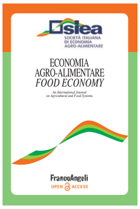
Economia agro-alimentare /
Food Economy

An International Journal on Agricultural and Food Systems

Vol. 27, Iss. 2, Art. 1, pp. 35-70 - ISSNe 1972-4802
DOI: 10.3280/ecag2025oa18700



Assessing Agricultural Resilience in Malaysia: The Impact of R&D Investments on Sector Stability

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Abstract

The agricultural sector is pivotal in Malaysia's economic development, primarily providing food, feed, and raw materials for industries while contributing to the country's GDP and absorbing labour. Despite its significance, the sector's resilience during economic shocks, such as financial crises, economic setbacks, and pandemics, requires further examination. This study addresses the issue of measuring the resilience of Malaysia's agricultural sector with an enhanced focus on the impact of research and development (R&D) funding allocation and investments, which is often overlooked in resilience studies. It aims to quantify the resilience of Malaysia's agricultural sector and analyse trends over time, thereby contributing to a deeper understanding of the sector's stability and the role of R&D in fostering resilience. Secondary data from 1996 to 2023 was collected from various sources, including the World Bank, the Department of Statistics Malaysia, the Ministry of Agriculture and Food Industries Malaysia, Bank Negara Malaysia, and the Malaysian Investment Development Authority. Principal component analysis (PCA) was utilised to construct the resilience index, while trend analysis examined the evolution of this index over the study period. Preliminary

Article info

Type:
Article
Submitted:
19/10/2024
Accepted:
06/06/2025
Available online:
11/09/2025

JEL codes:
J30, O40, Q16, Q18

Keywords:
Agricultural sector resilience
Malaysia
Principal component analysis
R&D

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results indicate that the resilience of Malaysia's agricultural sector fluctuates over time, with a positive correlation between increased R&D investments and higher resilience levels. The findings suggest that strategic R&D investments are crucial for enhancing agricultural resilience. By integrating R&D factors, this research provides a comprehensive framework for assessing the resilience of the agricultural sector, offering policymakers and stakeholders valuable insights. The methodology and findings can also be applied to other countries, making a significant contribution to the literature on agricultural resilience.

Managing Editor: Søren Marcus Pedersen

Introduction

The agricultural sector is not only a mainstay of economic development and poverty reduction (World Bank, 2020) but also plays a vital role in maintaining food security and safety in most developing countries (Diao *et al.*, 2007). However, the agricultural sector in Malaysia faces various challenges, including climate change (Firdaus *et al.*, 2020), economic uncertainty (Yang *et al.*, 2022; Hamidu *et al.*, 2022), and a shortage of skilled labour (Cassey *et al.*, 2018). These challenges affect the resilience of agricultural production and require urgent adaptation, enabling the agricultural sector to remain productive despite disruptions from climate change, economic uncertainty, and labour shortages.

In addition, several agricultural sectors, such as rice, are highly vulnerable to external shocks that affect exports. Both sectors face pressure from fluctuating commodity prices in global markets, currency depreciation and trade policies from trading partner countries (Hamidu *et al.*, 2022). This, in turn, affects the income of smallholders and limits investment in modern agricultural techniques. Therefore, the oil palm and rubber sectors always need financial assistance to help diversify other agricultural products to overcome these challenges.

In addition, there is also a labour shortage (Prasad, 2017; Tittonell, 2020), and most young people are more likely to migrate to rural areas to work in other sectors. They are less interested in jobs in the agricultural sector. This has led the agricultural sector to rely more heavily on foreign labour in the plantation sector, raising concerns about long-term sustainability, particularly with the increasingly strict recruitment of foreign labour and the rising minimum wage for foreign labour. Meanwhile, the younger generation is more interested in finding more modern job opportunities than traditional agricultural jobs. This has led to a constant shortage of labour

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in the agricultural sector. Modernisation can overcome this challenge in the agricultural sector through government initiatives from the Technical Vocational Education and Training (TVET) program to attract young people to modern agriculture. This approach ensures that labour in the agricultural sector is always sufficient, allowing the sector to remain competitive and resilient. Agricultural resilience refers to the ability of the agricultural sector to remain productive and adapt and recover from the effects of disruptions. These include climate change disruptions (Firdaus *et al.*, 2020), changes in commodity prices (Cassey *et al.*, 2018) and labour shortages (Tittonell, 2020; Meuwissen *et al.*, 2019). Agricultural resilience is crucial for ensuring food security (Tendall *et al.*, 2015; FAO, 2020) and maintaining the stability of the food chain (Hamidu *et al.*, 2022).

Among the practices to increase agricultural resilience are climate-smart practices such as conserving cropland, maintaining sound drainage systems, and agroforestry (Tittonell, 2020; FAO, 2020). These are examples of competitive agricultural practice systems. They aim to ensure that the agricultural sector remains productive despite extreme weather changes, and are a step towards modernising agricultural technologies such as automated irrigation and remote sensing techniques.

Second is economic resilience, in other words, the financial resilience of farmers during economic uncertainty and climate change without affecting the productivity of the agricultural sector. Financial assistance includes encouraging crop diversification, using innovative technology, and using machinery. This secures the entire food supply chain. Financial support and R&D investment are needed to ensure economic resilience (Fuglie, 2018).

Third, agricultural resilience in terms of the social and institutional roles that support food security in the face of economic uncertainty, climate change and labour shortages. There is a network of government or community agencies that can provide training and technical assistance support to farmers (Meuwissen *et al.*, 2019), such as the use of digital marketing platforms that enable wider marketing of agricultural products and the use of cold storage technology to ensure that agricultural products remain fresh and last longer. In addition, the use of sophisticated machinery can overcome labour shortages.

Therefore, investment in R&D is essential to maintain food security by ensuring continued productivity despite current challenges, and several other countries have implemented similar measures. For example, in Africa, climate-smart agriculture (CSA) is used to overcome rainfall problems and, at the same time, promote drought-resistant crops and agroforestry (Adger *et al.*, 2020; Lipper *et al.*, 2020). Meanwhile, Brazil is practising crop diversification (Altieri & Nicholls, 2020), and farmers from the European Union and the United States are adopting drone support systems and artificial intelligence

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in agriculture to help farmers make the right decisions (Fuglie, 2018). The Netherlands uses hydroponics to overcome land scarcity and unpredictable weather conditions (Fuglie, 2018). Vietnam, Indonesia and the Philippines are relevant in using flood-resistant rice seeds to enhance food resilience (Rumanti *et al*., 2018). China promotes solar-powered irrigation programs, organic farming and crop insurance (Pingali, 2019).

The Malaysian agricultural sector faces various challenges that can affect productivity and sustainability in the long term. Among them are climate change, extreme weather, and drought affecting agricultural production (Firdaus *et al*., 2020), mainly due to deforestation and land degradation activities that affect the sustainability of oil palm and rubber areas (FAO, 2020). In addition, economic and global market uncertainties affect global agricultural product demand (Cassey *et al*., 2018) and increase fertiliser costs, significantly impacting the resilience of smallholder farmers (World Bank, 2020). At the same time, the agricultural sector is experiencing a shortage of workers due to over-reliance on foreign workers. In addition, foreign worker recruitment policies are becoming stricter to reduce the recruitment of illegal foreign workers (Low, 2017) and local workers are less interested in the agricultural sector (Abdullah *et al*., 2016). The challenge of agriculture to remain resilient occurs with technological constraints and facilities that smallholder farmers face, such as limited access to modern agricultural technology and digital equipment (Zahari *et al*., 2024). Capital constraints to use technology cause inefficiencies in the food supply chain, such as a lack of storage facilities and transportation networks.

