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The impact of food security concept, supply and demand management, domestic agriculture, and agricultural technology on Malaysia's food security: A Delphi expert consensus approach

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Abstract

This study examines how food supply and demand management, domestic agriculture, agricultural technology, and conceptual understanding of food security influence Malaysia's food security, aiming to align strategies with SDG2 (Zero Hunger) by 2030. A two-round Delphi method with 33 experts from Malaysia's public and private sectors was used in this study. Qualitative insights and quantitative analyses (e.g., Kendall's Coefficient) determined consensus on the relative importance of these dimensions. Experts identified robust food supply and demand management, strengthened domestic agriculture, and the adoption of advanced agricultural technologies as key drivers for improved food security. Although conceptual understanding is essential, it was ranked as the least critical factor. The study provides practical recommendations for policymakers, emphasizing targeted investments, improved logistics, and technological innovation. The findings contribute to food security research by offering a structured, expert-driven framework for addressing Malaysia's food security challenges. This consensus-driven approach offers a unique, expert-validated model that contributes to both academic literature and practical policy formulation in the context of Malaysia's evolving food security challenges.

Keywords: Agriculture technology, Agriculture, Delphi technique, Food security, Supply and demand, Zero hunger.

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1. Introduction

Agriculture is the backbone of every country, providing the essential necessity of food. With sufficient food production, governments can focus on broader development. Food shortages, as seen during the pandemic, cause significant challenges, including public distress. The United Nations' SDG-2 aims to end hunger, improve nutrition, achieve food security, and promote sustainable agriculture. However, Malaysia faces major challenges in meeting this goal, with progress stagnating. To address food security issues, the government needs to understand its complexities, manage the food supply chain efficiently, and actively engage in the agriculture sector. This includes overseeing the entire process from seed sowing to food distribution, enabling effective solutions to food crises.

The Agricultural Producer Price Index (PPI) rose by 18.9% between January 2020 and June 2024, highlighting increased production costs affecting food security (Refer to Figure 1). Additionally, food prices surged by 19% from January 2021 to July 2022, with maize and wheat prices rising by 15% and 24%, respectively, according to the Department of Statistics, Malaysia (DoSM). Since Malaysia imports 100% of its maize and wheat, global food market trends underscore the urgency of food self-reliance. Understanding food security issues in Malaysia is crucial to overcoming the ongoing crisis and achieving SDG2.

The UN Food System Summits aim to improve food security by making it healthier, safer, more sustainable, efficient, and equitable by 2030 [1]. Food security is commonly defined as the physical and economic access to food, with key components being availability, stability, accessibility, and utilization [2]. The FAO further emphasizes ensuring sufficient, safe, and nutritious food for all to support a healthy life [3].

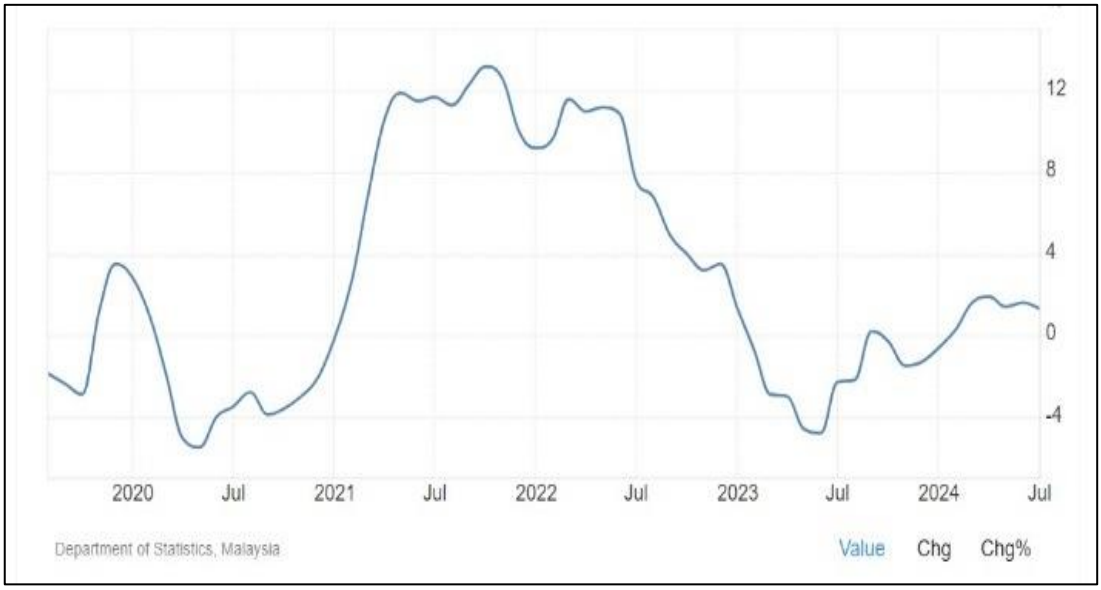

Figure 1.
Producer Price Index (PPI) of Malaysia from 2020 to 2024.

Malaysia has implemented short- and long-term measures under the National Food Security Policy to address these challenges [4]. These strategies are vital as the country continues to import food worth 78.79 billion Malaysian ringgit (Malaysia Import Value of Food 2023, refer to Figure 2) while struggling to meet domestic production demands (refer to Table 1).

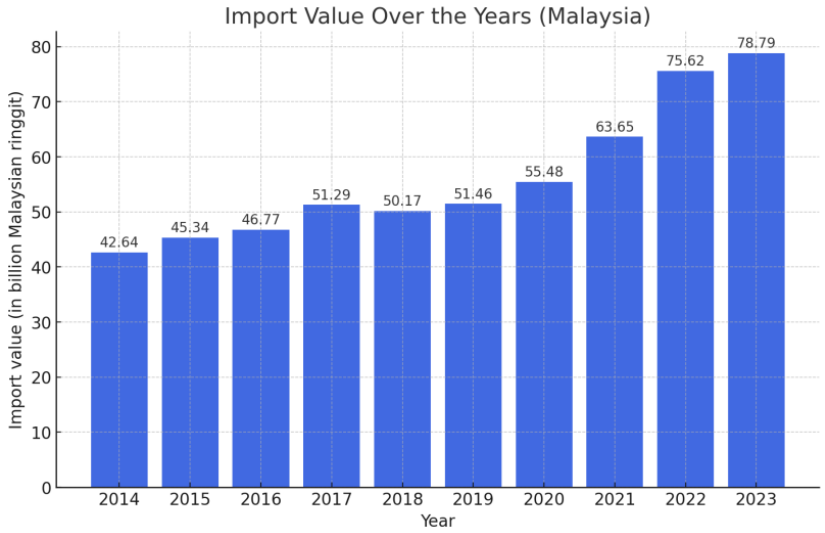

Figure 2.
Import Value of Food in Malaysia from 2014 to 2023.
Source: Statista [5].

