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# A Foresight Study on Utilising AI Infrared Camera on Smartphone to Fully Digital Quality Assessment of Vegetables and Fruits Freshness Among Malaysian Farmers

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**Abstract**

Artificial Intelligence (AI) is one of the mechanisms used to detect and read signals or obtain information that humans could not acquire directly. AI infrared cameras can be attached to smartphones that act as a tool to access the usage of infrared cameras. The purpose of this study is to identify the issues, challenges, and trends of utilising AI infrared cameras on smartphones for a fully digital quality assessment of vegetables and fruits among Malaysian farmers. This research also discusses key drivers and the future image of using AI infrared cameras on smartphones to fully digital quality assessment of vegetables and fruits among Malaysian farmers. The target respondents selected are government agencies related to the agriculture sector, and farmers, who consist of 384 respondents. This research utilized foresight instruments such as STEEPV analysis and SPSS analysis. Eight merged key drivers have been identified in this study. SPSS is used to show the results of key drivers and the second research phase with impact-uncertainty analysis. The top two drivers are sustainable and technological advancement. 384 questionnaires were distributed online, and the return rate was 16.15%. The scenario analysis has been formed with the top two drivers, and four scenarios represent the possible future image from 2024 to 2034. Hence, this research aims to help future researchers create awareness of utilising AI infrared cameras in the agriculture sector. A further explanation of the findings is provided below.

## 1. Introduction

This research will introduce the trend and evolution of utilising Artificial Intelligence (AI) infrared cameras on smartphones to fully digital quality assessment of vegetables and fruits among Malaysian farmers. Additionally, the advantages and disadvantages of utilising AI infrared cameras on smartphones for fully digital quality assessment of vegetables and fruits among Malaysian farmers are also discussed. Besides that, research questions, and research objectives will also be explained in detail for this research. In the report of Human Resource Development Corporation, it had stated that Malaysia is gradually converting the traditional method of agriculture farming into the stage of Smart agriculture, which brings out the meaning of “Smart Farming” or “Precision Agriculture (PA)”. This concept focuses on the fundamental management of agriculture businesses using modern technologies such as Artificial Intelligence (AI), Internet of Things (Iot), big data, and others to analyse and monitor the processes of agriculture. Artificial Intelligence (AI) that is being used in infrared cameras can be used in the agriculture sector to detect variations that happen under different temperature circumstances. For instance, infrared cameras help farmers identify areas of crops that have insufficient water or nutrients. This can assist farmers in adjusting the fertilisation practices, leading the crops to be healthier, thus increasing the quality of vegetables and the freshness of fruits. (Still *et al*., 2019).

Fresh fruits and vegetables are major sources of biologically active compounds that are essential for human wellbeing. Fresh fruits and vegetables belong to perishable goods that require certain coordinated actions and environmental factors by growers, storage operators, processors to maintain their good quality and freshness. The incorporation of technology, which is AI could help to keep the freshness of vegetables and fruits. It is crucial for the role players, including growers, shippers, and retailers to maintain the quality and freshness of it to reduce food losses (Mahajan *et al*., 2017). There are a few reasons why the implementation of AI is crucial for the agriculture sector. Traditional farming is still being implemented in Malaysia could be due to the reason of under investment of research and development (R&D) in the sector of agriculture. The reason why investment of R&D declined is due to large number of researchers from crop R&D agency had retired, resulting a loss of considerable knowledge and experience from the expertise (Gert-Jan *et al*., 2020). Additionally, young scientists who are capable are hard to be retained and attracted because the salary level and benefit packages offered were not satisfied. Due to the reason of young youths declining to join agriculture sector with reason of low wages, the age range of farming is now in the peak of ageing farmers and shortage of domestic skilled labour. Foreign workers might not be trained enough in modern farming methods, which will cause difficulties in completing duties smoothly (To & Us, 2023). The implementation of AI in infrared cameras could aid in the identification of potential pest infestations or diseases that would affect the quality of vegetables and fruits' freshness (Ronald Van Loon, 2023). Not only that, the implementation of Artificial Intelligence (AI) in infrared cameras on smartphones could also benefit agriculture from the beginning of the plantation, ranging from irrigation scheduling, crop maturity and yield mapping, soil properties mapping, crop residue cover and tillage mapping, and others (Aryalekshmi *et al*., 2019). Besides that, AI infrared cameras can also be used as a practical and cost-effective tool for monitoring vegetables and fruits freshness in cooling and storage temperatures (Produce, 2022).

However, AI infrared cameras on smartphones also have limitation, the disadvantages of utilizing AI infrared cameras on smartphone to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers is the different type of infrared camera gives different results. Infrared cameras are divided into ios and Android versions, which causes different resolutions of image processing. Based on the issues and limitations that had been discussed, the researcher aims to study the foresight of AI infrared cameras on smartphones to fully digital quality assessments of vegetable and fruit freshness among Malaysian farmers by analysing the relevant issues, challenges, trends, and drivers of change.

This foresight study will be carried out with the view of future with 10 years in the future, which will range from year 2024 to 2034. The current research will focus on each source and information that is relevant to the trend of agriculture and AI infrared camera on smartphone to fully digital quality assessment of vegetables and fruits freshness among Malaysian Farmers. All the related information is collected from various platforms such as news, blogs, journals, articles, and any other platform that can be used for analysis purposes. The respondents of the studies would be Malaysian farmers, agro-technology companies, and government related agencies. Therefore, to achieve this study research objectives, the issues, challenges, trends, key drivers, and future image of utilizing AI Infrared Camera on smartphone to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers.