The Function of R&D in Enhancing Agricultural Resilience

Malaysia has adopted several policies to support innovation and improve agricultural resilience. However, a gap exists between the implementation of agricultural resilience policies and the actual situation (Hassan *et al*., 2022). This is due to the constraints of limited financial support and insufficient investment in R&D to develop sustainable agricultural systems (Zahari *et al*., 2024; Fuglie, 2018). Therefore, various aspects should be considered, such as strategies for climate change adaptation, economic policy reforms, workforce development and technological innovation to strengthen agricultural resilience and ensure food security in the long term. In other words, findings from R&D can also help policymakers and farmers restore agricultural productivity to overcome the challenges of climate change, global market volatility and shortages of raw material resources (Fuglie, 2018).

R&D also drives the creation of better breeds and provides better agricultural yields (Thornton *et al*., 2021). In addition to the use of smart

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agriculture, including the use of remote sensing applications, artificial intelligence (AI) and the Internet of Things (IoT) so that agricultural activities can be monitored remotely and more accurate decisions can be made by optimising the use of fertilisers, water and soil (Alston *et al.*, 2011). R&D provides empirically based insights to policymakers to improve food security. For example, modernising agricultural systems can reduce dependence on foreign labour, increase overall competitiveness, and ensure that agricultural systems can cope with future economic uncertainties.

R&D can potentially improve agriculture's long-term sustainability (Chandio *et al.*, 2025). However, financial constraints still exist, especially with investments in modern technologies, such as innovative harvesting equipment, weather-resistant crop genetics, and efficient irrigation systems. In addition, the lack of investment from the private sector in R&D has led to the slow development of agricultural technology (Fuglie, 2018). In addition, government initiatives such as the Young Agroprenuer Grant promote modern agriculture, but bureaucratic inefficiency still restricts accessibility and effectiveness (Hassan *et al.*, 2022). Meanwhile, banking institutions often see agriculture as risky, causing them to hesitate to lend to small farmers. In addition, the lack of technical knowledge and training for farmers is the main reason they do not practice and find it difficult to accept modern agricultural systems. Agricultural training and skills programs in Malaysia seem inadequate, and there is still a lack of research collaboration networks between universities and agricultural research institutions such as the Malaysian Agricultural Research and Development Institute (MARDI). Weak collaboration between researchers and agricultural practitioners hinders the development of new agricultural technologies and reduces agricultural sustainability.

Most agricultural areas in Malaysia are developed in rural and remote areas, with poor infrastructure, inadequate irrigation systems, and lack of electricity and internet coverage. This hinders farmers' ability to adopt modern farming systems (FAO, 2020), while limited internet coverage restricts farmers' access to weather forecasting applications, digital marketing, and remote sensing technologies (Lipper *et al.*, 2020).

However, several past researches have proposed various strategies for the agricultural sector. It is to become a resilient sector, such as strategies to increase productivity capacity (see Alston *et al.*, 2011; Pardey *et al.*, 2021; Fuglie, 2018). However, research gaps still exist, especially in assessing the extent to which resilience occurs in the agricultural sector and the role of R&D investment in the agricultural sector. It aims to strengthen resilience to face global economic uncertainties and climate change by developing the Agricultural Resilience Index (ARI) by combining social, economic and

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environmental indicators using Principal Component Analysis (PCA) and trend analysis from 1996 to 2023.

1. Literature Review

Related Theories

The current complex macroeconomic situation dramatically affects the agricultural environment, which various related theories can explain in terms of resilience in agriculture. It is important to understand how the agricultural sector can adapt when facing the uncertainty of economic pressure, labour market, economic resource market, government intervention, and the role of agricultural innovation to ensure the survival of the rapidly growing agricultural sector.

The theoretical relationship starts from the Business Cycle Theory, which explains fluctuating economic conditions and shows the economic phase expanding or contracting from time to time (Lucas, 1980). In the agricultural sector, the investment surge phase is the main impetus for agricultural productivity, and agricultural production is more capital-incentive to recovering the economy from the recession phase. On the other hand, monetary policy pressure slows down the expansion phase of the agricultural sector and affects the rate of labour participation in agriculture.

After the emergence of the Business Cycle Theory, the Resilience Theory became popular among researchers, economists, and policymakers in the late 20th century. It explores the response of an economy to shocks and readjusts after the effects of external disturbances (Hallegatte, 2014; Chavas, 2024). The theory explains the mechanism of stress absorption and adaptation to various uncertain economic economies. This study focuses on the resilience theory in the agriculture sector, which is important in facing various economic challenges such as global market uncertainty, extreme weather changes, and global economic policies. Economists have highlighted various strategies to ensure that the agricultural sector can enter the recovery phase and grow to be more productive despite the global economic slowdown like crop diversification (Vernooy, 2022), government support (Barbosa, 2024), and approaches for using innovation to increase the level of sustainability of the agricultural sector to adapt to various uncertain economic conditions (Cruz, 2023).

In the context of productivity, the Human Capital Theory emphasises the importance of investing in human capital through skills training and education to drive agricultural economic growth and increase the efficiency of agricultural productivity (Huffman & Orazem, 2007; Timmer, 2002;

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Hoang-Khac, Tiet, To-The & Nguyen-Anh, 2022). It emphasises the productivity and efficiency of adopting up-to-date agricultural techniques and using the latest technology to ensure sustainable agricultural practices. Then came the Innovation Theory that supports agricultural resilience by highlighting technological advances as the mainstay to ensure that economic growth always occurs in the context of modern agricultural productivity, mainly research and development (R&D), biotechnology, digitalisation, and the use of artificial intelligence (AI) in agriculture. This increases productivity efficiency, reduces input costs, fosters resilience, and becomes more competitive to face economic uncertainty.

The Wage Efficiency Theory further reinforces the Resilience Theory. It was first developed by Akerlof & Yellen (1986) to explain why employers prefer to offer higher wages rather than the market equilibrium to attract more highly skilled workers with the best motivation. Real wages also play an important role in productivity (Nikoloski, 2023). A positive two-way relationship exists between labour productivity and real wages, giving an advantage to technological change (Cruz, 2023). The theory suggests that higher wage levels can increase labour productivity by using machinery and artificially intelligent technology that requires high skills from skilled and professional labour. However, these studies may not mention wage efficiency in agriculture. High wages can also attract professional and skilled labour to work in agriculture. This may overcome the labour shortage issue in the agricultural sector by using high-tech machinery that requires minimal skilled labour but can produce higher productivity than unskilled labour, especially to overcome the use of unskilled foreign labour.

The Resource-Based View (RBV) theory also supports the Resilience Theory by focusing on efficiently managing economic resources such as land use, technology, and human capital. It highlights the role of efficient economic resources and innovative agriculture practices in increasing the use of sophisticated technological machinery that requires skilled labour to operate the machinery in addition to soil that is always fertile due to more efficient fertilisation techniques. This ensures the economic sustainability of agriculture in the long term. The RBV theory, initially proposed by Wernerfelt (1984), focuses on the efficiency of firms when using internal resources but not producing products. This approach was later applied to the agricultural sector to understand competitive advantage (Madhani, 2009). Subsequently, the theory was used to study the sustainability of competitive advantage in agricultural commodities (Michaels & Gow, 2008). However, RBV may still not consider market uncertainty, which requires alternative strategic approaches (Furr & Eisenhardt, 2021).