In 2023, the import value of food to Malaysia was approximately 78.79 billion Malaysian Ringgit (MYR), an increase from 75.62 billion Malaysian ringgit in the previous year. The value of food imports has been increasing steadily since 2014, from 42.64 billion.

Table 1.
Percentage of current production that meets domestic requirements in Malaysia.

Commodities	Production that meets domestic requirement (%)
Vegetable	44
Fruit	78
Liquid Milk	63
Beef Production	22
Poultry meat, eggs, fish, and pork	90
Chili	31
Round cabbage	37
Sweet potatoes	75
Coconut	34

Malaysia: Import Value of Food 2023.
Source: Statista [5].

Malaysia to this date continues to import 58% of the food that it consumes. Effective food supply and demand management is a key factor in achieving food security [6]. The food value chain extends beyond production to include value-adding processes that create edible products [7]. Food supply management covers farm production, logistics, and trade, ensuring food reaches consumers efficiently [8]. Additionally, sustainable agriculture plays a vital role in food security, as local production offers more direct, affordable, and accessible food sources. Conservation agriculture should also be practiced to maintain soil and water health.

Malaysia's limited adoption of advanced agricultural technology hinders food security. Rising production costs reflected in an 18.9% increase in the Producer Price Index from January 2020 to June 2024, challenge farmers' profitability. Barriers such as high initial costs, lack of knowledge, and insufficient government support prevent smallholders from adopting modern farming technologies [9]. Additionally, inadequate training underscores the need for better farmer education in contemporary agricultural practices. Strengthening the agricultural sector requires integrating innovative technologies, enhancing financial incentives, and expanding training programs to improve efficiency [10].

Food security is a multifaceted issue requiring a holistic approach that includes a strong supply chain, support for local producers, technological advancements, and proactive government interventions [4, 11]. Despite over 700,000 hectares of agricultural land, Malaysia struggles to meet domestic demand due to climate change, information gaps, and supply chain inefficiencies. Addressing food security requires a focus on availability, accessibility, utilization, and stability [2, 12, 13].

This research underscores the role of agricultural technology in boosting local food production and reducing import dependence. Strengthening the agricultural sector helps Malaysia navigate global market fluctuations while ensuring food quality and quantity. Ultimately, this study enhances understanding of Malaysia's food security challenges and provides research-based policy recommendations for policymakers, stakeholders, and the public. By employing a two-round qualitative Delphi method, the study examines the links between food security, supply chain management, domestic agriculture, and agricultural technology [14]. These insights aim to guide sustainable strategies that ensure a stable, nutritious, and accessible food supply for all Malaysians, aligning with the Sustainable Development Goals.

1.1. Research Objectives

This study aims to identify key factors that positively influence Malaysia's current and future food security. The specific research objectives are:

i. To analyze the relationship between the concept of food security and its application in Malaysia.
ii. To examine the impact of food supply and demand management on food security in Malaysia.
iii. To assess the relationship between domestic agricultural production and food security in Malaysia.
iv. To evaluate the role of agricultural technology in enhancing food security in Malaysia.

2. Literature Review

Agriculture is crucial for Malaysia's food production and stability [15]. The COVID-19 pandemic exposed vulnerabilities in supply chains, emphasizing the need for adaptive food strategies [16]. Food security extends beyond availability to include variety, nutrition, and accessibility. Despite Malaysia's vast land and biodiversity, achieving SDG 2 - Zero Hunger- remains challenging, with progress stagnating. Food security is also linked to poverty eradication (SDG 1) and public health (SDG 3), requiring integrated policies. While technology offers solutions, local communities must adopt innovations for sustainability. Malaysia's reliance on food imports, according to the Department of Statistics, totaling RM 482 billion in the past decade, has weakened its food security. Dependence on imports for essentials like dairy, wheat, and meat, coupled with global crises, has led to supply shortages. Consequently, Malaysia's Global Food Security Index ranking declined from 40th to 41st post-pandemic [17].

2.1. Theoretical Framework

Rising food prices and geopolitical crises have worsened food insecurity, affecting 828 million people in 2021 [18]. Building resilient food systems requires technology, strategic policies, and stakeholder collaboration [19, 20]. Strong government support, including agricultural investment, quality monitoring, and technology adoption, is essential [2]. Bridging theory and practice is critical to achieving a sustainable and resilient food system [21]. This study adopts four key theories from previous research to analyze the independent variables related to food security in Malaysia:

2.1.1. Systems Theory

Developed in the mid-20th century by Bertalanffy [22], Systems Theory views food security as a dynamic system composed of interrelated economic, environmental, and social subsystems. This approach allows for a comprehensive understanding of how these interconnected elements influence food security. By involving experts from economics, agriculture, and environmental science, policies can be formulated to address these interlinkages effectively [23].

2.1.2. Innovation Diffusion Theory

Rogers [24] Innovation Diffusion Theory (1962) explains how new ideas, technologies, and practices spread within a society. This theory is relevant to understanding how agricultural innovations are adopted and integrated into Malaysia's food security strategies. It provides a framework for assessing the role of agricultural technology experts and the implications of adopting innovative farming practices to mitigate food security deficiencies [25].

2.1.3. Sustainable Development Theory

First introduced in the Brundtland Report (1987) by Brundtland [26], Sustainable Development Theory emphasizes meeting present needs without compromising the ability of future generations to meet their own. The theory integrates social equity, environmental conservation, and economic growth—three pillars that support long-term food security. It highlights the need for sustainable agricultural practices, the role of technological advancements in food production, and their impact on environmental health [27].

2.1.4. Resilience Theory

Developed by Holling [28], Resilience Theory focuses on how systems absorb shocks and recover from disruptions. Initially applied to ecological systems, the theory has since been expanded to include social and economic contexts. In food security research, it helps assess how Malaysian agriculture can enhance resilience against shocks such as climate change, supply chain disruptions, and economic instability. It also provides insights into how specific technologies and practices can strengthen the stability of Malaysia's food system [29].

By integrating these four theories, such as Systems Theory, Innovation Diffusion Theory, Sustainable Development Theory, and Resilience Theory, this study provides a comprehensive framework for analyzing food security in Malaysia. These perspectives help examine the role of agriculture, technological adoption, sustainability, and resilience in ensuring a stable food supply for present and future generations.

