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BRIDGING THE GAP: ENHANCING SUSTAINABILITY IN HARUMANIS MANGO FARMING THROUGH SMART TECHNOLOGIES AND FARMER READINESS

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Abstract: *Harumanis mango is known worldwide for its unique flavor and sweet taste thus making Perlis State the major focus for mango production in Malaysia. The unpredictable nature of Harumanis mango production causes severe difficulties for farmers due to its market demand. The inconsistent growth patterns linked to production variability negatively affect farmer incomes and the ability to supply this market. The implementation of sustainable and smart agricultural practices serves as a solution to deliver proper nutrients that will guarantee soil health along with ideal productivity of Harumanis mango trees. The research aims to determine the environmental sustainability levels of Harumanis mango growth in Perlis while also examining farmers willingness to implement sustainable smart agricultural methods. A content analysis of detailed interviews between Harumanis mango farmers and expert researchers determined how farmers approach sustainable farming implementations. This research applies to the Theory of Planned Behavior (TPB) framework to discover behaviour acceptance elements influencing farmers' adaptation decisions. Data analysis shows that Harumanis mango cultivation remains erratic because farmers lack understanding about the actual causes while also lacking enough knowledge to adopt sustainable farming methods. The study shows that cooperative approaches between stakeholders must be implemented to sustain Harumanis mango farming into the future.*

Keywords: *Challenges, Environmental Sustainability Performance, Harumanis production, Readiness, Smart farming*

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Introduction

People identify the signature sweet and aromatic scent of Harumanis mangoes as a defining trait of Perlis, despite its position as an area on the northwest coast of Peninsular Malaysia. The farming of these mangoes helps strengthen Perlis' economy through agricultural growth. In 2023, mango farming in Malaysia covers around 3,114 hectares, producing 9,213 metric tons and generating over RM99 million in production value. (Tanaman Buah-Buahan & Malaysia, 2023). Malaysia ranks among the top ten countries for mango production in terms of hectares in 2023, as illustrated in Figure 1.

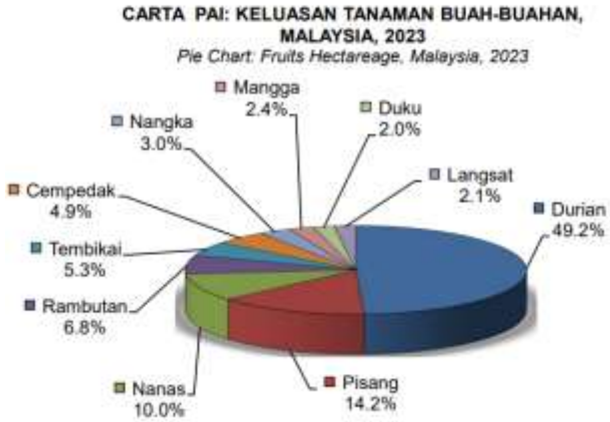

Figure 1: The Highest Hectarage for Ten Fruit Crops, Malaysia, (Tanaman Buah-Buahan & Malaysia, 2023)

The widely demanded Harumanis mangoes remain subject to environmental changes, which produce inconsistent production levels. The flowering process in mangoes requires an extended dry period, according to Talib et al. (2020), making these mangoes prone to the unpredictability's of weather patterns. The unreliable yield system creates major problems for farmers' financial security while decreasing market supply output. Longitudinal research shows that annual yield fluctuations can vary between 15-40%, highlighting the intricate relationship between environmental and agronomic elements. The susceptibility of Harumanis mangoes to climate change and environmental conditions has led to a supply deficit, even though demand remains high in Malaysia and other nations (Talib et al., 2020).

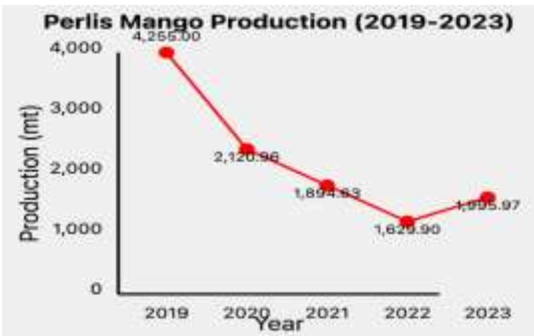

Figure 2: Production trends of mango in Malaysia from 2019-2023 (Tanaman Buah-Buahan & Malaysia, 2023)

Many of the current farming problems cannot be tackled with traditional agricultural systems, and this problem area requires sustainable smart farming concepts to find effective solutions. The implementation of advanced technologies supports natural resource performance and controls environmental damage while advancing agricultural output levels. Farmers need to study current environmental sustainability levels in Harumanis mango production before they can begin using new technology (Azizan et al., 2019).