To complete the theoretical framework of agricultural sustainability, the Market Failure Theory explains how the market fails to allocate resources

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efficiently in agriculture, such as public goods. Additionally, imperfect information requires government intervention to ensure that the agricultural market ecosystem is more sustainable regarding subsidy allocation, innovation investment from the government, and government support for R&D, enabling agriculture to be conducted modernly.

Factors Affecting Agricultural Resilience

Numerous factors influence agricultural resilience, including economic policies, technological innovation, market conditions, and environmental variability. Recent literature emphasises the importance of integrating these factors into resilience assessments to capture the complex dynamics (Folke *et al.*, 2016; Tendall *et al.*, 2015). Economic policies like subsidies, trade agreements, and financial support can significantly impact resilience by stabilising incomes and promoting investment or creating dependencies that may undermine long-term sustainability (Jayne *et al.*, 2018). Recent studies by Slijper *et al.* (2022) show that beyond economics, social capital and learning networks are vital drivers of resilience, especially in enabling farmers to adapt through shared knowledge and innovation.

R&D is critical in strengthening resilience through sustainable practices (Vermeulen *et al.*, 2018), integrating climate-smart technologies and practices (Fischer *et al.*, 2017), and resource efficiency by advancing technological innovation. It facilitates farmers in using agricultural tools that can help them estimate accurate resource use (Fuglie, 2018; Lipper *et al.*, 2020) and reduce waste of resources, such as water, energy, and nutrients, based on analytical data generated using drones and IoT sensors. For instance, AI and remote sensing now allow real-time crop health and resource efficiency monitoring, offering transformative potential in predictive farm management (Jung *et al.*, 2021). These technologies enhance the precision and scalability of resilience-building practices in agriculture. Therefore, R&D in agriculture can ensure food security by increasing resilience to global climate change shocks, thus serving as an investment opportunity in Malaysia's innovative agricultural technology.

The Malaysian agricultural sector has undergone significant transformation driven by modernisation, technological adoption, and policy reforms. However, the sector still faces challenges related to climate change (Firdaus *et al.*, 2020), labour shortages (Prasad, 2017; Tittonell, 2020), and market fluctuations (Cassey *et al.*, 2018). Recent studies on Malaysia's agriculture have highlighted the importance of resilience in ensuring food security and economic stability. For example, Lim *et al.* (2021) examined the impact of climate change on rice production in Malaysia, emphasising the need for

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adaptive strategies to enhance resilience. Another study by Hassan *et al.* (2022) explored the role of government policies in supporting agricultural resilience, focusing on the effectiveness of subsidies and infrastructure development. Malaysian rice production faces extreme weather, poor soil fertility, farmers' lack of awareness, and limited technological deployment (Dorairaj & Govender, 2023).

In China, Gao *et al.* (2024) found that digital inclusive finance significantly enhances agricultural resilience by improving rural industrial integration and financial access. Meanwhile, Luo *et al.* (2024) demonstrated through a spatial-temporal analysis that regional disparities, urbanisation, and spatial spillovers shape resilience outcomes, which suggests the need for spatially targeted policy interventions. These studies underscore that agricultural resilience is not static but evolves in response to geographic, institutional, and technological shifts. Additionally, Boahen *et al.* (2023) revealed that resilience research varies by region, suggesting that design strategies and objectives for agricultural systems should differ by region. For instance, Nguyen *et al.* (2019) proved that agricultural systems in Vietnam's Mekong and Red River deltas need improved resilience to adapt to increased salinity intrusion and social-ecological changes.

Despite these efforts, a comprehensive, multidimensional assessment of agricultural resilience in Malaysia, particularly about R&D investments, remains limited. This study addresses the gap by developing an Agricultural Resilience Index (ARI) and analysing trends over time using advanced statistical methods such as PCA and trend analysis. This study contributes new empirical evidence and a robust framework for enhancing Malaysia's agricultural resilience by integrating technological factors, labour, policy, and financial dimensions.

Methodologies for Assessing Resilience

The methodologies for assessing agricultural resilience have evolved significantly, with a growing emphasis on quantitative approaches that allow for integrating multiple indicators (Creswell & Creswell, 2018). Principal Component Analysis (PCA) and trend analysis are standard methods used in recent resilience studies. PCA has been widely employed to construct composite indices that capture the multidimensional nature of resilience (Jolliffe & Cadima, 2016). For instance, recent studies in Indonesia and South Africa have used PCA to develop resilience indices, highlighting the most significant factors contributing to agricultural stability (Siregar *et al.*, 2024; Bahta & Myeki, 2021).

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PCA is widely regarded among researchers for its effectiveness in reducing multiple indicators into a single, interpretable index. This method is particularly advantageous for capturing the multidimensional nature of agricultural resilience as it simplifies complex datasets without significant information loss (Jolliffe, 2002; Abson *et al.*, 2012). Compared to time-series models such as ARIMA or multivariate analysis, PCA handles correlated variables and constructs composite indices representing overall sector stability (Filmer & Pritchett, 2001).

On the other hand, trend analysis provides insights into how long-term climate change and short-term weather disturbances affect resilience based on experience to shape future resilience strategies (He *et al.*, 2024). The combination of PCA and trend analysis is particularly effective in assessing resilience as it allows for a comprehensive evaluation of the current state and the historical evolution of resilience (Yang *et al.*, 2019).

2. Methodology

Research Design

This study employed a quantitative research design to evaluate the resilience of Malaysia's agricultural sector. Specifically, the Agricultural Resilience Index (ARI) was developed to capture multidimensional aspects of resilience. The analysis was based on secondary annual data from 1996 to 2023 from reputable sources, including the World Bank, the Department of Statistics Malaysia, the Ministry of Agriculture and Food Industries, Bank Negara Malaysia, and the Malaysian Investment Development Authority. Principal Component Analysis (PCA) was utilised to construct the ARI, as it is particularly well-suited for reducing the dimensionality of complex datasets, identifying latent patterns, and transforming multiple correlated indicators into a single composite index with minimal information loss. In addition, trend analysis was conducted to examine the temporal progression of agricultural resilience over the study period.

Research Framework

Figure 1 illustrates the research framework by highlighting the selected indicators that can capture the resilience of the agricultural sector in Malaysia. The selection of indicators was guided by three key considerations: (i) relevant theoretical underpinnings, including Resilience Theory, Human Capital Theory, and Innovation Theory; (ii) empirical support from prior

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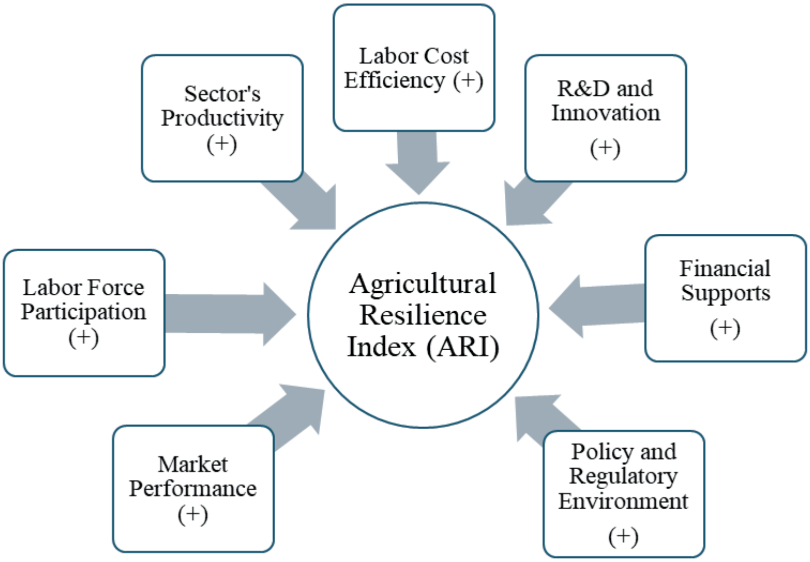
Figure 1 - The Framework of Agricultural Resilience Index (ARI)



Source: Developed by the authors.

studies (e.g., Siregar *et al*., 2024; Abson *et al*., 2012); and (iii) contextual applicability to Malaysia's agricultural sector. As illustrated in Figure 1, the research framework captures the multidimensional nature of agricultural resilience through seven core indicators: sector productivity, market performance, labour cost efficiency, innovation and technology (measured by R&D investment), labour and human capital, financial indicators, and the policy and regulatory environment. All indicators were standardised before analysis to satisfy Principal Component Analysis's (PCA) assumptions, particularly the normality requirements and equal variance contribution.