## 2. Literature Review

### 2.1 Artificial Intelligence (AI) Infrared Camera on Smartphone

An AI infrared camera is a device that can measure the conditions of crops, such as water loss by leaves, through the thermal imaging (Brown & Escombe, 1905). Ever since the introduction of thermal imaging, it has spread worldwide for different purposes and usages. Thermal infrared imaging has grown to become an essential technology; whereby now infrared instruments are no longer only hand-held or sensors with optical systems. Thermal infrared can now be paired with instruments which are portable (Ishimwe *et al*., 2014). The instrument that is used for the thermal infrared camera in this research is a smartphone. The companies that introduced portable infrared cameras that could be attached to smartphones are FLIR, Therm-App, Seek Thermal, and others.

## 2.2 Evolution of Infrared Camera

Thermal imaging technology is a practice that could be used to detect and measure the quantity of heat through the emission of an object based on the wavelength of electromagnetic radiation by infrared radiation. Thermal imaging technology was widely spread only in the 1970s for industrial and medical applications purposes. After that, the use of thermal imaging spread to home improvement and safety applications, such as for firefighters to rescue people who are trapped in smoke-filled rooms. Fast forward to today, thermal imaging technology is being widely used in other fields besides medical and industry due to the development of smaller devices and affordable prices. This advancement had introduced various possibilities of the future where it leads to infinity of new opportunities.

## 2.3 Types of Wavelengths Infrared Camera

Basically, wavelengths of thermal imaging cameras are divided into 3 types: short, mid-wavelength, and long. Special cameras were made to detect these wavelengths that could not be measured manually, which is infrared cameras. Infrared cameras are made to detect light or heat wavelengths depending on the type of wavelengths (Swansey, 2023).

### 2.3.1 Short Wavelengths of Infrared Camera

Thermal imaging cameras with short wavelengths capture infrared wavelengths ranging from 0.9 to 1.7 microns. In terms of shadow and contrast details, short-wavelength thermal imaging cameras have a higher resolution when compared to the visible light spectrum. The visible light spectrum is the segment of the electromagnetic spectrum which the human naked eye can view. Short wavelengths thermal imaging cameras can be used in process quality
control.

### 2.3.2 Mid-wavelengths Infrared Imaging Cameras

Mid-wavelengths thermal imaging cameras can capture the infrared wavelength of 2 to 5 microns that is higher resolution and accuracy compared to short wavelengths. Cameras with mid-wavelengths are usually exposed to the heat signatures of objects, which include living beings, machinery, and even natural elements. For example, mid-wavelength thermal imaging cameras can detect hotspots in an electrical system to prevent objects from overheating.

### 2.3.3 Long wavelengths Infrared Cameras

Long-wavelength thermal imaging cameras capture wavelengths between 7 and 12 microns. Long wavelengths thermal imaging is divided into uncooled and cooled types. Uncooled cameras use microbolometer technology, which is a specific type of bolometer detector to measure radiation through heat absorption. Uncooled cameras are usually suitable for the usage of outdoor activities such as surveillance or security. On the other hand, cooled long-wavelength thermal imaging cameras utilise cryogenically cooled detectors, which help to lower the sensor temperature to extreme levels, which is as low as -196.11 degrees Celsius. Typically, cool long-wavelength thermal imaging cameras are used for demanding tasks which involve the defence and industrial sectors.

## 2.4 AI Infrared Cameras on Smartphones to Fully Digital Quality Assessments of Vegetable and Fruit Freshness

In other advanced countries such as Japan and the United States, thermal imaging is being used in the field of agriculture to allow farmers to understand their crop situation and what steps should be taken to tackle the source. Not only that, the data that is collected through imagery can also provide insight for the government or higher stakeholders to decide on investments (Imaging *et al*., 2023.).

According to the differentiation of types in infrared cameras, the most common and suitable wavelengths that are used for the agricultural sector and quality of vegetables and fruits freshness are short-wavelength infrared cameras. In the field of agriculture, the moisture conditions of soil are the most crucial determinant of process management and quality control (Food *et al*., 2023)

Short-wavelength infrared cameras (SWIR) illumination is opaque in water. It can be used to determine the quality and health of crop health, and product ripeness or even dryness that requires moisture. To determine the water composition of a vegetable or fruit, simply use an AI infrared camera to image it, and if the area of vegetables and fruits is shown with high water composition that appears in a darker image, it could be a signal that signifies that there is a bruise in that vegetable or fruit. Such bruises are not visible with the human eye and can only be seen with the aid of AI infrared cameras on smartphones, which act as a tool to display images. The SWIR cameras also help in grading the quality of vegetables and fruits accordingly (Food *et al*., 2023.).

## 2.5 Advantages of Utilising AI Infrared Camera on Smartphone to Fully Digitalised Quality Access of Vegetable and Fruit Freshness

AI infrared cameras on smartphones offer a wide range of advantages for quality assessment of vegetables and fruit freshness. This study stresses the major advantages of utilising AI infrared cameras on smartphones to fully digitally assess the quality of vegetables and fruits, which include precise irrigation, portability and ease of use for wide-scale adoption, and monitor equipment performance.

### 2.5.1 Precise Irrigation

Precise irrigation is a method of sustainable agricultural approach which enables the application of water and nutrients to be provided to the plants at the right timing and place with accurately measured amounts to provide the optimal growing conditions of crops (Methods & Management, 2023.). It is important for the farmers to evaluate the prior changes of plants by evaluating the reaction of stomata, whether the plant needs water for the canopy temperature within the root zone.