This study is novel because it looks at the environmental sustainability performance (ESP) of the production of Harumanis mangoes, which face significant obstacles like unpredictable yields brought on by genetic predisposition, climate variability, and difficulties managing pests and diseases. It also investigates the readiness of smart farming technology to be adopted to address these yield fluctuations. Targeted research on the instability of Perlis's production of Harumanis mangoes is lacking. Only the technical efficiency of Harumanis mango production in Perlis, Malaysia, as well as fruit retention and fruit drop pattern, are covered in the studies (Abdullah & Tengku, 2022; Nor et al., 2024). Additionally, many studies on smart and sustainable agriculture concentrate on large-scale commercial farming, such as palm oil, paddy, or durian, leaving a gap in knowledge regarding its viability, scalability, and customisation for niche crops like Harumanis mangoes (Westermann et al., 2018; Li et al., 2023). This research aims to address existing gaps by investigating the ESP of high-value crop, such as Harumanis mango production and the crop-specific challenges related to this crop. The focus is on identifying factors that hinder farmers' willingness to embrace modern agricultural technology concerning Harumanis mangoes.

Research applies qualitative methods to study three areas: 1) the unknown aspects of Harumanis mango farming ESP, 2) farmer's preparedness for sustainable smart farming execution 3) the related difficulties. Data acquired from research expert interviews and field experience of experienced farmers will drive the creation of sustainable smart farming initiatives which serve farmers and environmental conservation.

Literature Review

Despite Perlis's high demand for Harumanis mangoes, the plantation has significant obstacles that impair its sustainability and productivity. There is also a lack of in-depth studies that explore the adaptation readiness of smart farming in the Harumanis plantation, particularly when it comes to behavioural intents.

South Asia, along with Malaysia, maintains mango cultivation as one of its major agricultural activities since this fruit holds high popularity among locals. Malaysia recognises Harumanis mango as its premium mango product due to its distinctive qualities of sweetness and texture alongside pleasant aromas (Azizan, 2019). While Azizan (2019) highlighted the popularity and distinctiveness of Harumanis, Musa (2010) explored the weaknesses of Harumanis mango plantation, where it is constantly exposed to fungal diseases, fruit fly threats and pest attacks. Persistent challenges in the cultivation of Harumanis mango trees produce major problems which disturb farm income stability and risk farming sustainability. The existing problems in mango cultivation indicate a critical gap and demand new agricultural approaches because conventional farming alone cannot support continuous mango production or preserve market performance stability.

The term Environmental Sustainability Performance (ESP) describes how effectively organisations achieve their environmental sustainability targets that involve resource efficiency

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alongside waste reduction with environmental impact reduction. Agricultural settings apply environmental sustainability performance through farming practices which both decrease production-related environmental impacts and maintain soil health, according to Rizvi and Garg (2022). The production of Harumanis mango implements ESP through three key practices, which include optimal nutrient resource management, minimal pesticide intervention and sustainable soil maintenance. The current optimisation strategies for resource utilisation in conventional farming systems do not provide satisfactory, all-encompassing, sustainable solutions. Smart farming technologies, like Wireless Sensor Networks (WSNs) and Internet of Things (IoT) systems, have shown great promise to improve sustainability within the Harumanis mango growing operations. These technologies include accurate agricultural monitoring, efficient data collection, and identification of crop health and requirements, as investigated and confirmed by Ismail (2021) and Rahu (2023) through their recent studies. Real-time collected data enables more educated decision-making processes for irrigation practices, along with pest management and fertilisation techniques. Smart farming systems reduce environmental impacts through improved water and fertiliser management practices, together with decreased pesticide usage, thus resulting in enhanced mango crop productivity. The implementation of smart farming technologies provides farmers with a superior alternative approach that improves environmental resource management and increases production efficiency (Azizan, 2019). Although various studies have demonstrated the technical potential of sustainable smart farming technology, there are relatively few studies that have examined the psychological willingness to use smart farming technology, notably emphasising Harumanis mango plantation in Perlis, which leaves a gap.