The first indicator is the Sector's Productivity. It is determined by measuring the average output produced by each worker in the agricultural sector, indicating labour productivity.

$$Agricultural\ Outputs\ Per\ Worker_t = \frac{Total\ Agricultural\ Output_t}{Number\ of\ Agricultural\ Workers_t} \quad (1)$$

Based on Eq. (1), total agricultural output is the total value of agricultural products produced within a specific period, typically measured in monetary terms. The number of agricultural workers refers to the total number of individuals employed in the agricultural sector within the same period. It

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includes all types of workers, such as full-time, part-time, and seasonal, regardless of skill level.

Higher agricultural output per worker indicates greater labour productivity, which is crucial for the competitiveness and resilience of the sector. Productivity gains can lead to cost reductions, higher profitability, and the ability to offer competitive prices in international markets. According to Diao *et al.* (2010), increased labour productivity in agriculture is associated with economic growth and enhanced sectoral competitiveness, especially in developing countries where agriculture plays a significant role in the economy. Studies have shown increased productivity correlates with reduced vulnerability to economic disruptions and natural disasters (Tittonell, 2020). Therefore, a positive impact is expected from the sector's productivity towards the sector's resilience.

The second indicator is Market Performance, which is measured using the trade balance in agriculture. The difference between agricultural exports and imports indicates the sector's ability to compete internationally.

$$Trade\ Balance\ in\ Agriculture_t = Agricultural\ Exports_t - Agricultural\ Imports_t \quad (2)$$

Based on Eq. (2), agricultural exports refer to the total value of agricultural products exported from Malaysia within a specific period. The data should include all major agricultural products, including crops, livestock, fisheries, and other related goods. Agricultural imports also describe the total value of agricultural products imported into Malaysia within the same period, including all major agricultural products.

A positive trade balance (where exports exceed imports) enhances resilience by diversifying income sources and reducing dependency on domestic markets, which can be vulnerable to localised shocks. Latruffe (2010) highlighted that a favourable trade balance is a key indicator of a competitive agricultural sector as it reflects the sector's ability to produce goods that are in demand globally while maintaining cost-effective production. Furthermore, Reardon *et al.* (2019) argue that integrated value chains and market diversification act as buffers against global price volatility, enabling sectors to sustain profitability during economic downturns. Accordingly, a positive impact is expected.

The third indicator is Labour Cost Efficiency, which measures how effectively the agricultural sector uses its labour force to produce output.

$$Labor\ Cost\ Efficiency_t = \frac{Total\ Labor\ Cost_t}{Total\ Value\ of\ Outputs_t} \quad (3)$$

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Based on Eq. (3), total labour cost is calculated by multiplying the average salary by the total number of agricultural workers. The input-output ratio measures the efficiency of resource use in production. A lower ratio indicates higher efficiency whereby the sector can produce more output with less input, leading to lower costs and higher competitiveness. Furthermore, efficient labour utilisation strengthens resilience by enhancing the sector's adaptability to labour market shocks. Stigler (1958) emphasised that optimising labour input during times of crisis can mitigate financial strain, ensuring continued operations and recovery. Studies on agricultural efficiency have emphasised the importance of optimising input use to enhance competitiveness, with efficient input management being a critical factor for maintaining competitive advantage in the agricultural sector (Coelli *et al.*, 2005).

Innovation and technology are important indicators under investigation in this study. Investment in research and development (R&D) represents the amount of funding allocated to R&D in agriculture, thus reflecting the sector's focus on innovation. This is captured by the total R&D expenditure, which refers to all funds spent on research and development activities within the Malaysian agricultural sector. It covers public and private sector investments, including government grants, private company spending, and contributions from international organisations. Investment in R&D drives innovation, leading to the development of new technologies, improved farming practices, and higher yields. This can drive resilience by equipping the sector with tools to adapt to climate change, resource scarcity, and other challenges. For example, precision agriculture technologies and drought-resistant crop varieties have been shown to mitigate the adverse effects of extreme weather events (Fuglie, 2018). These advancements eventually increase the sector's capacity to absorb shocks and maintain productivity. The relationship between R&D investment and competitiveness/resilience has been well-documented, with studies indicating that countries with higher R&D investments in agriculture tend to be more competitive internationally (Pardey *et al.*, 2006). Accordingly, a positive impact is expected from R&D towards ARI.

The fourth indicator is Labour and Human Capital. The proportion of the total labour force employed in agriculture indicates the sector's importance in the economy. Research indicates that labour force participation can significantly boost the agricultural sector's competitiveness when aligned with skill development and productivity enhancements (Martin & Mitra, 2001). High labour force participation can provide a competitive advantage if accompanied by adequate training and productivity. A skilled labour force is essential for resilience as it facilitates the adoption of new technologies and practices during crises. However, skill mismatches or an ageing workforce can reduce the sector's adaptability. Strengthening education and training

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programs can bridge this gap, thus enhancing the sector's capacity to respond to shocks.

The labour force participation in agriculture can be calculated using the following formula:

$$Labor\ Force\ Participation\ in\ Agriculture\ (\%)_t = \left(\frac{Number\ of\ Agricultural\ Workers_t}{Total\ Labor\ Force_t}\right) \times 100 \quad (4)$$

Based on Eq. (4), labour force participation in agriculture refers to the proportion of the total labour force employed in the agricultural sector. The total labour force represents the total number of economically active people, including those employed in all sectors and actively seeking work. This indicator reflects the importance of agriculture in the national economy and provides insights into the availability of labour resources within the sector. Hence, a positive impact is expected.

The fifth component is Financial Indicators, which are represented by the total domestic and foreign investment in the agricultural sector. In this context, investment in agriculture is captured by the total amount of domestic credit allocated to the agricultural sector by banks and other financial institutions. Domestic credit represents the total amount of loans, advances, and other forms of credit provided by domestic banks and financial institutions specifically for agricultural purposes. Investment in agriculture is a key driver of competitiveness as it enables the sector to adopt new technologies and improve production processes, leading to greater efficiency and market success (Binswanger *et al.*, 2009). Access to credit and investment acts as a financial buffer, enabling farmers to recover quickly from economic shocks or natural disasters. For example, Agrobank's smallholder financing schemes provide critical capital for recovery and innovation (Jayne *et al.*, 2018).

The final indicator is the Policy and Regulatory Environment, which represents government financial support to the agricultural sector, such as subsidies, tax incentives, and grants. This encourages innovation and expansion within the agricultural sector. Well-designed policies can enhance resilience by reducing input costs and promoting sustainable practices. For instance, the Malaysian Palm Oil Certification Scheme (MSPO) ensures compliance with environmental standards, reducing the sector's vulnerability to trade restrictions and environmental degradation (Hamid *et al.*, 2024). Numerous studies have highlighted the role of government subsidies in enhancing the resilience of the agricultural sector by reducing input costs and supporting farmers in adopting new technologies (Orden *et al.*, 2006).