### 2.5.2 Portability and Ease of Use for Wide-Scale Adoption

AI infrared cameras that are connectable directly onto smartphones can access wider fields of scale adoption by attaching them onto unmanned aerial vehicle (UAV) based systems. This enables farmers to have a wider range of vision to collect detailed data on crop health. A wide range of accessibility from aerial imaging can create visual data that assists farmers in detecting issues with vegetables and fruits (Lee & Manager, 2024).

### 2.5.3 Monitor Equipment Performance

AI infrared cameras on smartphones can also be a benefit for farmers by detecting the temperature of machinery that might be overheating or malfunctioning. This information could help farmers know the time to arrange a schedule to repair and conduct maintenance services for the machinery (Blackview, 2023). It is safe to use infrared cameras to detect overheating of equipment because it does not require physical contact to locate the diagnose.

## 2.6 Challenges in Utilising AI Infrared Camera on Smartphone to Fully Digital Quality Assessment of Vegetable and Fruits Freshness

### 2.6.1 Difficulty in Determining the Right Emissivity for Vegetables and Fruits

In infrared cameras, in order to measure the heat radiation by vegetables and fruits accurately, the emissivity of the subject must be determined clearly (Hellebrand *et al*., 2001). To get a perfect emissivity for vegetables and fruits is difficult as every item has a different emissivity. According to past research that is being done by Hellebrand (2001), the emissivity value for vegetables and fruits is close to 0.95. The radiation of vegetables and fruits is highly dependent on the thickness of the water layer, and only these areas will be measured correctly.

### 2.6.2 Dependent on Smartphone

AI infrared cameras depend on smartphones, whereby without them acting as the tool for AI infrared cameras, they could not be used. As we all know, smartphones have limited battery life. Once the battery life reaches its limit of usage, it needs to be charged again for some time before being used again (Leo Wong, 2023).

### 2.6.3 Lower Resolution

When comparing normal hand-held infrared cameras and AI infrared cameras that can be attached to a smartphone, the resolution of AI infrared cameras on a smartphone is generally lower than that of a hand-held thermal camera (Leo Wong, 2023). According to a blog contributor named Adrian Kingsley-Hughes, his review of the drawbacks of using an AI infrared camera on the smartphone is the refresh rate problem. He stated, the time taken for an image to be updated on screen is relatively slow. This issue could be troublesome because the image shown on a smartphone can cause lag when the camera is pointed at an object.

## 2.7 STEEPV Analysis

AI infrared camera has different issues, challenges, and trends that could be categorized following the acronym of STEEPV analysis, which includes social, technological, environmental, economic, political, and lastly value. The information that is separated accordingly is from various sources, which consist of journals, government-related articles, information from the Internet, non-governmental organisations, and others. Under this section, the findings obtained from STEEPV analysis would be used to determine the key factors of utilising AI infrared camera on smartphones to fully digitalise quality access of vegetable and fruit freshness among Malaysian farmers. A total number of eight drivers had been developed through the merging of Key Terms of Issues, Challenges, and Trends. These drivers are formed through merged issues, challenges, and trends as shown in Table 1. The drivers would be used to develop questionnaires for this study.

**Table 1** *Drivers of issues, challenges, and trends*

| No | Issues, Challenges, and Trends | Drivers |
|---|---|---|
| 1. | Conserve Resources, reduce environmental impact, timing crop irrigation, conserve water, sustainable development goals (SDGs), climate change. | Sustainable Crop Management |
| 2. | Modern smartphone-based Infrared Cameras (SBIR), real time monitoring device, useful tool, cost-effective thermal device, cost of the device. | Technology Advancement |
| 3. | Smart Farming, IoT, advanced algorithm, AI driven technology, active infrared thermography, thermal camera on drone. | AI Integration |
| 4. | Real time monitoring device, monitors refrigeration units and storage room, enable fast decision making, enhance productivity and reduce costs, thermal camera on drone, disseminate information. | Real-time Analysis |
| 5. | Market Expansion, open new possibilities, future purchasing behaviour, future development of food detection, bigger profit | New Market Opportunities |
| 6. | Stricter Legislation, regulatory and ethical, quality standard. | Regulation & Legislation |
| 7. | Promoting youth agropreneur, government initiatives and subsidies, intention of domestic farmers, social development, number of persons engaged in agriculture sector | Workforce Requirement |
| 8. | Inadequate management of supply chain, boost quality and quantity, monitor refrigeration units and cold storage room. | Quality Management |

## 3. Research Methodology

### 3.1 Research Design

Both quantitative and qualitative methods will be utilized in this research to have a better understanding. This research aims to analyse the issues, challenges, and trends of using AI infrared cameras on smartphones to fully digital quality assessment of vegetables and fruits freshness among Malaysian Farmers through a mixed-method foresight process. This foresight process utilises qualitative research of STEEPV Analysis, while quantitative methods will use SPSS software to analyse the data collected from respondents through the distribution of a questionnaire to government agencies of the agriculture sector and farmers.

### 3.2 Research Population and Sample

The research population refers to the target population of a study that is being conducted. The targeted population could be in groups, individuals, objects, or events that have the specific requirements that will fulfil the researcher's interest in the area. In this research study, target respondents will consist of Malaysian farmers, agro-technology companies, and government-related agencies. According to the Department of Statistics Malaysia (DOSM), the number of people engaged in the agriculture sector as of 2021 is 496,683. According to the table of Krejcie & Morgan (1970, the population for this research would be 384 samples.