Numerous obstacles prevent farmers from embracing the numerous advantages delivered by smart farming systems. Operating these technologies demands advanced expertise from farmers since they need to understand how their data collection and decision-making processes work with minimal intuitive understanding (Tey & Brindal, 2012). High initial investment costs are still cited in the majority of recent studies by Musa & Basir (2021), Balafoutis et al. (2020), and Thomas et al. (2023), even though they were identified as one of the primary obstacles to the adoption of smart farming more than eight years ago. The required capital needed during implementation remains high even though initial costs have become more affordable since its introduction, and this presents a major obstacle for farmers who struggle financially to invest in such technology. Farmers hold back from adopting these innovations because they doubt that such investments will provide long-term profitability, together with practical feasibility.

Smart farming intentions from farmers depend on multiple elements which determine their capability to embrace modern agricultural technologies. The way farmers view innovation and their belief in technology implementation and adoption powers their desire to adopt sustainable farming practices (Sarvestani and Millar, 2024). The farming community along with society sets subjective norms through which farmers develop their attitudes about accepting new farming systems (Shah, 2022). According to Han and Niles (2023) agricultural technology adoption requires supportive external programs and government policies in addition to positive sustainable farming attitudes to facilitate sustainable farming practice implementation. The assessment of social aspects along with psychological aspects remains fundamental to determining farmer adoption levels of novel farming technologies and sustainable farming methods.

The Theory of Planned Behavior (TPB) helps researchers understand all the elements which determine farmers' decisions about sustainable farming practices adoption. TPB demonstrates that human actions depend primarily on three aspects including individual behavioral attitudes together with social expectations and perceptions of control capabilities (Ajzen, 1991).

The adoption of smart farming technology by farmers depends on their technological attitude, together with peer and community acceptance and their self-assurance in technology utilisation and management. Studies have shown that farmers judge the value of novel technologies and local community backing functions as major predictors which determine their choices on adopting sustainable agricultural practices (Shah, 2022). Their decision-making depends heavily on how challenging they think it will be to implement these practices together with resource availability factors.

Smart farming technology adoption faces multiple barriers, which make it a complex challenge even though its environmental advantages are obvious. Plenty of obstacles make it difficult for farmers to adopt new methods. Farmers have issues related to financial or technical limitation thus may affect psychological and social influences on their behavioural choices. Specific interventions involving knowledge and training, resource management combined with community network creation, present important solutions to address these obstacles. Through educational programs, financial support, and support system for technological adoption, stakeholders enable farmers to adopt better methods of sustainable farming. Sustainable Harumanis mango agriculture, together with Malaysian farming, will reach long-term stability through these initiatives.

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Theme	Author(s) & Year	Key Findings	Identified Gaps	Relevance to Current Study
Harumanis Mango Cultivation Challenges	Azizan (2019), Musa (2010)	Harumanis mango is premium but vulnerable to pests and diseases.	Limited integration of technological solutions to address sustainability.	Establishes need for smart farming in Harumanis context.
Environmental Sustainability Performance (ESP)	Rizvi & Garg (2022), Ismail (2021), Rahu (2023)	ESP practices improve soil health and reduce environmental impact; IoT and WSNs enhance monitoring.	Few studies link ESP with behavioral adoption in mango farming.	Supports smart farming as a sustainable solution.
Smart Farming Technology Potential	Azizan (2019), Ismail (2021), Rahu (2023)	Smart farming improves resource management and productivity.	Lack of behavioral intent studies specific to Harumanis mango.	Highlights technical feasibility and need for psychological readiness.
Adoption Barriers	Tey & Brindal (2012), Musa & Basir (2021), Balafoutis et al. (2020), Thomas et al. (2023)	High costs and technical complexity hinder adoption.	Persistent financial and knowledge barriers despite tech evolution.	Identifies obstacles to adoption requiring policy and support.
Behavioral Intent and Social Influence	Sarvestani & Millar (2024), Shah (2022), Han & Niles (2023)	Attitudes, norms, and external support influence adoption decisions.	Limited application of behavioral models in tropical fruit farming.	Justifies use of TPB to assess farmer readiness.
Theoretical Framework (TPB)	Ajzen (1991), Shah (2022)	TPB explains adoption through attitudes, norms, and perceived control.	Need for contextual validation in Harumanis farming.	Provides theoretical basis for examining behavioral intent.

Figure 3: Literature review summary

Theoretical Framework

The Theory of Planned Behaviour framework (Figure 1) evaluated farming obstacles and barriers to smart practice adoption through the analysis of attitude, subjective norm, and perceived behavioural control constructs. Analysis of interviews with a mango farmer at Harumanis farm identified adoption barriers that initiate each component of the Theory of Planned Behavior.