2.2. Review of Variables

2.2.1. Food Supply and Demand Management

Food supply and demand management spans production to consumption, involving farmers, processors, distributors, and consumers [12]. Global crises like the Ukraine war and COVID-19 have disrupted supply chains, limiting movement, workforce availability, and food accessibility [30, 31]. These disruptions affect cultivation, livestock management, and transportation, threatening food security [32, 33]. Effective management ensures food stability by increasing crop yields, improving storage and transport, and promoting fair distribution, diet diversity, and reduced waste [34]. Balancing supply

and demand stabilizes prices, prevents malnutrition, and supports SDG 2 and SDG 3, while international trade mitigates shortages [35]. Malaysia's RM55.5 billion food import reliance in 2020 heightens vulnerability, necessitating strategic planning, robust infrastructure, and proactive policies [36]. Resilience Theory offers a framework to strengthen food systems against shocks, ensuring stable food availability [19, 29]. This study examines how effective supply and demand management can secure Malaysia's food system amid resource constraints, climate change, epidemics, and political instability.

2.2.2. Domestic Agriculture Production

Domestic agriculture, cultivating crops and rearing livestock within national boundaries is essential for ensuring a consistent supply of food and raw materials [37]. Critical processes like seeding underscore its importance in food production [38]. As a key economic sector, domestic agriculture generates income, provides employment in rural areas, and supports cultural practices, thereby enhancing food security through improved availability, access, utilization, and stability of food. Local production minimizes dependency on costly imports caused by fluctuating prices and trade barriers, while also promoting better nutrition and health by making fresh, culturally important foods readily available [39].

Emphasis on sustainable farming practices such as crop rotation, organic methods, and integrated pest management conserve natural resources, builds resilience against climate change, and protects biodiversity [40]. Supportive government policies, enhanced infrastructure, and improved market access are critical to fostering these practices [41]. Employing a Sustainable Development Theory framework [27] to examine the link between domestic agriculture and food security can guide policymakers in developing targeted strategies that bolster local production, enhance farmer support, and ultimately secure a sustainable and resilient national food system [42].

2.2.3. Utilization of Agricultural Technology

Agricultural technology enhances efficiency, productivity, and sustainability through advanced machinery, biotechnology, nanotechnology, and IT [43, 44]. In Malaysia, smart farming using AI, IoT sensors, and nano-fertilizers optimizes resources and boosts crop yields [45]. These innovations improve water, fertilizer, and pesticide management, ensuring efficient food distribution while minimizing waste [46]. Technological advancements also strengthen food supply resilience. Blockchain and IoT enhance transparency, reducing losses from delays and spoilage. Smallholder farmers benefit from improved access to technology, addressing capital and knowledge barriers [47]. Applying Innovation Diffusion Theory guides strategic investments and policies, positioning agricultural technology as a key driver of a sustainable and resilient Malaysian food system.

2.2.4. Food Security in Malaysia

Food security depends on four key factors—availability, accessibility, stability, and utilization [48] and is closely linked to sustainability. Malaysia's food security ranking dropped to 41st post-pandemic, despite improvements in affordability and quality (refer to Figure 3). The country remains less developed than regional competitors like Singapore, relying on imports for 20–70% of its food, including staples like rice, sugar, and beef. In 2023, food imports reached 78.79 billion ringgits, highlighting a fragile food security system. Strengthening domestic production through policy revisions, R&D, and crop insurance is crucial [49]. Climate change threatens food security, particularly rice production, necessitating heat-tolerant crops and efficient farming technologies. The Malaysian Agricultural Research and Development Institute (MARDI) advances green technology, resource management, and biotechnology. Government programs, such as the Student Farmer Entrepreneur initiative, support integrated farming [50]. Internationally, UN Food System Summits aim to make food security sustainable and equitable by 2030, yet Malaysia still imports 78% of its food, stagnating SDG 2 progress [51]. Global Food Security Index (GSFI), from 2017 to 2022. Malaysia has dropped to 41st ranking after the COVID-19 pandemic compared to the previous years.

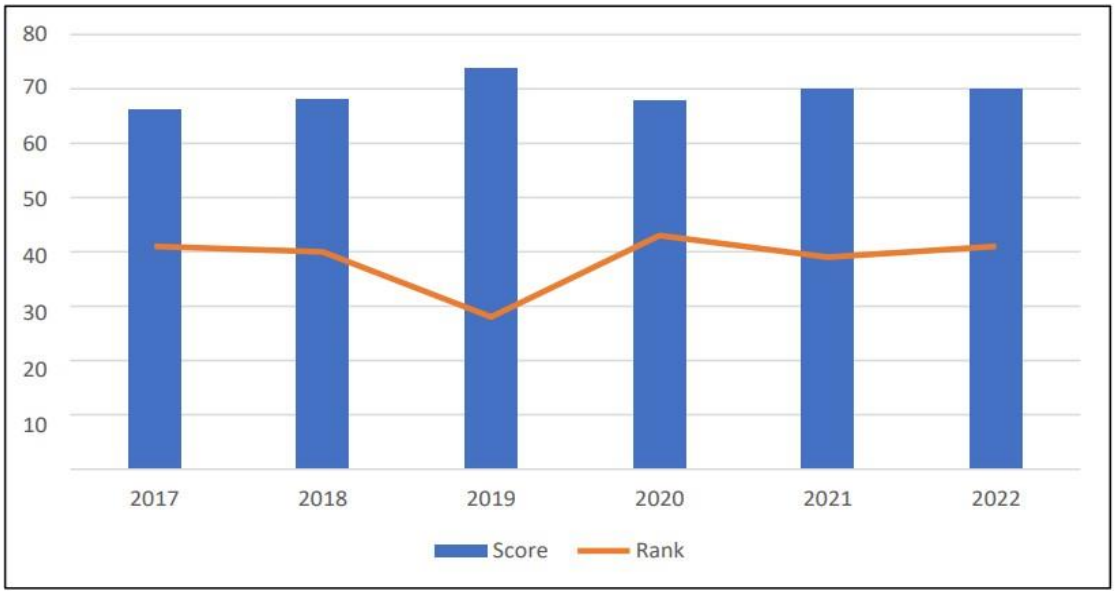

Figure 3.
Position of Malaysia in global food security index Ranking from 2017- 2022.

Biotechnology offers solutions to enhance production and reduce post-harvest losses, supported by policies like the National Biotechnology and Agro-food Policies. Urbanization further strains food security, raising costs and limiting local food sources. Urban farming faces challenges such as knowledge gaps and limited government support [52]. Collaboration among government agencies, the private sector, and educational institutions, along with improved market access and transportation, can help smallholder farmers overcome income instability [9].

2.3. Conceptual Framework

The framework presented in Figure 4 reflects the linkage between the four impacting factors (independent variables) such as conceptual understanding of food security, food supply and demand management, domestic agriculture, and agricultural technology, on food security in Malaysia (Dependent variable).