### 3.3 Sampling Method

The sampling technique that would be used in this research study is a purposive sampling method. This is a non-probability sampling method in which specific units with the characteristics needed in the research are selected. Purposive sampling can also be referred to as mixed-method sampling. Purposive sampling's goal is to identify the cases, individuals, or even communities that are best suited to answer the question of the research study (Kassiani Nikolopoulou, 2023). Thus, the purposive sampling method is suitable for studies in which the researcher is clear about the specific requirements needed for the sample of research (Dovetail Editorial Team, 2023).

### 3.4 STEEPV Method

STEEPV Analysis identifies the past and predicts factors that will affect future trends (Austin Black, 2021). STEEPV is an abbreviation for Social, Technological, Economical, Environmental, Political and Values. The advantage of using STEEPV analysis is to discuss the future of the agriculture sector for the drivers and trends of vegetables and fruits. Moreover, the approach of STEEPV also includes analysis that takes articles, books, journal articles, and newspapers into account for future analysis.

## 3.5 Impact-Uncertainty Analysis

This study used descriptive analysis to identify the key driving force. The drivers would be listed according to their importance, impact, and uncertainty. Through a reliability analysis test, the mean of importance, impact, and uncertainty is determined. Then, the top 2 drivers with the highest impact and uncertainty level will be selected to develop scenario analysis. The top 2 drivers that have been identified are Sustainability and Technology Advancement.

## 3.6 Scenario Building

Scenario building was designed to use the top two drivers from impact-uncertainty analysis. The future image of events and trends of AI infrared cameras on smartphones to fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers was broken down into four distinctive alternative scenarios, regardless of outcomes that are favourable or unfavourable. These alternative scenarios represent the four possibilities that might happen in the future of 2024 to 2034.

# 4. Results and Discussion

## 4.1 Survey Return Rate

Based on Table 2, the survey return rate yielded 62 responses, resulting in a 16.15% response rate. The 384 sets of valid questionnaires were distributed through various channels, including email, personal calls, social media through Facebook, WhatsApp, and others. The survey yielded 62 responses out of 384 questionnaires, resulting in a response rate of 16.15%.

**Table 2** *Survey Return Rate*

| Population | Quantity |
|---|---|
| Sample Size | 384 |
| Questionnaire Returned (Valid) | 62 |
| Questionnaire Distributed | 384 |
| Response Rate (%) | 16.15 |

## 4.2 Reliability Analysis

The reliability test was conducted with 15 respondents for the pilot study and 62 respondents for the actual data, and the data result was calculated and presented in the form of values by using SPSS software, as shown in Table 3. There is a total of three parts of the questionnaire that were being tested in this pilot and the actual study.

**Table 3** *Reliability of Pilot Test and Actual Study*

| Factors | Cronbach's Alpha Value | | | |
|---|---|---|---|---|
| | Pilot Study | No. of Respondents | Actual Study | No. of Respondents |
| Level of Importance | 0.84 | 15 | 0.75 | 62 |
| Level of Impact | 0.82 | 15 | 0.73 | 62 |
| Level of Uncertainty | 0.90 | 15 | 0.85 | 62 |

## 4.3 Demographic Analysis

Table 4 describes the demographic background of the respondents who are from government agencies of agriculture, agri-technology companies, and farmers in Malaysia. The demographic analysis was conducted to describe the tabulation of the respondents. Demographic analysis consists of gender, age, years of experience, whether respondents had heard about Artificial Intelligence (AI) Infrared camera that can be attached to a smartphone, and whether they would consider utilising technology to transform into "Smart Farming" in the future. The demographic breakdown indicated a total of 62 respondents contributed their knowledge in this research, prevailing male majority (54.8%), with the predominant age group of 41-50, and 50 and above (29%).

23 out of 62 respondents had the experience of farming between 4-6 years (37.1%). 28 respondents (45.2%) are aware of an AI infrared camera that can be attached to a smartphone, and 48 people (77.4%) are positive about transforming into "Smart Farming" in the future.

**Table 4** *Demographic Analysis*

| No. | Characteristics | Category | Frequency | Percentage |
|---|---|---|---|---|
| 1. | Gender | Male | 34 | 54.8 |
| | | Female | 28 | 45.2 |
| 2. | Age | 20-30 | 15 | 24.2 |
| | | 31-40 | 11 | 17.7 |
| | | 41-50 | 18 | 29 |
| | | 50 and above | 18 | 29 |
| 3. | Races | Malay | 22 | 35.5 |
| | | Chinese | 24 | 38.7 |
| | | Indian | 16 | 25.8 |
| 4. | Which Type of plantation are you planting? | Vegetable | 29 | 46.8 |
| | | Fruits | 29 | 46.8 |
| | | Oil Palm | 3 | 4.8 |
| | | Policy Maker | 1 | 1.6 |
| 5. | Years involved in the field of agriculture | 1-3 | 15 | 24.2 |
| | | 4-6 | 23 | 37.1 |
| | | 7-10 | 15 | 24.2 |
| | | 10 years and above | 9 | 14.5 |
| 6. | Have you heard about Artificial Intelligence (AI) Infrared Camera that can be attached onto smartphone? | Yes | 28 | 45.2 |
| | | No | 34 | 54.8 |
| 7. | Have you considered utilizing technology to transform into "Smart Farming" in the future? | Yes | 48 | 77.4 |
| | | No | 14 | 22.6 |

## 4.4 Descriptive Analysis of Drivers

This section discusses eight drivers that have been voted based on three aspects: importance, level of impact, and level of uncertainty. The result of the driver will be presented based on the mean scores. The impact-uncertainty analysis approach was constructed to determine the top two drivers that contributed the most significant impact and uncertainty in the future. Table 5 shows the comparison between mean values for eight drivers based on their level of impact and uncertainty. The main purpose of having this analysis is to identify the top two drivers that have the highest outcome of level of impact and uncertainty. Table 5 below shows the graph of impact-uncertainty analysis based on the eight drivers.