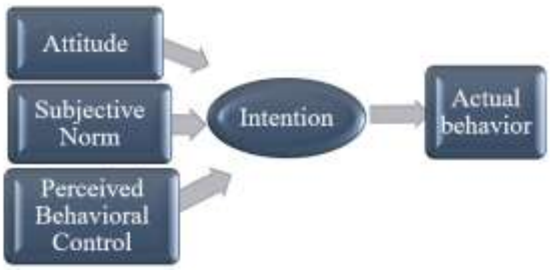

Figure 4: Theory of Planned Behaviour (TPB)

Volume: 10 Issues: 62 [September, 2025] pp. 414 - 430
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Methodology

Sampling Strategy

The study adopts purposive sampling as a research method to purposefully pick one (1) Harumanis mango farmer and one (1) Harumanis mango research expert to achieve objectives of the study (Ken-Giami, 2022). The researchers applied purposive sampling to choose a farmer who matched requirements for accurate and relevant sampling. The study criteria selected a farmer who had engaged in Harumanis mango cultivation for five or more years, while having knowledge or experience of sustainable farming practices and working with farm areas between 2 and 20 hectares. The well-defined selection criteria enabled researchers to collect in-depth insights which offer a critical understanding of agricultural sustainability acceptance among farmers. The research requirements necessitated choosing both a researcher and a farmer who brought specialised knowledge about the Harumanis mango industry practices and field experience of the present production methods. Among all research candidates, the chosen subjects enabled researchers to obtain essential data directly linked to their research requirements. The participants were selected by the program head, after which scheduled interviews were arranged before the fieldwork. The participants provided consent while the interview process ensured their complete confidentiality and anonymity protection. The research team had sole access to audio recordings and transcription files, which were stored in a secure manner. The Human Research Ethics Committee of USM (HREC) provided the study with human ethics approval that used the code USMJEPem/PP/23060524.

Data collection

In-depth interviews with a semi-structured approach were held with two participants: a Harumanis mango farmer and a Harumanis research expert. The researcher successfully gathered comprehensive information from the respondents, who provided detailed insights regarding their experiences and expertise. A small number of participants is frequently used in qualitative research to obtain an in-depth, comprehensive understanding of a given phenomenon. The objective is to gain a thorough grasp of a specific context or phenomenon rather than extrapolating findings from a sample to the entire population (Guest, Namey & Mitchell, 2013; Creswell & Poth, 2018). Getting a comprehensive picture of the participant's perspective on the research topic is the aim of the in-depth interview approach (Milena et al., 2008). This interview portion was carried out in a one-to-one, in-person setting. The Harumanis mango researcher was interviewed for about an hour, while the Harumanis mango farmer was interviewed for around two hours and twelve minutes. Before the data analysis process started, the interviews were verbatim transcribed and audio recorded with both participants' consent.

Data Analysis

The investigation of data will proceed through conventional content analysis methods. Content analysis suits this study because it helps researchers identify recurring themes as well as naturally emerging patterns in semi-structured in-depth interview data related to foreign concepts related to smart farming. The codes were developed inductively from the participants' statements through the transcripts. The researcher builded codes from transcript data that were manually transcribed by selecting themes about environmental sustainability performance and farmers' responses to yield instability, as well as possible origin factors. No software such as Atlas.ti or NVivo was used, but the reliability was ensured through repeated checking and reviews across all themes and codes developed by the research team to ensure accuracy in data interpretation. The TPB and its components regarding attitudes, subjective norms and perceived behavioural control will help analyse how farmers prepare to accept sustainable smart farming

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practices. A methodology will show the merging impacts between environment-related forces and social-psychological elements which determine farmers' decision-making choices. The researcher moves ahead to pick suitable codes that will fit under primary themes, following the coding procedure. Data interpretation will occur after a thorough analysis of the main themes extracted from the collected information.

Limitation

Research derived from studying one case generates significant results, although these results hold restricted implications for greater populations of Harumanis mango producers. Wider research would gain value by conducting additional interviews among agricultural experts and farmers because this would allow for a broader understanding of the examined problems.