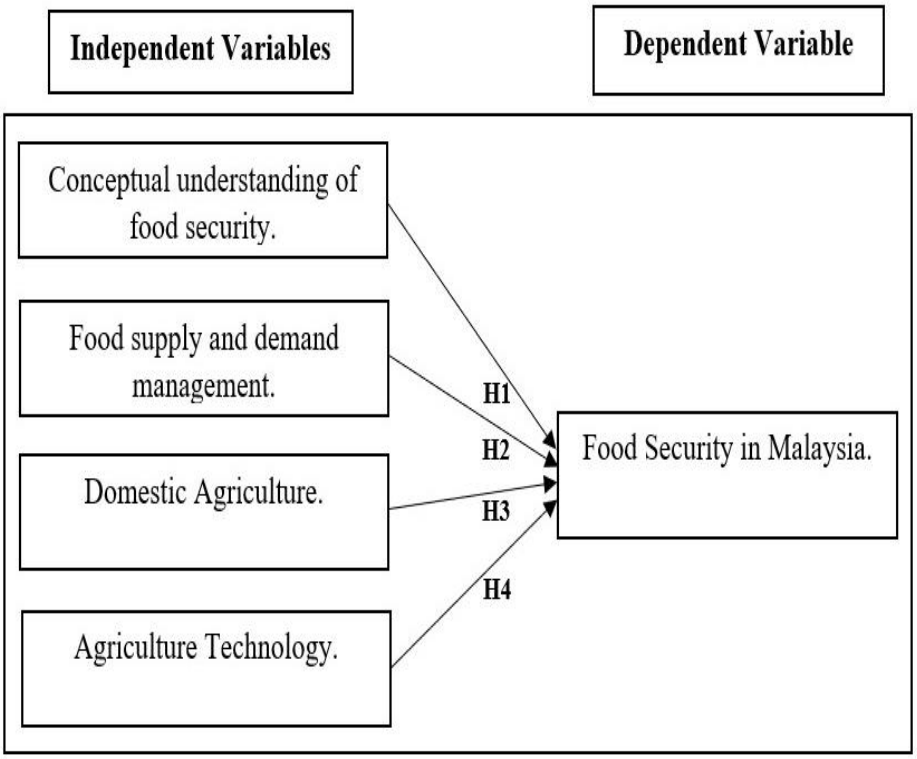

Figure 4.
Conceptual Framework of the Independent and Dependent Variables.

2.4. Hypothesis Development

Malaysia has faced recent food shortages, in 2022, a crisis where the government had to import food commodities from India and banned exports to Singapore. This situation, along with a drop in the global food security ranking from 39th in 2021 to 41st in 2022, indicates vulnerabilities in the country's food system. A comprehensive understanding of food security, encompassing availability, accessibility, utilization, and stability, is critical for addressing these issues from the ground up. Therefore,

Hypothesis 1 (H1) posits that a significant relationship exists between agricultural stakeholders' conceptual understanding of food security and the overall food security in Malaysia.

Food supply and demand management covers the entire chain, from agricultural input supply and farming practices to logistics, trading, and processing [53]. Each segment, whether ensuring high-quality seeds for farmers or addressing consumer concerns about nutrition and price, plays a vital role. Climate risks and supply chain disruptions, as seen during the COVID-19 pandemic, further emphasize the need for a well-coordinated food supply system [33, 54]. Hence,

Hypothesis 2 (H2) suggests that effective management of food supply and demand has a significant impact on food security in Malaysia.

Despite possessing vast land resources, Malaysia remains heavily import-dependent for key food and agricultural commodities, partly due to urbanization and population growth limiting available agricultural land [40]. Enhancing domestic agricultural production through improved inputs, better resource management, and increased capacity building is essential. Thus.

Hypothesis 3 (H3) asserts that increased production of domestic agriculture is significantly related to improved food security in Malaysia.

Advanced agricultural technologies, including precision farming tools, AI, IoT sensors, and nanotechnology, enable farmers to work more efficiently, increase yields, reduce chemical usage, and manage resources better [47]. These innovations not only streamline production but also enhance postharvest handling and supply chain transparency, ultimately contributing to better food quality and availability [55]. Although challenges such as low awareness and infrastructural limitations exist, the integration of these technologies is vital. Therefore,

Hypothesis 4 (H4) proposes that the utilization of agricultural technology has a significant positive relationship with food security in Malaysia.

These hypotheses collectively form the basis for this study's examination of how understanding food security concepts, managing the supply chain, boosting domestic production, and integrating technology can together enhance food security in Malaysia.

3. Methodology

This study used the Delphi method to gather expert insights on key factors influencing food security, including conceptual understanding, supply and demand management, domestic agriculture, and agricultural technology. Chosen for its effectiveness in engaging geographically dispersed experts, the study conducted two rounds of online questionnaires. The first round featured open-ended questions to identify broad factors, while the second refined and ranked these insights for consensus. The expert panel comprised agriculturists from government and non-government organizations, with surveys distributed via social media. Qualitative analysis facilitated stakeholder agreement, and theoretical frameworks were developed to measure the independent variables food security understanding, supply and demand management, domestic agriculture, and agricultural technology against the dependent variable, food security in Malaysia.

3.1. Delphi Method Approach

The Delphi method is a structured process for gathering expert opinions, refining ideas, and achieving consensus through iterative questionnaires while maintaining anonymity [56]. Developed at RAND in the 1950s, it consolidates expert perspectives for qualitative forecasting [57]. By refining responses, it minimizes bias and enhances reliability in addressing complex issues [58]. Widely used in health and food systems research, it aids in developing indices, frameworks, and measurement tools, especially for geographically dispersed experts [13].

This study implemented the Delphi method in four stages to gather expert insights on factors influencing food security in Malaysia. Figure 5 outlines the Delphi method [59].

i. Preparation Stage: Questionnaires were designed using Google Forms, with a pilot test conducted among five participants (later excluded) to refine clarity, reliability, and validity. A panel of 33 experts from the food and agriculture industry was recruited, ensuring ethical considerations and informed consent.
ii. First Round (Brainstorming): The questionnaire, distributed via Google Forms, collected demographic data and open-ended responses to identify key factors affecting food security. Descriptive and thematic analyses were conducted to refine these insights.
iii. Second Round (Consensus-Building): Experts ranked identified factors from 1 (most important) to 4 (least important) to establish a priority hierarchy. This iterative process ensured convergence in expert opinions.
iv. Data Analysis: Statistical measures, including mean, standard deviation, and interquartile range, were computed in Microsoft Excel. Kendall's Coefficient of Concordance (W), along with Chi-Square and p-values, was analyzed using IBM SPSS Statistics 30 to assess expert agreement. The findings identified critical factors shaping Malaysia's food security, providing a framework for future policy recommendations.