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Using government expenditure on agriculture is a straightforward and effective way to measure government support. Government expenditure on the agricultural sector refers to the government's public funds for various agricultural programs and initiatives. This includes spending on subsidies, R&D, infrastructure, training, and other support forms to enhance the sector's productivity, competitiveness/and resilience. More focus and operational expenditures have been used, which refers to the day-to-day costs of running the agricultural sector. This encompasses expenses related to the maintenance of existing infrastructure, salaries of government employees in the agricultural sector, ongoing subsidy programs, and other recurring costs.

Variables and Data Sources

Table 1 presents the data used in this study and its sources.

Table 1 - Variables and Data Sources

Variable	**Unit**	**Data Source**
Total Agricultural Output	RM Million	World Bank
Number of Agricultural Workers	Thousand worker	Department of Statistics Malaysia *The agricultural industry is classified according to the "Malaysia Standard Industrial Classification (MSIC) 2008"
Agricultural Exports	RM Billion	World bank *at constant price
Agricultural Imports		
Total Labour Cost	RM Thousand	Department of Statistics Malaysia *at a constant price
Average Salary in the Agriculture Sector	RM	
Total R&D Expenditure in Agriculture	Billion	World Bank
Total Labour Force	Thousand	Department of Statistics Malaysia
Total Agricultural Credit	RM Billion	World Bank
Total Government Expenditure on Agriculture	RM Million	Ministry of Finance Malaysia

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Data Analysis Techniques

Principal Component Analysis (PCA) was utilised to reduce the dimensionality of the dataset while retaining the most significant variables contributing to agricultural resilience in Malaysia. It is a popular method used to asses sector performance and resilience (e.g., Siregar *et al.*, 2024). This method allows the construction of a composite measure of the sector's stability, such as investment, labour, or government spending. Among the advantages of PCA is the reduction of the complexity of the dataset by transforming it into a smaller set of uncorrelated variables known as principal components. This process is crucial for managing the multiple indicators of agricultural resilience in a manner that simplifies analysis without significant loss of information (Jolliffe & Cadima, 2016). These indicators were selected based on their relevance to agricultural resilience, as identified in the literature. Such a method identifies the most important indicators contributing to the overall variability in the data. In this study, PCA helped pinpoint the critical factors – such as investment, labour, or government spending – that contribute to the resilience of Malaysia's agricultural sector (Jolliffe, 2002). Lastly, PCA is particularly effective for constructing composite indices like the Agricultural Resilience Index (ARI). Combining the principal components, PCA provides a comprehensive measure of resilience that reflects the combined effect of all selected indicators (Jolliffe, 2002).

According to Siregar *et al.* (2024), there are six important steps for using PCA to analyse the resilience of the agricultural sector. Similar steps were followed in this study. However, PCA assumes linear relationships among variables and is sensitive to outliers, which was addressed in this study through standardisation and robust data cleaning. The data was standardised using Z-score normalisation to ensure comparability across indicators (Jiang *et al.*, 2018). Such a method entails that each variable contributes equally to PCA without altering the underlying distribution of the data. This can be achieved using the following formula:

$$Z_i = \frac{X_i - \mu}{\sigma} \quad (5)$$

Where Z_i is the standardised value, X_i is the observed value, μ is the mean, and σ is the standard deviation of the data sample. The principal components were extracted based on eigenvalues greater than 1.0, and factor loadings were analysed to identify the most influential variables contributing to resilience. The cumulative variance explained by the selected components was used to assess ARI robustness.

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Trend Analysis

Trend analysis was performed to assess the temporal evolution of ARI from 1996 to 2023, providing information on how the resilience of the agricultural sector has evolved. The slope of the regression line indicated the rate of change in resilience over time, while the R^2 value assessed the model's goodness of fit. The statistical significance of the trend was evaluated using p-values, ensuring robust conclusions. The trend analysis aimed to identify whether the sector has become resilient, providing insights into the effectiveness of policies and investments over the years. The results of time trend analysis can have significant policy implications. If specific trends are identified as positive or negative, policymakers can use this information to guide strategic planning, ensuring that resources are allocated effectively to enhance or maintain resilience. The regression model used to analyse the trend is given by:

$$Y = a + bX + \varepsilon \quad (6)$$

Where Y represents the ARI over time, X represents time (year), a is the intercept, b is the slope indicating the rate of change in ARI, and ε is the error term. A limitation of trend analysis is that it may oversimplify cyclical or nonlinear patterns, which was mitigated by complementing it with residual diagnostics and error metrics like Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE).

Validity and Reliability

Validity and reliability are fundamental concepts in research, particularly in data analysis studies, such as assessing agricultural resilience. These tests ensure that the results are accurate and consistent, enhancing the credibility and generalisability of the findings. Validity refers to the degree to which a research instrument measures what it is intended to measure. In the context of this study, validity ensures that the indicators and methods used (like PCA) accurately capture the concept of agricultural resilience. The validity of the PCA results was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value of 0.718 indicates a middling adequacy for PCA. Meanwhile, a KMO value above 0.7 is generally considered acceptable. It can reasonably proceed with factor analysis, though the results might not be as strong as they would be with a higher KMO value (Kaiser, 1974).

On the other hand, reliability refers to the measurement's consistency over time or across different observers. A reliable instrument will yield

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the same results under consistent conditions. Bartlett's test confirmed the appropriateness of the factor analysis with a significant p-value (Bartlett, 1950; Kaiser, 1974). The Chi-Square value was 187.012 with 21 degrees of freedom, and the significance level was 0.000, which is highly significant. It indicates that the correlations between variables are statistically significant and not random, thus supporting the suitability of the data for factor analysis. The significant Bartlett's test suggests adequate relationships between the variables, further justifying factor analysis.

Table 2 - KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.718
Bartlett's Test of Sphericity	Chi-square value	187.012
	Degree of freedom	21
	Significant value	0.0000

Source: Authors' calculation using SPSS.

3. Results and Discussion

Table 3 summarises the descriptive statistics of the ARI indicators over the 28-year study period to provide a basic understanding of the dataset used in this study. The mean values for Labour Cost and Innovation and Technology are 0.0188 and 0.7657, respectively. This indicates that modernising the agricultural sector by using high-tech machinery helps increase labour productivity relative to labour cost. At the same time, agricultural innovation supports the development of advanced technologies in agriculture. The ARI indicators, such as Productivity and Finance Indicators, range from 18.4990 to 102.5962 and 4.8226 to 16.2218, respectively, highlighting the dynamic nature of Malaysian agricultural resilience. Productivity (69.3426), Labour and Human Capital (13.5354), and Market Performance (9.8077) have higher medians, indicating that their contributions to resilience are slightly skewed towards higher values. These statistics provide an overview of the dynamics and distribution of the data, complementing both PCA and trend analysis.

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Table 3 - Summary of Descriptive Statistics for Indicators of ARI

Indicator	**Mean**	**Median**	**Maximum**	**Minimum**	**Standard Deviation**
Productivity	60.95512	69.3426	102.5962	18.4990	26.0246
Market Performance	9.8077	9.3479	15.0951	1.0976	3.7529
Labour Cost Efficiency	0.0188	0.0185	0.0236	0.0131	0.0032
Innovation and Technology	0.7657	0.8687	1.4722	0.1274	0.4302
Labour and Human Capital	13.6388	13.5354	19.3611	10.2240	2.6790
Financial Indicators	9.5828	9.8250	16.2218	4.8226	2.8472
Policy and Regulation	2.9700	2.8745	5.4150	1.1210	1.4285

Source: Authors' calculation using EViews.