Results and Discussions

Environmental Sustainability Performance in Harumanis Mango Production.

a) MyGAP Certification

The MyGAP certification acts as a complete certification system aiming to support Malaysian agriculture and aquaculture and livestock sectors. The Malaysian Standard Crop Commodities serve as basic requirements for carrying out MyGAP with the crop sector module dedicated to Good Agricultural Practices (GAP). Farmlands participating in MyGAP certification must perform strict adherence to seven GAP fundamental elements which encompass proper documentation systems along with plant breeding controls for pesticide management of work environments harvesting operations and irrigation techniques and fertilizer management practices. These operational guidelines work to improve sustainable agricultural system performance. The Harumanis mango farm operates under MyGAP certification protocols by implementing strict standards for all obligatory agricultural practices such as irrigation methods and correct chemical usage and pesticide control. The farm demonstrates its dedication towards sustainable farming approaches through this commitment. Our company earned the MyGAP certification which validates complete adherence to necessary requirements. The mango farm executes MyGAP guidelines from the Department of Agriculture together with Standard Operating Procedures (SOP) following strict adherence to recommendations (Own fieldwork, June 2024).

b) Minimizing Chemical Use

Farmers maintain their dedication to use minimal amounts of chemical inputs by replacing them with organic fertilization methods while permitting only the essential application of chemical fertilizers. The farmers apply only small amounts of calcium carbide for triggering Harumanis mango ripening apart from demonstrating their progressive farming methods. The research expert described how plant hormones act as growth regulators instead of chemical-based alternatives. The farmers maintain high standards by applying limited quantities of pesticides that have government approval for the sake of human well-being and environmental safeguarding (Damalas & Eleftherohorinos, 2011). Farmers adopt Confidor pesticide treatment because of its low dosage approach instead of the standard high-dose pesticide methods used by mango producers in general. The farmers demonstrate their dedication to sustainable practices through this approach in their Harumanis mango cultivation operations. The farmers use the Confidor pesticide as their standard insecticide because it provides the best results to preserve fruit quality. Confidor functions as the top pesticide because farmers use minimal amounts of it during application. Different producers select pesticides which require much

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bigger amounts than those employed by the responder. The company utilizes correct plant hormone-based growth regulators and avoids chemical alternatives for tree management (Own fieldwork, June 2024).

c) Pruning for Tree Health

Regular pruning forms an essential part of the Harumanis mango farmer's method of tree maintenance for achieving optimal growth together with shape and health. The removal of diseased and dead tree branches stops infection spread and protects both plant health and its lifespan. Mango cultivation requires proper pruning because it works as an essential practice to care for trees and boost their fruit yield. The trimming of dead or disease-infected and excessive growth branches functions by decreasing pest intrusion risks and infections to offer better tree health (Cantu, 2019). When done correctly pruning delivers better air flow together with enhanced light penetration throughout the tree canopy and these factors help both fruit development and block fungal infections (Lara, 2022). The MNK Farms team maintains tree health through extensive pruning procedures while avoiding total removal of trees. The pruning techniques renew trees to increase both their strength and production capacity (Interview in June 2024).

d) Waste Reduction and Resourcefulness

Fruits that do not meet the criteria for being classified as premium produce, which account for approximately 20% to 30% of the total fruit production, are not discarded. Instead, farmers seek innovative methods to transform these off-grade fruits into value-added products such as mango chips, puree, juice, and other items. This strategy helps minimize waste while maximizing the utilization of resources. Such practices contribute to the broader goal of resource efficiency in agriculture, aligning with the principles of a circular economy (Ghosh & Singh, 2021). "We aim to transform any misshapen or off-grade mangoes into chips, puree, juice, and even glutinous rice. These efforts are part of our ongoing research and development to reduce fruit waste" (Own fieldwork, June 2024).

e) Innovation of Sustainability

The research expert shared that they are currently investigating the use of microbes to enhance nutrient absorption in solid materials. This approach aims to reduce reliance on chemical fertilizers, thereby ensuring long-term soil fertility and sustainability. The application of microbial consortia has been shown to increase the bioavailability of essential nutrients, which improves soil fertility and reduces the need for chemical inputs (Bashan & Holguin, 2020). "We are currently studying microbes with the hope of formulating them to absorb nutrients beneficial for the soil. That is my aspiration" (Own fieldwork, June 2024).

Farmer Experiences with Yield Instability

The content analysis shows yield stability among farmers includes three primary factors: crop production changes, inadequate growth regulator results, and agricultural sustainability uncertainty.

a) Fluctuation in Production

The yield output of Harumanis mangoes shows seasonal changes according to what the Harumanis mango farmer and research expert documented. Over time, certain years provide higher fruit production yet other years deliver much lower quantities and reach levels up to fifty percent below previous year totals. According to research conducted by Yang et al. (2019) environmental conditions which incorporate temperature and rainfall patterns extensively

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impact fruit crop yield stability resulting in wide variations between peak and trough production years. There is a projected decrease in the second season production of Harumanis mangoes followed by an unknown duration of reduced output during the third season before its expected increase in the fourth season. Other factors being equal the fourth season output should increase because the trees have sufficient carbohydrate reserves. According to information collected in June 2024 the output reaches levels much lower than what was achieved the prior year ("Own fieldwork, June 2024").