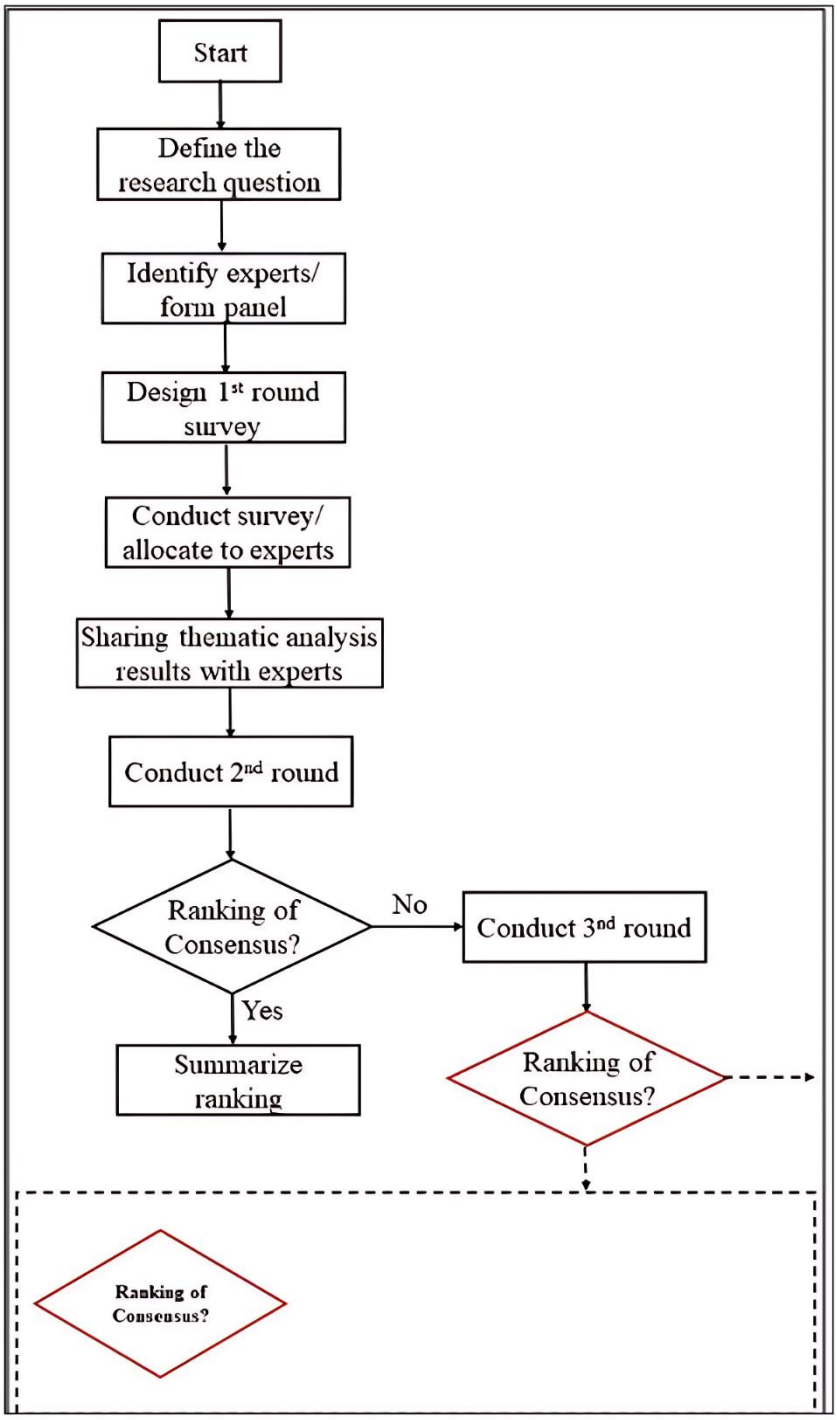

Figure 5.
Flowchart of Delphi Method.
Note: if consensus cannot be achieved in the 3rd round, the process will continue till the nth round.
Assessment of consensus is by using Kendall's Coefficient of Concordance.

3.2. Research Design

This study evaluates key dimensions influencing food security in Malaysia, focusing on conceptual understanding, supply and demand management, domestic agriculture, and agricultural technology. Using the Delphi method with purposive sampling, experts were selected based on relevant criteria [13]. The method facilitated structured communication, forecasting, and decision-making while ensuring anonymity to prevent bias. The process began with expert recruitment and identifying food security dimensions. The first questionnaire gathered qualitative insights, which were analyzed and refined for the second round. Experts then ranked the most critical dimensions, with Kendall's Coefficient of Concordance (W), Chi-square tests, and p-values assessing agreement and statistical significance.

A pilot test with five agriculture and food industry experts ensured survey clarity and usability. A draft open-ended question explored key themes, followed by an expanded pilot questionnaire. Feedback on clarity and relevance refined the survey, ensuring reliability and validity for the full Delphi study. A panel of 33 agricultural experts (2 to 11+ years of experience) from government and non-government sectors participated. Identities remained anonymous to minimize bias.

The two-round Delphi process identified and ranked key food security factors, achieving consensus despite minor attrition. Completed in 1.5 months, the study ensured iterative feedback and expert-driven conclusions. Data was collected via Google Forms, maintaining validity, reliability, and ethical integrity, with informed consent obtained and diverse measurement scales incorporated.

The initial open-ended questionnaire was designed to elicit qualitative responses from experts regarding food security, covering definitions of the subject along with approaches to supply and demand management, domestic agriculture, and agricultural technology. This questionnaire provided respondents the opportunity to express their opinions, experiences, and knowledge freely, which allowed for a deeper understanding of the underlying dynamics of food security by uncovering factors and ideas that might otherwise remain hidden. In this round, the experts were asked a single, open-ended question: "What are the key factors that you believe positively influence food security and its resilience in Malaysia?" The responses collected from the 33 experts were then synthesized into themes, which were later grouped into four dimensions: the conceptual understanding of food security, food supply and demand management, domestic agriculture, and agricultural technology.

In the *second round*, the same group of experts was contacted to further refine these findings. Instead of using a traditional Likert scale, the experts were asked to rank the importance of the four identified dimensions on a scale from 1 to 4, where 1 represented the most significant factor and 4 the least significant. This ranking approach was chosen based on recommendations from Tee et al. [59], and it was clearly communicated to the participants that there were no correct or incorrect ratings and that each dimension should receive a unique ranking to avoid duplication. All 33 experts who participated in the first round also completed the second round, ensuring consistency and reliability in the data collected for the study.

For the quantitative data, such as responses to ranking questions, descriptive statistics, including means or medians, were used to evaluate the level of agreement or priority among the participants. At the conclusion of each round, experts were given the opportunity to review and refine their responses based on collective feedback, which fostered deeper discussion and helped to build consensus in subsequent rounds.