**Table 5** *Mean value of the eight Drivers on Level of Impact and Uncertainty*

| No | Drivers | Mean Value | |
|---|---|---|---|
| | | Level of Impact | Level of Uncertainty |
| D1 | Sustainable Crop Management | 4.23 | 3.89 |
| D2 | Workforce Requirement | 3.92 | 3.63 |
| D3 | New Market Opportunities | 3.87 | 3.77 |
| D4 | Regulation & Legislation | 4.08 | 3.66 |
| D5 | Technology Advancement | 4.23 | 3.98 |
| D6 | AI Integration | 3.90 | 3.73 |
| D7 | Real-time Analysis | 3.94 | 3.89 |
| D8 | Quality Management | 3.97 | 3.79 |

## 4.5 Impact-Uncertainty Analysis

Fig. 1 shows the impact-uncertainty analysis. The decision of having the highest level of impact and uncertainty will be based on the two most significant impact and uncertainty drivers. Coordinate D1 (4.23, 3.89) for Sustainability and Coordinate D5 (4.23, 3.98) for Technology Advancement were selected. This is because D1 is the driver that has the highest level of impact, whereas D5 has the highest level of uncertainty. Hence, these two key drivers were chosen as the top key drivers that are used to construct scenario-building analysis.

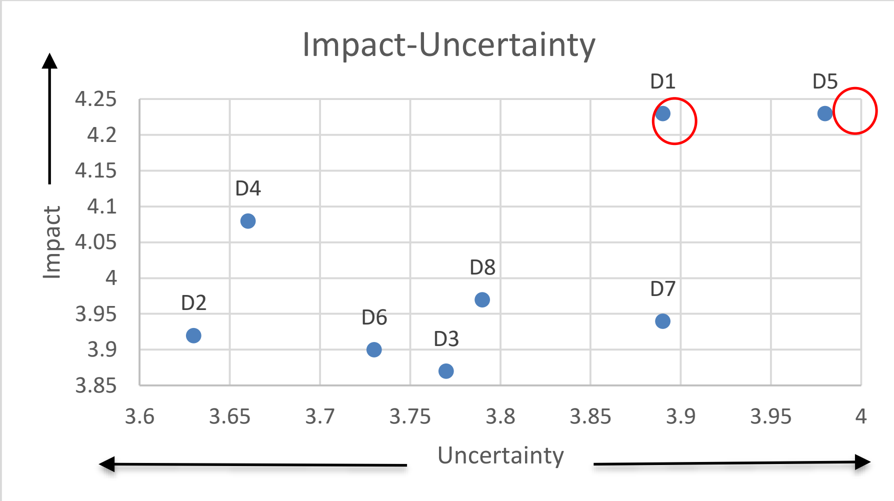


**Fig. 1** *Impact-Uncertainty Analysis*

## 4.2 Discussion based on the First Research Objective

This study had generated two objectives that act as a guidance for the researcher to understand and be clear about the next step that must be achieved in this study. The primary objective of this research is to use STEEPV analysis to identify the issues, challenges, and trends in utilising Artificial Intelligence (AI) Infrared camera to fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers. STEEPV analysis had assisted researchers in utilising AI Infrared camera in Malaysia in facilitating the evaluation of data in a simpler manner. As Malaysian farmers are still in the process of evolving to "Smart Farming", it is critical that agriculture sector professionals understand the advantages, issues, and challenges before applying it to the Malaysian agriculture sector. Therefore, several issues and challenges are identified before an organisation decides to adopt this technology into the agriculture sector. The first objective was achieved, whereby eight key drivers were identified to complete the second objective.

## 4.3 Discussion based on the Second Research Objective

Based on the STEEPV analysis, the issue, challenges, and trends are merged into key drivers, and eight key drivers were identified. The drivers include "Sustainable", "Workforce Requirement", "New Market Opportunities", "Regulation and Legislation", "Technology Advancement", "AI Integration", "Real-time Analysis", "Quality Management". Later, these drivers will undergo impact-uncertainty analysis by using SPSS software to calculate the means. Impact-uncertainty analysis is conducted to determine the feasibility and reliability of utilizing AI infrared camera to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers. Based on impact-uncertainty analysis, only two primary drivers that have the highest level of impact and uncertainty are used to fulfil the third objective, which is to foresee the future image of utilising AI infrared camera to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers. Eight drivers were identified through the STEEPV Analysis. Then from there, the drivers that has the highest level of impact and uncertainty would be chosen for the consideration of utilizing AI infrared camera to fully digital quality assessment vegetable and fruits freshness among Malaysian farmers.