Several farmers report witnessing large alternating periods of strong production and weak output besides typical seasonal changes. The farmer said that 2017 brought record-breaking yields before production dropped steeply from 2022 until it made a minor recovery in 2023. Both the farmers and field experts have yet identified the precise factors behind this extended production pattern. The peak in Harumanis yield reached its maximum point during 2017. In 2018, the yield fluctuated until 2022. The production levels from 2022 rose somewhat in 2023. The production shows unpredictable patterns, which we cannot identify the cause of these irregularities (Own fieldwork, June 2024). Research conducted by Singh and Singh (2021) shows that season-to-season variability of fruit yields occurs because of environmental factors as well as changes in climatic conditions. The study confirms that unpredictable fluctuations in farming output result in the pattern of erratic and dramatic production variations that occur between consecutive years. Available data show the same pattern as farmer observations regarding irregular mango output levels and occasional yield drops.

b) Limited Impact of Growth Regulators

Growth regulators that farmers use to enhance flowering and fruiting cannot ensure successful results. The farmers noted that growth regulators offer some assistance for attaining successful harvests yet these treatments prove to be unpredictable in their results. According to Wu et al. (2020) the effectiveness of gibberellin growth regulators depends on exact timing combined with dosage rates along with crop species selection. Our attempt to boost Harumanis fruit growth through growth regulator application resulted in production problems caused by natural genetic characteristics of the tree. The method proved effective after replicating it on a different tree type. The Harumanis tree remains resistant to all attempts at fruit production stimulation. The available evidence from June 2024 fieldwork shows that the Harumanis fruit will produce only during one harvest cycle (own fieldwork, June 2024).

c) Sustainability Is Not Guaranteed

The reliability of production remains uncertain even though farmers follow Standard Operating Procedures (SOPs) with the seven MyGAP-recommended good agricultural practices. The Harumanis mango farmer demonstrated the best agricultural practices with proper soil health inspection alongside Confidor pesticide use and pruning techniques yet production runnings remain uncertain while tree health sustainability becomes unclear. Yearly production of the product remains unchanged regardless of whether the standard operating procedures (SOP) are followed. The MyGAP standard implementation has not stopped Harumanis production from being affected despite our compliance (Own fieldwork, June 2024).

Volume: 10 Issues: 62 [September, 2025] pp. 414 - 430
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Journal website: www.academicinspired.com/ijafb
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Potential causes of yield instability

The analysis revealed multiple yield fluctuation causes grouped into four main sections: natural pointing, environmental elements and pest management complications as well as poor soil conditions (Own fieldwork, June 2024).

a) Genetic Predisposition

According to the Harumanis mango farmer the natural genetic traits that begin at planting might influence mango tree fertility. The farmer thinks that the genetic characteristics of the Harumanis tree help explain its irregular ability to produce fruit. More genetic research among Harumanis mango cultivars would probably resolve the fertility uncertainties that farmers face. The mango tree refrains from yielding fruit during the periods when it should bear fruit. I implemented several methods while informing the department that genome-related causes might be responsible for the situation. Field research conducted in June 2024 indicated that the Harumanis tree remained fruitless since its very beginning therefore possibly responsible for its barren state (Own fieldwork, June 2024). Research by Kumar et al. (2021) supports the farmer's theory about genetic factors determining fruit production capacity and cultivation behavior of the plant. According to Almeida et al. (2022) an analysis of genetic diversity among fruit cultivars yields essential data for yield improvement and resolution of poor fruiting problems. Studies demonstrate that research teams need to examine genetic variations found in the Harumanis mango cultivar because this helps address farmer concerns.