Table 4 shows the PCA results for selected indicators of agricultural sectors in Malaysia. Productivity obtained a factor score of 0.4470, a significant positive contributor to agricultural resilience in Malaysia. Higher productivity means the sector can produce more output with the same or fewer inputs, which is critical for sustaining its growth and resilience. For instance, while the local rice sector is vital for food security, it faces challenges with low productivity due to outdated farming techniques, poor soil fertility management, and limited mechanisation (Dorairaj & Govender, 2023). However, government programs like the Paddy Estate Model aim to consolidate small rice farms and introduce modern farming techniques to improve productivity.

Table 4 - Results from Principal Component Analysis

No.	**Agricultural Sector Resilience Indicators**	**Factor Score**
1.	Productivity	0.4470
2.	Market Performance	0.2435
3.	Labour Cost Efficiency	0.1329
4.	Innovation and Technology	0.4716
5.	Labour and Human Capital	–0.4488
6.	Financial Indicators	0.4206
7.	Policy and Regulatory Environment	0.3501

Source: Authors' calculation using EViews.

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Furthermore, Malaysia's fisheries sector has seen efforts to increase productivity through sustainable aquaculture practices. For instance, the introduction of advanced aquaculture technologies and better management practices, such as the adoption of biofloc technology and automated feeding mechanisms, has improved yields in shrimp farming, which is a significant export commodity for Malaysia (Khanjani *et al.*, 2023; Joffre *et al.*, 2019; Department of Fisheries Malaysia, 2022). As one of the world's largest, Malaysia's oil palm sector has also seen improvements in productivity due to the adoption of better agricultural practices and improved palm oil varieties. However, there is ongoing pressure to further enhance productivity to maintain global competitiveness, particularly with the rise of Indonesia as a major producer that challenges Malaysia's position in the worldwide market (Institute of Strategic and International Studies Malaysia, 2024). While these sectors have improved productivity, continued innovation and strategic investments are essential to ensure Malaysia remains competitive and resilient in the global agricultural landscape. A study by Li *et al.* (2011) concluded that agricultural systems' resilience gradually increased as more materials and technology were accumulated, based on the significant increase in grain yield and agricultural profitability.

Market Performance obtained a factor score of 0.2435, indicating its positive influence over resilience. It reflects the importance of strong market access, favourable trade conditions, and competitive positioning in global markets. However, market performance is heavily influenced by trade relations and consumer preferences, making it essential to maintain quality and navigate trade policies effectively. For instance, Malaysia has positioned itself as a major exporter of durians, particularly the Musang King variety. The government's efforts to penetrate the Chinese market have paid off, significantly boosting the agricultural sector's income and resilience and ultimately leading to a sharp increase in demand. The export value of Malaysian durians to China reached RM887 million in 2022, and such a figure is expected to continue rising as Malaysia expands its market share in China, where durian is considered a premium product. This will be achieved by diversifying its export portfolio and reducing its dependency on traditional commodities (Malay Mail, 2024; South China Morning Post, 2023).

Furthermore, palm oil is Malaysia's leading agricultural export, contributing significantly to the country's trade balance. However, the sector faces challenges from fluctuating global prices, trade barriers, and increasing competition from other palm oil-producing countries such as Indonesia and Thailand. Despite these challenges, the strong performance of palm oil in international markets has helped sustain the sector's resilience. Malaysia's participation in trade agreements like the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) has had mixed impacts

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on agricultural market performance, providing opportunities for growth and competitive advantage while increasing competition in others (MIDA, 2020).

Meanwhile, Labour Cost Efficiency obtained a factor score of 0.1329, indicating its small yet important role in resilience. The efficient use of labour resources can help lower production costs, which is crucial for maintaining profitability in a competitive market. This aligns with the Theory of Economies Scales, which states that efficient labour utilisation reduces labour costs and contributes towards lower production costs (Stigler, 1958). In many local sectors like fruit and vegetable farming, particularly in Cameron Highlands, labour cost efficiency has been improved using drip irrigation systems and other modern farming techniques. These methods reduce the reliance on manual labour and increase efficiency, leading to better profit margins (Abdullah *et al.*, 2021). Interestingly, the Malaysian tea industry, particularly in Cameron Highlands, has gradually shifted towards mechanisation to improve labour cost efficiency. However, the high cost of machinery and the steep terrain present challenges to widespread mechanisation, making labour cost efficiency an ongoing issue.

Malaysia's agricultural sector heavily relies on foreign labour, particularly in plantations like palm oil. For instance, the Malaysian palm oil sector reported a shortage of approximately 40,000 foreign workers in 2024. It significantly impacted production, leading to an estimated loss of RM7.9 billion in export value due to the unharvested fresh fruit bunches (FFB) (New Street Times, 2024). This reliance has led to concerns about labour cost efficiency, especially when considering rising labour costs, dependency on low-skilled labour, and challenges in mechanisation. Efforts to improve labour cost efficiency through mechanisation have been slow, particularly in smallholder farms. The government has initiated programs to encourage technology adoption, but the high cost of mechanisation remains a barrier.

The PCA results also showed that Innovation and Technology are Malaysia's most significant contributors to agricultural resilience, with a factor score of 0.4716. It emphasises the importance of adopting new practices and technologies to stay competitive and sustainable. The Malaysian government has been promoting smart farming practices that integrate the Internet of Things (IoT), data analytics, and automation. For instance, IoT sensors are used in the chicken farming industry to monitor temperature, humidity, and feed levels in real-time, thus optimising conditions for better productivity and reduced losses. A study by Hidzir and Ismail (2022) explored the implementation of IoT in poultry farming and found that IoT-based monitoring systems, which include sensors for temperature and humidity alongside automated feeding mechanisms, help maintain optimal conditions in chicken coops. This leads to better growth rates and reduced mortality, ultimately contributing to higher productivity and profitability

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in the sector. Additionally, the integration of agroforestry practices, where trees are grown alongside crops or livestock, has been gaining attention in Malaysia. This method diversifies farmers' income streams and improves soil health and resilience against climate change impacts.

Furthermore, Malaysia has invested in precision agriculture technologies, such as drones, IoT sensors, and data analytics, to optimise crop yields and reduce resource use. For example, drone technology is increasingly used in palm oil plantations for monitoring and precision spraying, significantly boosting productivity and sustainability (Ismail, 2024). The Malaysian Agricultural Research and Development Institute (MARDI) has been at the forefront of agricultural innovation by focusing on developing high-yield crop varieties, sustainable farming practices, and biotechnology advancements. Therefore, Malaysia is moving in the right direction in adopting and enhancing innovation and R&D in the agricultural sector to create sustainability and resilience.

Interestingly, Labour and Human Capital had a factor score of -0.4488, indicating its negative impact on the resilience of Malaysia's agricultural sector. This might be attributed to challenges like skill mismatches, ageing workforces, and possibly a lack of training in new technologies. This is contradicted by the prediction that a positive impact is expected, which can be linked to structural reforms and labour emigration from one sector to another. For instance, the local cocoa sector faces significant challenges due to an ageing farmer population, with many young people opting for jobs outside agriculture (Malay Mail, 2023). This has decreased production as older farmers are less likely to adopt new techniques that could improve yields. Siregar *et al.* (2024) found that agricultural workers' income strongly correlates with ARI, followed by NTUP, total credit, investment, government spending, and trade. In contrast, a higher proportion of agricultural workers in total labour tends to lower resilience. This shows that agricultural workers hurt ARI, which is equivalent to our study.