To compare the ranked scores, *Kendall's Coefficient of Concordance* (W) was used to assess the level of consensus among experts in the second round of the Delphi study. By analyzing the p-value and comparing the Chi-square test results with the critical value, the study determined that the Kendall's W coefficients were statistically significant. As noted by Siegel [60], the goal of Kendall's W is to establish an agreed-upon set of rank scores. A high Kendall's W—close to 1—indicates that participants are using a similar standard to rank the elements, thereby demonstrating strong agreement. When this high W is coupled with a low p-value (less than 0.05), it strongly supports the consistency of the responses. Therefore, the null hypothesis, which posits no consistency among the experts' responses, can be rejected, confirming that there is a significant level of consensus in the rankings.

Ho: The rankings of the experts are not consistent (Disagreement of responses).

There will be no, or little, or minor agreement among the responses of the experts (the rankings of the experts are not consistent). One approach is that the p-value is high (greater than 0.05) when using Kendall's Coefficient of Concordance. Here, the value of W is low, which means that the ratings given by different experts are not regulated. If so, the Delphi technique would require a third round.

4. Results and Discussion

The Delphi method is a structured forecasting technique that gathers expert opinions through multiple rounds of questionnaires [59]. The iterative process allowed for the refinement of ideas and facilitated consensus on the factors impacting food security.

4.1. Demographic Analysis

In this first round of the survey, a panel of 33 experts was selected based on the primary criteria required, which is having experience in the related fields of agriculture and the food industry. The participants were invited and obtained consent to voluntarily participate in the Delphi study. Table 2 shows the demographic information of the experts collected in this study.

Table 2.
Demographics of experts who participated in the Delphi method.

No.	Age	Gender	Sector	Experience (Years)	Position	Academic	Organization
E1	51 - 60	M	Public	11>	Professor	PhD	Universiti Sains Malaysia
E2	21 - 30	F	Private	2 - 5	Director	Bachelor's degree	Snowwy Cafe
E3	31 - 40	F	Private	6 - 10	Biotechnologist	PhD	AIMST
E4	31 - 40	F	Public	2 - 5	Professor	PhD	Seameo
E5	41 - 50	F	Private	11>	Director	Bachelor's Degree	Jayam Spice Sdn Bhd
E6	31 - 40	M	Private	6 - 10	Operation Manager	Bachelor's degree	YTL International
E7	21 - 30	F	Private	2 - 5	Biotechnologist	Bachelor's degree	Island Foundation
E8	21 - 30	F	Private	2 - 5	Quality Assurance Manager	Master's degree	Gainwealth Engineering & Trading
E9	21 - 30	F	Private	2 - 5	Food Lab Technologist	Master's Degree	Love & Loaf Sdn.Bhd
E10	21 - 30	F	Private	2 - 5	Operation Manager	Master's Degree	PsyHome Sdn.Bhd
E11	31 - 40	M	Public	2 - 5	Research Officer	Bachelor's degree	Centre for Drug Research
E12	31 - 40	F	Private	2 - 5	R&D Manager	Master's Degree	Clarivate
E13	31 - 40	F	Public	2 - 5	Research Officer	PhD	Universiti Sains Malaysia
E14	31 - 40	F	Private	2 - 5	Project Manager	Master's Degree	Clarivate
E15	31 - 40	M	Private	11>	Quality Assurance Manager	Master's degree	Agritech Sdn.Bhd
E16	21 - 30	M	Private	2 - 5	Operation Manager	Bachelor's degree	Arati Vilas Sdn Bhd
E17	31 - 40	F	Public	2 - 5	Research Officer	Bachelor's Degree	University Malaya
E18	31 - 40	F	Public	6 - 10	Research Officer	PhD	Universiti Sains Malaysia
E19	31 - 40	F	Private	6 - 10	Production Manager	Bachelor's degree	Zebra Technology
E20	31 - 40	M	Public	2 - 5	Research Officer	Master's Degree	Universiti Sains Malaysia
E21	31 - 40	F	Public	11>	Food Lab Technologist	Bachelor's Degree	Ministry Of Health
E22	21 - 30	F	Private	6 - 10	Operation Manager	Bachelor's degree	Passions of Kerala
E23	31 - 40	F	Public	2 - 5	Research Officer	Master's Degree	Universiti Sains Malaysia
E24	31 - 40	F	Private	2 - 5	R&D Manager	Bachelor's Degree	GNC Sdn Bhd
E25	31 - 40	F	Public	6 - 10	Senior Executive	Master's Degree	Government
E26	31 - 40	F	Private	2 - 5	Operation manager	Master's degree	Nine Food Grp Ltd
E27	31 - 40	F	Public	6 - 10	Research Officer	PhD	UiTM
E28	41 - 50	F	Private	11>	Project Manager	Master's Degree	Astra Academy
E29	21 - 30	M	Public	2 - 5	Sustainability Manager	Bachelor's degree	PYDC
E30	31 - 40	F	Private	2 - 5	Project	PhD	Arcadia Life Sciences

					Manager		
E31	21 – 30	F	Public	2 - 5	R&D Manager	Master's Degree	NUHS
E32	31 – 40	M	Private	11>	Operation Manager	Master's Degree	China Yangzte Sdn.Bhd
E33	31 – 40	F	Private	11>	General Manager	Master's Degree	Raviraj Sdn Bhd

In this study, a total of 33 experts participated, with the majority (64%) in the 31–40 age group (21 participants), followed by 9 participants aged 21–30, 2 aged 41–50, and 1 aged 51–60. The sample was predominantly female (76%, or 25 participants) compared to 8 males. Experts were drawn from both sectors, with 20 from the private sector and 13 from the public sector. In terms of work experience, 19 experts (58%) had 2–5 years of experience, while 7 had 6–10 years and another 7 had 11 or more years. Academic qualifications varied, with 13 holding Bachelor's degrees, 12 holding Master's degrees, and 8 possessing Ph.D.s in fields such as Biotechnology, Food Technology, Nutrition, Chemical Engineering, Food Safety, Pharmacology/Toxicology, and MBA. Regarding job positions, 90% were in middle management roles, including managers, biotechnologists, food lab technologists, R&D officers, and professors, while 10% held top management positions such as directors and senior executives.

4.2. Round One of the Delphi Method

The survey questionnaire was distributed to the panel of experts on the 6th of October 2024, and they were given time to complete and return it by the 19th of October 2024. The first round of the Delphi technique received a favorable response from 33 experts. Google Forms were used as the questionnaire instrument to collect the data from the participants and obtain their points of view on the factors positively contributing to food security in Malaysia. The questionnaire consists of two parts, where the first part is the collection of the demographic profile for details like email address, age, gender, working sector, academic qualification, years of working experience, and job position of the experts. The second part is an open-ended question that asks, "What are the key factors that you believe positively influence food security and its resilience in Malaysia?" The experts were required to provide their insights and the anonymity of the participants was kept confidential.