b) Climate Factors

A major difference in daytime and nighttime temperatures plays a critical role in making flowers develop correctly according to the Harumanis mango farmer. The farmer implied that a favorable climate remains essential to get maximum Harumanis mango yields since interruptions to this cycle will hurt production levels. Optimum plant development occurs when the daytime temperatures significantly differ from nighttime temperatures. Plants require expanded temperature variability because it activates hormonal signals for bloom development thus increasing output (Own fieldwork, June 2024). Unpredictable rainfall exposes mango trees to pest damage along with diseases including the 'Kutu Trip' bug because it removes protective pesticide coverage from the surfaces of the trees according to the farmer's description. The farmer must apply pesticides with greater frequency because of this leading to increased production expenses. Unpredictable weather has become a significant problem for mango farmers because it affects pesticide effectiveness which results in increased populations. The farmer applies pesticide before each operation, but unpredictable rainfall destroys the protection through water washout. The improper growth of Harumanis plant shoots occurs because of pesticide wash-off which makes the plant more vulnerable to pests including 'Kutu Trip'" (Own fieldwork, June 2024). Similar to Wang et al. (2021), the farmer confirms that meaningful temperature fluctuation leads to optimal mango flowering. Nair et al. (2018) explain that unpredictable weather events especially rainfall lead to the removal of pesticides through water washes which leaves crops susceptible to pests and plant diseases. The combination of these conditions enlarges both production expenses and harvest reductions according to direct field observations.

c) Pest and Disease Management Challenges

The excessive price of pesticides has led farmers to minimize their usage because they apply pesticides once a month but should do it twice a month according to the farmer. The excessive costs for labor and chemical acquisitions with their subsequent production instability create an elevated risk of pest attacks in the agricultural field. The farmer follows pesticide application

Volume: 10 Issues: 62 [September, 2025] pp. 414 - 430
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every two weeks but carries it out only once a month when plants begin sprouting. The daily wages for at least four labourers expense between RM 70 to RM 100 which amounts to an expensive overall cost (Own fieldwork, June 2024). The high expenses linked to pesticide applications present a widespread agricultural issue that leads to inadequate dosage application. Sharma, Sharma and Pandey (2020) describe financial boundaries as barriers that block regular pesticide applications among farmers resulting in damage to crops and decreased production amounts. Economic constraints limit farmers to use pesticides less frequently according to Feng et al. (2018) which disrupts fruit production quality and intensifies pest control issues. The study confirms what the farmer has experienced regarding costly pesticides and labor requiring insufficient pesticide utilization affecting both mango crop yield and condition.

The readiness of farmers, issues, and challenges in the implementation of sustainable smart farming.

a) Attitude (Reliance on Conventional Practices)

According to the Harumanis mango farmer numerous farmers remain satisfied with current farming techniques since the implementation of even standard sustainable methods demands tremendous work while some farmers do not practice sustainability at all. The farmer showed doubt that local agricultural producers would accept and implement superior sustainable and smart farming methodologies. Numerous farmers show resistance to accept the benefits linked to the promoted technologies. According to Kaliba et al. (2020) elderly farmers adopt new farming practices with extreme caution because they tend to have risks avoidance tendencies. The concerns about sustainable farming practices result from people not knowing their long-term advantages which include higher productivity and improved resource use efficiency as well as better quality fruit.

b) Subjective Norms (Limited Awareness and Lack of Discussion)

During our interview the farmer revealed that his workers showed low knowledge of technological tools including both sensors and drones for smart farming operations in their region. The farmer explained that farmers face minimal social force to implement new technology because they notice few conversations and minimal knowledge about cutting-edge technologies. Workers in his area view advanced farming technology because it appears complicated and costly. Manual operations control our farm since all workers are from the village and elderly. The workers in their area are unfamiliar with high-tech farming sensors because they are not part of the younger generations unlike factory-based employees" (Own fieldwork, June 2024). The slow adoption of smart farming occurs because farmers lack basic understanding about smart technologies while facing resistance from their community due to social pressure. Studies confirm these observations because Tey and Brindal (2012) discovered insufficient knowledge acts as a primary obstacle for new agricultural technology adoption in farming. Rogers (2003) demonstrates that restricted open exchanges and community social impacts between farmers reduce their motivation towards adopting new technology. According to Lee et al. (2019) the absence of widespread peer adoption together with weak social activity among peers impedes individual technological adoption efforts. The data demonstrates that farmers avoid modern agricultural technologies because they lack proper understanding and do not get sufficient social backing.