The key driver of "Sustainable" has the highest impact and most uncertainty drivers compared to the other drivers. It had the highest value of 3.89 and 4.23 in impact-uncertainty analysis. Sustainable agriculture practice is important to reduce the negativity of environmental impact. The ecosystems, biodiversity, and natural resources could be protected if sustainable agriculture is conducted. To achieve the sustainable agriculture policy in Malaysia, it is important to have the support of the government (Ed Asscheman 2023). The government can provide initiatives and subsidies to promote the adoption of precision agriculture to help farmers invest in technology that not only enhances their productivity but also maintains the sustainability of farming in Malaysia.

Sustainability is important for the agriculture sector because it would help to conserve resources and reduce the emissions of greenhouse gases, which are harmful to our environment. The conditions of plantation are closely related to the factors of environment such as temperature, humidity, and others. Therefore, to the quality and freshness of vegetable and fruits, it is essential for farmers and related agencies to be fully aware of the importance of sustainability for agriculture sector.

The second highest impact-uncertainty of utilization of AI Infrared Camera that can be attached onto smartphone compared to other drivers is "Technology Advancement." The value of the driver is 3.98 and 4.23 in impact and uncertainty respectively. Majority of the responses from the respondents has an unclear view of the technology advancement of utilizing AI infrared camera to fully digital quality assessment vegetable and fruit freshness among Malaysian farmers in the future development of Malaysia's agriculture sector. In the era whereby technology is rapidly evolving and changing, most of the industries are now adopting advanced technologies in respective fields, and agriculture sectors is also one of them. "Smart Farming" is one of the examples whereby advanced technologies are being applied and developed to optimize agricultural production (Gomstyn & Jonker, 2023).

The implementation of AI in infrared camera brings great impact on agriculture sector. This is because the quality of vegetable and fruits freshness can be benefited by AI infrared camera starting from the beginning of plantation from yield mapping, irrigation scheduling, crop maturity, and others. (Ronald Van Loon, 2023). With the utilization of AI infrared camera on smartphones, the burden of farmers could be eased as conditions of vegetables and fruits can be examined using AI infrared camera acting as a tool to monitor cooling and storage temperatures (Produce, F. 2022). This is because AI infrared camera can be used to detect overheating machinery that is overheating or malfunctioning, whereby farmers can utilize this technology to impose maintenance service at the right time. It is aware that Malaysia is currently working hard on utilizing latest technology to implement knowledge-based production system to improve agriculture sector (Salleh & Yusof, 2006). Therefore, if Malaysia decides to revolutionise traditional farming into "Smart Farming" with technology advancement by considering adding on AI infrared camera that can be attached onto smartphone in agriculture sectors, it will surely be able to expand the field of agriculture dramatically from the aspects of quality, management of vegetables and fruits in the future.

## 4.4 Discussion based on Third Research Objective

To achieve the third objective, scenario analysis was conducted. In this analysis, four different scenarios had been formed based on the top two drivers which had been identified earlier, which is D1 (Sustainable), and D5 (Technology Advancement). These scenarios had outlined the future image of utilizing AI Infrared Camera on smartphone to fully digital quality assessment of vegetables and fruits freshness among Malaysian Farmers. Four different scenarios have been formed based on the top two key drivers from impact-uncertainty analysis, D1 (Sustainable), and D5 (Technology Advancement). These scenarios highlight the potential trajectories of utilizing AI infrared camera to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers from 2024 to 2034. Fig. 2 depicts different possibilities for the future of AI infrared cameras, ranging from smart sustainability to sustainability disruptions. These outcomes will be analysed to outline the favourable and unfavourable future image of utilizing AI infrared camera to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers.

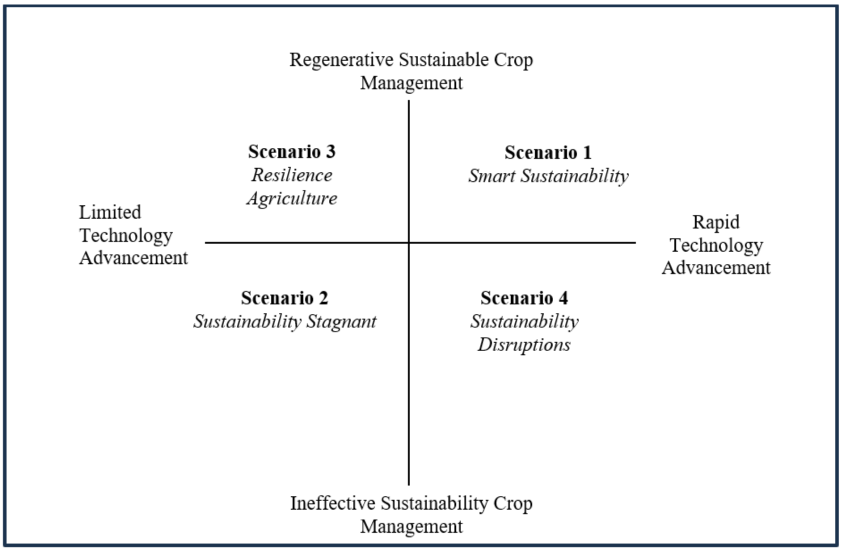


**Fig. 2** *Future Scenario Analysis*

### 4.4.1 Scenario 1 "Smart Sustainability"

The first scenario took place where there is an improvement in regenerative sustainable crop management and rapid technology advancement. This combination shows the way on how smart sustainability is started, signifying the starting of an era whereby the utilization of AI Infrared to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers could emerge as a new technology to enhance agricultural sectors. As highlighted by the report of Human Resource Development Corporation (2021), Malaysia is slowly shifting from traditional method of agriculture farming into "Smart Sustainability". This scenario will show how traditional farming could transform into new agricultural methods by the utilization of advanced technology.