There is also a growing recognition of skills mismatch in Malaysia's agribusiness sector (Howell, 2022). Many agricultural workers lack the technical skills to operate modern machinery or apply new farming techniques, which hampers productivity and innovation. The local agricultural sector faces a significant challenge with an ageing workforce. Young people are increasingly reluctant to enter farming, leading to a lack of skilled labour and a declining workforce, negatively impacting the sector's resilience. Reports indicate that only 15% of youth are involved in the agriculture business in Malaysia (BusinessToday, 2021, 2023). Despite the government's efforts to enhance agricultural education and training, there remains a gap in skills and knowledge, particularly in adopting

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new technologies. This gap reduces the effectiveness of human capital in contributing to resilience.

Next is Financial Indicators, with a factor score of 0.4206. Financial factors are crucial for resilience, highlighting the importance of access to credit, investment, and financial stability in the agricultural sector. Smallholders in the palm oil and rubber sectors often struggle to access finance due to stringent loan conditions. However, initiatives like Agrobank's financing schemes for smallholders aim to bridge this gap, enabling farmers to invest in improvements that can enhance resilience. Malaysia's implementation of the Halal Industry Master Plan 2030 (HIMP 2030) aimed to enhance industry competitiveness, expand markets, and develop a pool of halal experts to meet global demand. The initiative attracted significant investment in the halal food industry, providing financial support for businesses to expand and innovate (MIDA, 2023). This financial backing is crucial for maintaining the sector's growth and resilience against global competition.

The Malaysian government has provided various financial incentives to support farmers and agribusinesses, including subsidies and grants such as the Young Agropreneur Grant and Halal Industry Development Grant. These financial supports are crucial for maintaining productivity and enabling the adoption of new technologies. However, smallholders often face difficulties accessing finance due to stringent requirements and limited collateral. This limits their ability to invest in improvements, making them more vulnerable to economic shocks.

Lastly, the Policy and Regulatory Environment obtained a factor score of 0.3501, indicating its positive influence on resilience. Well-crafted policies can significantly enhance the sector's capacity to adapt and thrive. The Ministry of Finance Malaysia reported that the government allotted RM2.6 billion in fertiliser subsidies for paddy farmers to reduce production costs and boost productivity (Ministry of Finance Malaysia, 2023). This policy helps sustain the rice sector's resilience by ensuring farmers can afford essential inputs. Furthermore, Malaysia has implemented sustainable fisheries policies to combat overfishing and protect marine biodiversity. These policies include quotas, seasonal bans, and the promotion of aquaculture as an alternative to wild-capture fisheries. Such regulatory measures will ensure the long-term sustainability and resilience of the fisheries sector. Implementing the MSPO certification has helped improve the sustainability of palm oil production in Malaysia, enhancing the sector's resilience by ensuring compliance with environmental and social standards. Furthermore, regulatory policies related to land use, such as converting agricultural land for industrial purposes, have a mixed impact on resilience. While these policies can drive economic diversification, they also reduce the availability of land for agriculture,

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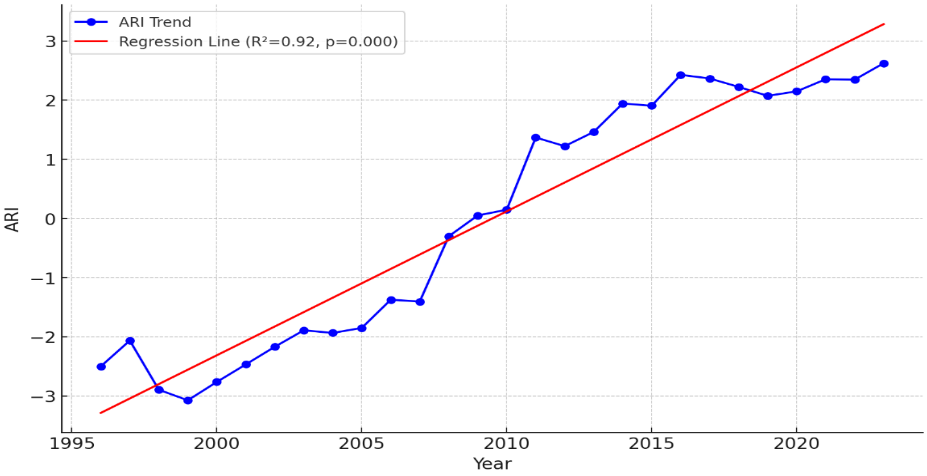
potentially weakening the sector's resilience. This is supported by Qun *et al.* (2024), who highlighted that agricultural science and technology innovation have a nonlinear and significant positive effect on agricultural resilience, which relevant fiscal policies can further support.

In summary, the factor analysis revealed that innovation and technology, productivity, and financial support are crucial drivers of agricultural resilience across various sectors in Malaysia. However, labour and human capital challenges, market dynamics, and policy implementation must be addressed to enhance the sector's overall resilience. Diversifying the focus to include different agricultural sectors, such as rice, fisheries, rubber, and fruit farming, provides a more comprehensive understanding of the factors influencing resilience in Malaysia's agricultural landscape.

Figure 2 - The Agricultural Resilience Index (ARI) Trend of Malaysia's Agricultural Sector



Source: Illustrated using EViews.

Figure 2 shows the ARI trend in Malaysia's agricultural sector from 1996 to 2023. A clear upward trend can be observed in the ARI values, and the regression line fitted to the data has a positive slope of approximately 0.24. This indicates that, on average, the ARI value increases by 0.24 units yearly. Meanwhile, the slope of the regression line represents the rate at which ARI changes each year. The slope of 0.24 suggests that ARI has steadily increased over the 28 years. This positive slope suggests a consistent upward movement in ARI, which might imply an increasing frequency of the event or metric being measured by ARI, depending on its specific definition.

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The R^2 value of 0.92 is very high, indicating that the regression model explains about 92% of the variance in ARI values. This means the trend is strong, and the ARI values closely follow a linear pattern over time. In simpler terms, the year-to-year changes in ARI are primarily predictable based on the time variable alone. The p-value associated with the regression line is extremely small (i.e., 0.0000), indicating that the upward trend is statistically significant. This means that the observed increase in ARI over time is unlikely due to random variation; instead, it reflects a real, underlying pattern.

As shown in Figure 2, the ARI values began in negative territory (e.g., –2.498 in 1996) and gradually increased, crossing into positive territory around 2008 (0.05) and continuing to rise after that. By 2023, the ARI value was 2.62, showing substantial growth. This upward trend could indicate the increasing frequency or severity of the events or conditions ARI measures. For example, if ARI is related to environmental factors, this might suggest worsening conditions or more frequent occurrences of a particular phenomenon over time. It would be important to consider external factors or events that could have influenced the ARI values during the period. For example, policy changes, technological advancements, or significant global events might have contributed to shifts in the trend. In parallel, R&D investments showed gradual increases, particularly in the 2010s, driven by government initiatives like the National Agrofood Policy and increased allocations for agricultural research under Malaysia's Five-Year Plans. These investments facilitated the adoption of precision agriculture, biotechnology, and sustainable farming practices, which are reflected in the upward ARI trend. Despite these improvements, some periods, such as the late 1990s Asian financial crisis, witnessed a decline in resilience. This underscores the sensitivity of agricultural systems to economic shocks, even in the presence of R&D investments. Furthermore, the challenges in the early 2020s, such as labour shortages exacerbated by the COVID-19 pandemic, highlight ongoing vulnerabilities despite technological advancements.