c) Perceived Behavioral Control

Volume: 10 Issues: 62 [September, 2025] pp. 414 - 430
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The farmer reports their small understanding of smart farming technology because most farm employees come from a rural area and consist of both uneducated elderly workers. The farmer highlighted inconsistent government support for vital agricultural materials such as fertilizers and pesticides together with minimal financial aid as their main concern because the farm must frequently pay for these inputs with their own funds. The monetary limitations existing in Malaysia make it harder to implement smart farming technology since implementing these approaches demands significant financial resources. The farmer noted the government has withheld Harumanis mango subsidy support since a long time. The insufficient government financial backing and ongoing changes in policies create obstacles for farmers to depend on such programs. The farmer noticed that the government devotes more attention to exporting papayas and starfruits instead of sustaining Harumanis mango production. For the present moment the government does not provide any support. Fertilizers were the last assistance farmers received from them in 2018, yet farmers needed to pay partially for the cost. The government authorities maintain frequent changes that result in inconsistent policy structures. The farmer noted during an interview in June 2024 that federal authorities maintain current priority on papaya and starfruit exports rather than Harumanis mango production. The farmer explained there is an elderly workforce on his Harumanis mango plantation due to the fact that few members of the younger generation want to take over the business. The disconnect between generations prevents modern technology adoption since young people who excel at technology avoid agricultural work to pursue city-based career paths. Modern youth choose employment in Kuala Lumpur together with other cities. These Harumanis plantations do not interest the current generation of workers for succession. The present situation shows that every worker employed on the plantation comes from the community and belongs to the older generation according to my field observations during June 2024. The unwillingness of young people to pursue farming while different view of emerging agricultural technologies by senior farmers creates substantial challenges for modern technology implementation. Zhang et al. (2019) mark the division between younger and older generations as the main reason that hinders agricultural practice modernization. According to Liu et al. (2021) younger adults are receptive to technology adoption but their choice of urban occupations blocks them from taking advantage of smart farming innovation. The farmer demonstrated doubt about new technological effectiveness because previous attempts to boost yields produced continuous fruitless results. People have developed a conviction that all attempts including new smart farming techniques are destined to fail. All conceivable measures to produce fruit from the tree have proven unsuccessful while it sometimes delivers only four to five fruits. The farmer doubts whether the upcoming smart farming system will be successful considering all available methods have already been exhausted (Own fieldwork, June 2024). The farmer's previous failed outcomes diminish their control perceptions because they doubt the effectiveness of recently introduced farming technologies. Perceived behavioral control stands as one of the main factors that determines whether people will adopt new technologies according to Ajzen (1991). The repeated failures of farming experienced by farmers results in decreased optimism toward new methods since past results determine their belief systems regarding these interventions. New technology efficiency becomes diminished through self-efficacy failure according to Bandura (1997). The farmers experience constraints from having few resources and knowledge therefore resist implementing new agricultural techniques and practices.

Conclusion

This research studied the sustainability outcomes of Harumanis mango cultivation while evaluating farmer preparedness for sustainable smart agriculture practice implementation alongside their faced difficulties. The long-term yield stability depends on a combination of weather irregularities and management difficulties for pests and diseases together with genetic tendencies. Farmers decide to adopt sustainable smart farming technologies because of their attitudes together with social influences and their assessment of control over the technology which follows the Theory of Planned Behavior (TPB) model.

The study possesses various limitations that need proper recognition. However effective the purposive sampling technique proved to be for gathering deep analysis it established possible selection bias among participants. Future sustainability research should reach out to more extensive populations of farmers to gain complete information regarding sustainable practices together with farmer adoption readiness of smart agricultural techniques. The collected information from the chosen participant fails to reflect the entire range of opinions among Harumanis mango farmers.

The main obstacles uncovered during this research demonstrate farmers' reliance on traditional techniques while society lacks smart farming knowledge and farmers express worry about labor shortages and believe government financial and policy assistance is inadequate. The government along with stakeholder entities should execute multiple policy measures to eliminate these barriers. Government-led public relations initiatives and training programs and financial assistance schemes target to promote smart farming technology awareness and reduce its costs for widespread adoption. The United States dedicated millions of dollars to enhance farm production through water management and fertilization innovations which resulted in new agricultural problem-solving methods (Farooq et al., 2019).
Xie & Huang (2021) advocate for the expansion of information systems while developing trust in sustainable smart farming regulations alongside practical field-level advice. Smart farming technology adoption will require farmers and researchers plus industry professionals to maintain cooperative communication channels for advancing implementation strategies. The combination of Western Mindanao State University (WMSU) with the University of Southeastern Philippines (USeP) proves the benefits of this method for developing crop heat stress monitoring using smart farming technology techniques. The collaborative team searches for an efficient strategy to counter heat stress so producers can reach maximum yields while using minimal resources (Farooq et al., 2019).

The long-term sustainability of smart farming technologies requires the younger generation to participate in Harumanis mango production while utilizing their technological skills according to Tey and Brindal (2012). The adoption of sustainable smart farming depends on solving both social and technical requirements to empower farmers to use these practices for improving resource efficiency while sustaining Malaysia’s Harumanis mango industry long term.

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