The starting point is crucial to advance in the technological area. Government has to be the one taking initiative to plan and make changes on how to convert traditional farms into modern farms by utilizing the knowledge-based production system (Salleh & Yusof, 2006). Malaysia, which is a developing country are also looking at things positively by adding on modern technologies into agricultural practices by implementing National Food Security Policy Action Plan 2021-2025 and the National Agrofood Policy 2021-2030 (Hazlin Hassan, 2023).

Artificial Intelligence (AI) Infrared camera could assist the agriculture sector in many ways. For instance, AI Infrared camera can provide real-time analysis conditions of vegetables and fruits by using short wavelength infrared cameras. The spoilage of vegetables and fruits could be detected in the early stage where it could not be seen with the naked eyes. With the help of AI Infrared camera, it can detect the spots that have the highest moisture which indicates excessive water. It is very important for farmers to detect the bruises of vegetables and fruits in the early stage by analysing the degree of bruising because it could ensure the accuracy of grading, thus minimising the economic losses (Du *et al*., 2020).

However, from an environmental perspective, regenerative, sustainable crop management and rapid technology advancement in utilising AI infrared cameras also bring potential impact towards the environment. The rapid technology advancement could improvise the condition of sustainability in growing crops by identifying the actual needs of soils and crops to reduce environmental impacts for the farm, and precision agriculture could be done. (Basso *et al*., 2016). For instance, precision agriculture will provide the most accurate timing and application of water and nutrients for the plantation to provide an optimal growing condition (Mushtaq *et al*., 2024). The improvement of high technology in the agriculture sector can ultimately improve and solve most of the issues regarding sustainability and environmental impact. Therefore, farmers and related agencies must develop an agricultural process that optimises an innovative farming method that could guarantee arable and environmental resources, improving the condition of sustainability for growing crops of vegetables and fruits with quality freshness (Gerhards *et al*., 2019).

In the highlight of regenerative sustainable crop management and rapid technology advancement, this scenario is the fit to be deployed in utilizing AI infrared camera to fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers. The strong technology advancement provides a real-time analysis of vegetables and fruits, guaranteeing the quality of freshness. At the same time, rapid technology advancement also emphasises precision agriculture whereby crops can get the right amount of water and nutrients without damaging the ecosystem and causing harm to the environment. Excessive usage of fertiliser not only damages the condition and health of soil, but also will cause wastage of water flowing. The combined effect of regenerative sustainable crop management and rapid technology advancement will drive the utilisation of AI infrared camera to fully digital quality assessment of vegetable and fruit freshness among Malaysian farmer in the future. The greater the dependability and efficiency that is shown by AI infrared camera in the agriculture sector, the more it will enhance the public acceptance among Malaysian farmers, thus paving the path for the agriculture sector's acceptance of AI infrared camera.

In this study, questionnaires are used to measure the level of operational performance among manufacturing industry. There are seven Likert Scale questions, and the answers will be examined descriptively. The replies' ratings are averaged, and the findings are used to assess the level of operational performance. The score was assigned depending on whether the respondents strongly disagreed, disagreed, slightly agreed, or strongly agreed.

The capacity to adjust product mix had the highest mean rating, with a mean value of 4.49. Meanwhile, the lowest mean was 4.22 for product durability, production throughput time, and the flexibility to adjust delivery date. The perceived overall product quality comes in second with a mean value of 4.40. The mean value for responding quickly to customer concerns was 4.38, while the mean value for achieving delivery deadlines was 4.31. The average mean value for operational performance was 4.3206. As a result, Batu, Pahat's manufacturing industry should increase their operational performance. Investing in employee training programs to increase skills and knowledge, for example, can result in a more skilled workforce, which leads to higher production and output. Furthermore, increasing employee participation and engagement can boost morale and efficiency.

### 4.4.2 Scenario 2 "Sustainability Stagnant"

At this stage, this is the most undesirable and worst scenario for the future of utilising AI Infrared camera to fully digital quality assessment freshness of vegetables and fruits among Malaysian farmers. Sustainability stagnant occurs when there is a limited technology advancement coincides with ineffective sustainability crop management. It would be a very challenging future for agriculture sector if this situation happens because it will lead to the issue of resource exhaustion, whereby farmers had used up all the available resources they could afford yet agriculture sector remains stagnant. Without the effort of improved innovation and effective management, environmental degradation worsens. Therefore, this scenario shows the importance of technology advancement to maintain a sustainable environment. With the absence of technology, the agriculture sector could only remain farming with traditional method, without any improvement. As mentioned by United Nations, the most difficult task to achieve the second Sustainable Development Goals, which is "End hunger, achieve food security, improved nutrition, and promote sustainable agriculture."

The scenario showed that AI infrared camera in agriculture sector is unreliable. If agriculture sector decides to implement it in the future, it may cause a few issues towards the agriculture sector. If there is a limited technology advancement, farmers will stop improving themselves in plantation and just go on with the traditional method such as depending on sun, rain, soils, and animals to improve the growth of vegetables and fruits. The knowledge of using traditional method for farming is usually passed down by older generations. (Eleanor Telling, 2022). As traditional farming do not rely on technology, farmers are not able to obtain the real-analysis data of vegetables and fruits, which it may cause farmers to water and provide nutrient based on their intuition, and crops could wither due to excessive water.