4.2.1. Thematic Analysis Findings

The outcome from the first round of the Delphi technique was presented in 35 themes collected from the responses of the 33 experts. The themes were synthesized and grouped into four dimensions consisting of Conceptual Understanding of Food Security (D1), Food Supply and Demand Management (D2), Domestic Agriculture (D3), and Agriculture Technology (D4). Four themes represent D1, 13 themes represent D2, eight themes represent D3and ten themes represent D4. The themes and dimensions are compiled and presented in Table 3.

Table 3.
Consolidation of Round One Delphi Findings.

Dimensions	Themes
Conceptual Understanding of Food Security (D1)	• Ensuring food availability, food accessibility, food stability and food affordability. • Revising government policies and regulations for stability. • Both availability and accessibility are crucial to achieving true food security. • Understanding food supply and management in food security involves ensuring reliable, sustainable production, distribution, and access to sufficient, safe, and nutritious food for all populations, thereby preventing hunger and malnutrition.
Food Supply and Demand Management (D2)	• Management of food supply to overcome natural disasters. • Good resource management and proper segregation of subsidies • Food supply chain management • Inventory and supply chain management to ensure a consistent and sustainable food supply for the country. • Consistent supply of nutritious food • Quality and the manufacturer's process • Good trade relations will enable seamless imports and exports, enabling a more stable food supply and leading to food availability • Food supply and demand management will definitely impact food security to enable better resource planning • Risk Management • Sustainability • Forecasting and demand planning to predict how future food demand and supply trends are likely to develop in order to guarantee production and distribution. • Understanding consumer preferences and behaviors to better align supply with demand. • Revise global trading policy

Domestic Agriculture (D3)	• Boost the production of agriculture in Malaysia to enhance food security • Government subsidy and policy to develop local agriculture. • Enhancing agricultural productivity involves investing in contemporary farming techniques and research to boost crop yields and support sustainable practices. • Access to natural resources • Land management • Improving nutritional quality for local produce, ensuring a stable food supply for the population. • Diverse food resources • Socioeconomic
Agriculture Technology D4	• The adoption of precision farming techniques and technologies improves productivity and resource efficiency. • Adopting modern and advanced technologies, Malaysia can boost productivity and reduce reliance on food imports, enhancing overall food security. • Government policies that support agricultural advancements, technology and subsidies will contribute to food availability. • Embracing agrobiotechnology and digital agriculture technologies has greatly enhanced crop yields and farming efficiency. • Improve technology and infrastructure • Implementation of biotechnology and food innovation. • Enforcement of the Fourth Industrial Revolution (4IR) can be best utilized to address food security issues in Malaysia. • Innovations like precision farming, smart irrigation systems, and drone-based crop monitoring are increasingly prevalent. • Opting for standardized remote-controlled sensors, drones and robots to monitor, water and fertilize crops and not to rely solely on manpower to meet the increasing food demand. • Optimize and utilize effective food technology will ensure not only the continuous food supply but also to preserve the nutritional values.

4.3. Round Two of the Delphi Method

In the second round of the Delphi study, conducted on 20 October 2024 with responses due by 1 November 2024, the same expert panel received Google Forms containing a closed-ended questionnaire. In this round, experts provided their contact information and were asked to rank, on a scale from 1 (most important) to 4 (least important), four dimensions that had been identified and synthesized from the first round. These dimensions were: Conceptual Understanding of Food Security (D1), Food Supply and Demand Management (D2), Domestic Agriculture (D3), and Agricultural Technology (D4). Experts were instructed to assign each rank only once to ensure clear, non-duplicated results. Although one expert did not participate in this round, leaving 32 responses, such attrition is common in Delphi studies [61].

4.3.1. Non-Parametric Analysis

Data from the 32 experts in round two were analyzed using Microsoft Excel to calculate the mean, standard deviation, and interquartile range for the four dimensions (D1, D2, D3, and D4). The overall mean scores ranged from 1.78 to 3.06. Specifically, D2 recorded the lowest mean (1.78, SD = 1.09) and a median of 1, indicating it was ranked as the most important factor. D3 followed with a mean of 2.28 (SD = 0.68) and a median of 2, while D4 had a mean of 2.81 (SD = 0.81) and a median of 3. D1, with the highest mean (3.06, SD = 1.26) and a median of 4, was considered the least important. These results, as summarized in Tables 4 and 5, clearly reflect the experts' consensus on the relative importance of the factors contributing to food security in Malaysia.

Table 4.
Second Round of Delphi Method.

Experts No.	Dimensions D1	D2	D3	D4
	Conceptual Understanding of Food Security	**Food Supply and Demand Management**	**Domestic Agriculture**	**Agriculture Technology**
E1	4	1	2	3
E2	4	1	2	3
E3	4	1	2	3
E4	1	2	3	4
E5	4	1	2	3
E6	3	4	2	1
E7	2	1	3	4
E8	4	1	2	3
E9	4	3	2	1
E10	4	1	2	3
E11	4	1	2	3
E12	4	1	2	3
E13	2	3	2	1
E14	3	2	1	4
E15	3	4	2	1
E16	4	1	2	3
E17	1	2	3	4
E18	4	1	2	3
E19	1	4	2	3
E20	1	3	4	2
E21	1	4	2	3
E22	4	1	2	3
E23	4	1	2	3
E24	4	1	2	3
E25	4	1	2	3
E26	4	1	2	3
E27	2	1	3	4
E28	4	1	2	3
E29	4	3	2	1
E30	4	1	2	3
E31	1	2	4	3
E32	1	2	4	3
Mean	**3.06**	**1.78**	**2.28**	**2.81**
Group Rank	**4**	**1**	**2**	**3**
Kendall's W of 0.190; p-value of <0.001 Chi-Square Value: 18.216				

Table 5.
Statistical Analysis of the Mean, Standard Deviation and Interquartile Range.

Dimension (D)	Mean, *M*	Standard Deviation, *SD*	Min.	25 (%)	50 (%)	75 (%)	Max.
D1: Conceptual Understanding of Food Security	3.06	1.26	1	2	4	4	4
D2: Food Supply and Demand Management	1.78	1.09	1	1	1	2	4
D3: Domestic Agriculture	2.28	0.68	1	2	2	3	4
D4: Agriculture Technology	2.81	0.89	1	2	3	3	4

Following the completion of the second round, Kendall's Coefficient of Concordance (W) was calculated using IBM SPSS Statistics 30 to assess the level of consensus among experts. Although the calculated Kendall's W was 0.190 a low to moderate level of agreement, it was statistically significant ($p < 0.001$), indicating that the raters' scores were not random and that they were using a similar standard to rank the dimensions. The Chi-Square value of 18.216 further supports this conclusion by showing significant deviation from the null hypothesis, which stated that there was no agreement among raters. As a result, the null hypothesis was rejected, confirming that there is a statistically significant level of consensus among the experts, and no further rounds of the Delphi method were required.

