultural and solar energy systems. *Technology in Society*, vol. 77, p. 102561, 2024, doi: 10.1016/j.techsoc.2024.102561.
15. E. T. Yuniarsih, M. Salam, M. H. Jamil, and A. N. Tenriawaru (2024). Determinants determining the adoption of technological innovation of urban farming: Employing binary logistic regression model in examining Rogers' framework. *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 10, no. 2, p. 100307, 2024, doi: 10.1016/j.joitmc.2024.100307.
16. N. Wang (2025). Technological Innovations in Urban and Peri-Urban Agriculture: Pathways to Sustainable Food Systems in Metropolises. *Horticulturae*, vol. 11, no. 2, p. 212, 2025, doi: 10.3390/horticulturae11020212.
17. A. R. Zailan and M. N. Hamid (2025). AgriSmart: An IoT-Based Smart Gardening Model for High-Rise Academic Buildings. *International Journal of Research and Innovation in Social Science*, pp. 911-920, 2025, doi: 10.47772/IJRISS.2025.90500075.