Moreover, without the integration of AI infrared cameras to detect the temperature of machinery, the agriculture sector experiences overheating or malfunctioning of machinery. If a machine malfunctions, it would cause the efficiency of agriculture activities to be lowered, and the time consume for plantation could be longer. Machinery of refrigeration units and cold storage room could also be affected because it storage room and refrigeration units are used to monitor the optimal conditions of vegetable and fruits, to ensure the quality of fruits are being maintained in a good manner (Pathmanaban *et al*., 2020).

These impacts are the evidence why agriculture sector in Malaysia falls behind even though agriculture provides economic benefits to the country. This will result in agriculture sector to lose the opportunity to enhance efficiency, reduce environmental impact, and to change traditional farming practices into "Smart Farming".

### 4.4.3 Scenario 3 "Resilient Agriculture"

This scenario happens when there is regenerative sustainable crop management and limited technology advancement towards the utilisation of AI infrared camera to fully digital quality assessment of vegetables and fruits freshness among Malaysian farmers. The focal point of the agriculture sector would be sustainable efforts. It integrates sustainable practices such as regenerating resources to ensure a long-term productivity of vegetables and fruits with the minimisation of technological advancements. Resilient agriculture mostly prioritises the sustainability of environmental health. Farmers utilise limited technology advancements by using natural pest control in order to maintain their soil health and productivity by optimising mixed cropping, or crop rotation. These two methods do not utilizes much technology, which is suitable for farmers who are conscious about sustainability of vegetable and fruits crops.

The changing of climate change, optimising water use in agriculture is one of the key components whereby limited technology advancement is used, yet regenerative and sustainable practices are being conducted. For instance, to produce more quality vegetables and fruits, it is advisable for farmers to understand and have knowledge in food system transformation. (International Potato Centre 2023). Food system transformation aims to create a sustainable and resilient food system that be suitable for the needs of current sustainability.

The limitation of technology advancement causes irrigation scheduling to not go according to the plan. as the smartphone that acts as a tool to assist in identifying plantation conditions could not be functioned. Then, farmers could not determine the right amount of water that should be provided for the plantation, causing over-use of water, affecting the conditions of soil and wasting water usage which is not a sustainable practice. Precision tools may also misinterpret data when there is a glitch or a data breach.

### 4.4.4 Scenario 4 "Sustainability disruptions"

This scenario happens when there is rapid technology advancement, yet ineffective sustainability crop management. Sustainability disruptions arise when there are challenges, events, or any changes that hinder the ability system to maintain sustainability goals. These disruptions could be due to mismanagement of technology, resource depletion, and other factors.

The rapid technological advancement has no doubt improved the process of agricultural farming methods because the utilisation of AI infrared cameras could help in crop monitoring, precise irrigation, and more. But, the utilisation of AI infrared cameras must be developed and optimised further to ensure the availability of global food. This is because the land and environment may have already reached the limit of sustainability (Gerhards *et al*., 2019). If farmers do not follow the right farming method, such as optimising water use and minimising the excessive use of fertiliser, then it would cause an environmental impact towards sustainability.

As an AI infrared camera is dependent on the smartphone, which acts as a tool, the usage of an AI infrared camera is also limited. The smartphone has to be recharged again once the battery life is up (Leo Wong, 2023). This brings inconvenience as efficiency would be slowed down. According to a blogger's post that reviews the usage of AI infrared cameras, he also revealed that smartphone faces the problem with refresh rate.

This could affect the data accuracy, whereby farmers could not determine the right amount of water, nutrients, or the correct timing to deploy water irrigation. Excessive nutrients and water could also cause the occurrence of ineffective sustainability.
goods meet or exceed customer expectations.

## 5. Conclusion

In a nutshell, this study has identified the issues and drivers of the utilisation of AI infrared cameras for fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers. Conducting a foresight study on the utilisation of AI infrared camera to fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers unveils the emerging trends that could help in revolutionising the future of the agriculture sector in future, regardless of the timeline. Not only that, but this research also offers novel insights and perspectives from respondents who have vast information and knowledge regarding the utilisation of AI infrared cameras for fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers.

The top two key drivers that were identified through impact-uncertainty analysis have also been utilised to construct a scenario-building analysis. This approach has led to the development of four scenarios with the aim of determining the future landscape of utilisation of AI infrared camera for fully digital quality assessment of vegetable and fruit freshness among Malaysian farmers. Sustainability and technology advancement both have a strong relationship to evolve the farming method of the agriculture sector.

These two drivers have also created an ideal scenario labelled “Smart sustainability” whereby both sustainable and technological advancement could be emphasised together to transform the agriculture sector. Subsequently, scenarios such as “Sustainability Stagnant”, “Resilient Agriculture”, and “Sustainability Disruptions”. In conclusion, it is very important to take note that whenever there is a new technology that is being planned to be implemented, there are challenges and limitations. Therefore, both the government and private sectors should collaborate and offer support for each other to foster the development of new technology that can be implemented in Malaysia sooner in the future.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Adeline Tay Yu Xian and Nor Kamariah Kamaruddin;* ***data collection:*** *Adeline Tay Yu Xian and Nor Kamariah Kamaruddin;* ***analysis and interpretation of results:*** *Adeline Tay Yu Xian and Nor Kamariah Kamaruddin;* ***draft manuscript preparation:*** *Adeline Tay Yu Xian and Nor Kamariah Kamaruddin. All authors reviewed the results and approved the final version of the manuscript.*

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