5. Conclusion and Recommendation

5.1. Findings of the Study

This study emphasizes the criticality of food security in Malaysia by examining four key dimensions: food supply and demand management, domestic agriculture, agricultural technology, and a conceptual understanding of food security. The study traces the interrelationships among these factors to provide an overview of the challenges and opportunities for achieving a more stable, nutritious, and accessible food system. Further discussion on the four dimensions is presented as follows.

Food Supply and Demand Management: Food supply and demand management is essential for ensuring food security in Malaysia amid challenges such as climate change, pandemics, political instability, urbanization, and global price fluctuations [33]. Effective management stabilizes food prices, which is crucial for low-income households, and reduces food waste through improved logistics, storage, and distribution [38, 53]. Enhancing local production by promoting subsidies, training, and modern agricultural technologies can decrease reliance on imports and improve Malaysia's standing in the Global Food Security Index [10]. Moreover, ensuring a diverse food supply supports nutritional security and addresses malnutrition, and adopting climate-smart practices builds resilience against environmental risks [34, 40]. Ultimately, strategic government policies and long-term food planning are critical to sustaining a robust, resilient, and self-reliant food system.

Domestic Agriculture: Strengthening Malaysia's domestic agriculture is crucial for reducing import dependence and mitigating global market volatility [36]. Investing in local farming stabilizes food supply, keeps prices affordable, and protects lower-income households [52]. It also supports rural economies, promotes diverse crop production for nutritional security, and combats malnutrition [62]. Sustainable farming practices and climate-resilient crops help counter climate change effects, ensuring long-term food availability. Subsidies, training, and modern agricultural technologies further enhance productivity and resilience, while urban gardens and community initiatives supplement food supplies and lower carbon footprints [63]. Strengthening domestic agriculture not only improves food security but also drives economic growth and environmental sustainability in Malaysia.

Agriculture Technology: Agricultural technology is vital for enhancing Malaysia's food security by improving productivity, efficiency, and sustainability. Precision farming using GPS and IoT optimizes resources, minimizes waste, and increases yields, addressing land and water constraints [43]. Genetically engineered crops enhance resilience to pests, diseases, and climate change, while automation and robotics lower labor costs and attract future generations to farming [64]. AI and data analytics improve decision-making by analyzing weather patterns, soil health, and crop performance [65]. Innovations like vertical farming and hydroponics maximize urban agricultural space. With government support in subsidies, training, and infrastructure, these technologies can reduce import dependence, stabilize food supply, and foster a resilient, sustainable agricultural sector that drives economic growth and improves livelihoods.

Conceptual Understanding of Food Security: Agricultural technology plays a crucial role in strengthening Malaysia's food security by enhancing productivity, efficiency, and sustainability. Precision farming, utilizing GPS and IoT, optimizes resource use, minimizes waste, and boosts yields, addressing land and water limitations [43]. Genetically engineered crops improve resilience to pests, diseases, and climate change, while automation and robotics reduce labor costs and attract future generations to farming. AI and data analytics enhance decision-making by assessing weather patterns, soil health, and crop performance. Meanwhile, innovations like vertical farming and hydroponics maximize urban agricultural space [64]. With government support in subsidies, training, and infrastructure, these technologies can reduce import dependence, stabilize food supply, and foster a resilient, sustainable agricultural sector that drives economic growth and improves livelihoods.

5.2. Recommendations

To strengthen food security in Malaysia, priorities should be set as follows: food supply and demand management, domestic agriculture, agricultural technology, and a robust conceptual understanding of food security. Effective supply and demand management is key to ensuring food availability, affordability, price stability, and waste reduction. This requires improved supply chain logistics, adequate food reserves, and equitable distribution policies to protect low-income households from price volatility. Strengthening domestic agriculture further enhances self-sufficiency by reducing import dependency, supporting farmers with subsidies, modern technologies, and training, and promoting community-based and urban farming.

Integrating advanced agricultural technologies such as precision farming, biotechnology, automation, and data analytics optimizes resource use, enhances crop resilience, and lowers labor costs, making farming more efficient and sustainable. Lastly, a strong conceptual understanding of food security, encompassing availability, accessibility, utilization, and stability, is essential for shaping comprehensive policies. By prioritizing these areas, Malaysia can build a resilient and sustainable food system, ensuring consistent access to safe, sufficient, and nutritious food for all.

5.3. Research Implications

This research offers valuable insights into enhancing food security in Malaysia by leveraging the Delphi method to identify and prioritize key factors. The expert-driven approach highlights best practices for managing food supply and demand, strengthening domestic agriculture, and integrating advanced technologies. These findings can inform policies that ensure a stable, nutritious, and accessible food supply.

Practically, the results guide policymakers in implementing efficient logistics, storage, and waste-reduction strategies to stabilize food prices and improve affordability. Strengthening domestic agriculture can boost local production, reduce import dependency, and support rural economies. Additionally, adopting advanced technologies optimizes resource use, increases crop resilience, and lowers production costs, fostering a more sustainable agricultural sector. A comprehensive understanding

of food security concepts further aids in developing holistic policies addressing availability, accessibility, utilization, and stability.

Theoretically, this study enhances the understanding of food security as a multidimensional issue by clarifying its interrelated components. Methodologically, it demonstrates the Delphi method's effectiveness in systematically synthesizing expert opinions through iterative rounds, anonymity, and structured feedback. This adaptable approach offers a robust framework for tackling food security challenges in Malaysia and beyond.

5.4. Limitations and Future Research

Despite its strengths, this study has several limitations. First, the data were collected solely from experts in Malaysia's agriculture and food industry, which confines the findings to the Malaysian context and may limit their generalizability to other regions. Additionally, the study employed a cross-sectional design using the Delphi method over two rounds, which may introduce bias. Experts' responses could be influenced by their personal experiences or by the feedback summaries provided between rounds, potentially affecting the objectivity of the consensus reached.

Future research should expand to Southeast Asia and beyond to explore global food security issues. Studies could refine and measure these four dimensions while integrating additional factors for quantitative analysis. A mixed-methods approach is recommended to enhance reliability through triangulation. Furthermore, testing these indicators in diverse projects can validate their effectiveness in addressing food security challenges and prioritizing key factors for a sustainable food system.

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