The robustness of ARI was evaluated using ACF and PACF tests and reported in Figure 3. These tests assessed the presence of serial correlations in the residuals and provided insights into the short-term dependencies within the data. The analysis was conducted in differencing to achieve stationarity (Lin *et al.*, 2023). The ACF results suggest that the residuals exhibit low dependencies over time. This finding supports the assumption that ARI adequately captures the underlying trends in agricultural resilience without significant autocorrelation. Similarly, the PACF results indicate that the ARI's construction minimises direct relationships with lagged terms. The combined results of the ACF and PACF tests validate the robustness of the trend analysis by confirming the absence of systematic patterns or dependencies that could compromise the reliability of ARI.

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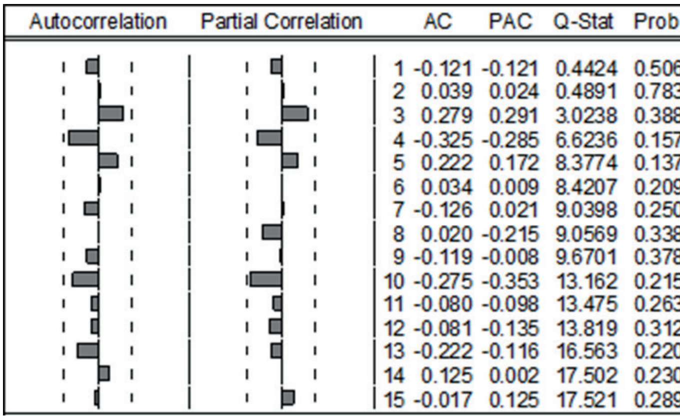
Figure 3 - The Autocorrelation (ACF) and Partial Correlation Function (PACF) Test Results for Agricultural Resilience Index in Malaysia



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.121	-0.121	0.4424	0.506
		2	0.039	0.024	0.4891	0.783
		3	0.279	0.291	3.0238	0.388
		4	-0.325	-0.285	6.6236	0.157
		5	0.222	0.172	8.3774	0.137
		6	0.034	0.009	8.4207	0.209
		7	-0.126	0.021	9.0398	0.250
		8	0.020	-0.215	9.0569	0.338
		9	-0.119	-0.008	9.6701	0.378
		10	-0.275	-0.353	13.162	0.215
		11	-0.080	-0.098	13.475	0.263
		12	-0.081	-0.135	13.819	0.312
		13	-0.222	-0.116	16.563	0.220
		14	0.125	0.002	17.502	0.230
		15	-0.017	0.125	17.521	0.289

Source: Illustrated using EViews.

Table 5 - Diagnostic Test Results for Agricultural Resilience Index Trend Analysis in Malaysia

Normality Test (Jarque-Bera)	3.3187 (0.1903)
Heteroskedasticity Test (Breusch-Pagan-Godfrey)	0.0489 (0.8268)

Source: Authors' calculation using EViews.

Diagnostic tests were conducted to assess normality and heteroskedasticity and further validate the robustness of the ARI trend analysis in Malaysia. The results are summarised in Table 5. The Jarque-Bera Normality Test yielded a test statistic of 3.3187 with a p-value of 0.1903, indicating that the residuals do not significantly deviate from a normal distribution. This supports the assumption of normality, which is critical for ensuring the reliability of the trend analysis and interpreting subsequent inferential statistics. The Breusch-Pagan-Godfrey Heteroskedasticity Test produced a test statistic of 0.0489 with a p-value of 0.8268, suggesting no evidence of heteroskedasticity in the residuals. This confirms that the variance of the residuals remains constant across observations, thereby validating the homoscedasticity assumption of the model.

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Table 6 - Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE) Analysis Results for Agricultural Resilience Index Trend in Malaysia

Mean Absolute Error (MAE)	0.2517
Mean Squared Error (MSE)	0.0804
Root Mean Squared Error (RMSE)	0.2835

Source: Illustrated using EViews.

Lastly, Table 6 presents the error metrics used to evaluate the accuracy and robustness of the ARI trend analysis in Malaysia. The MAE, MSE, and RMSE quantitatively assess the model's performance (Gomez *et al*., 2024; Praveenkumar *et al*., 2024). The MAE, calculated at 0.2517, indicates that, on average, the model's predictions deviate from the actual values by approximately 0.25 units. This reflects a relatively low error level, demonstrating the model's accuracy in capturing the dynamics of agricultural resilience (Akbari *et al*., 2024).

The MSE, which is reported as 0.0804, indicates the average squared deviation between predicted and actual values. The small magnitude of the MSE highlights the model's ability to minimise significant prediction errors, which is critical for maintaining reliability in long-term trend analysis. The RMSE, derived as 0.2835, represents the typical magnitude of prediction errors in the same units as ARI. The slightly higher RMSE value than MAE suggests that significant outliers or extreme deviations do not significantly impact the model (Hassanat *et al*., 2023).

These error metrics confirm that the trend analysis provides reliable predictions of ARI with minimal errors. The results align with other diagnostic tests conducted in this study, further supporting the robustness and validity of the methodological framework.

Conclusions

The resilience of Malaysia's agricultural sector is crucial for ensuring the nation's food security, economic stability, and sustainable development amidst the mounting global and local challenges. This study has developed an Agricultural Resilience Index (ARI) to provide a comprehensive measure of resilience by incorporating multiple dimensions, such as economic stability, technological innovation, environmental sustainability, and social adaptation. By employing PCA and trend analysis, the study offers valuable insights into

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the indicators that influence resilience and the trends that have shaped the sector's performance over the past few decades.

The findings of this study highlight the significant role of research and development (R&D) investments in enhancing agricultural resilience. R&D has proven to be a key driver of innovation and productivity, facilitating the adoption of advanced technologies and practices that enable the agricultural sector to adapt to changing environmental and economic conditions. The positive correlation between R&D investments and resilience underscores the importance of sustained and targeted investments in this area to ensure the long-term viability of Malaysia's agriculture.

Furthermore, the study revealed important trends in agricultural resilience, showing how various factors, such as government policies, market conditions, productivity, and labour efficiency, have impacted the sector over time. These trends indicate that while Malaysia's agricultural sector has made considerable progress in certain areas, significant challenges remain, particularly in addressing the impacts of labour productivity shortages and market volatility.

This study also offers policy-relevant insights to enhance the resilience of Malaysia's agricultural sector. The substantial impact of innovation and finance on resilience highlights the urgency of sustained investment in agricultural R&D, innovative technologies, and inclusive financing mechanisms. These findings align with the National Agrofood Policy 2.0 (NAP 2.0), particularly under Policy Thrust 1, which aims to modernise the agro-food sector through structured R&D efforts, particularly by accelerating the development of resilient crop varieties, enhancing agro-innovation ecosystems, and increasing public-private partnerships.

Meanwhile, workforce development strategies must be intensified to address the negative impact of labour and human capital on resilience. NAP 2.0's Policy Thrust 3 emphasises TVET expansion, youth agropreneur training, and automation incentives to modernise the agricultural workforce. Specific action plans such as developing model farms and providing training infrastructure can increase the adoption of precision technologies among smallholders. Moreover, resilience strategies should consider spatial variation. NAP 2.0 advocates for regionalised approaches such as agro-based economic zones and controlled-environment farming to support high-value production tailored to local conditions. Community farming initiatives and agro-cluster linkages are also vital to facilitate inclusive growth. Aligning national strategies with the findings of this study will enable Malaysia to build a resilient, competitive, and sustainable agro-food system in line with its Shared Prosperity Vision 2030 and the Sustainable Development Goals (SDG, 2030).

While this study provides a robust analysis, several limitations must be acknowledged. The PCA approach assumes linear relationships and

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orthogonal principal components, which may oversimplify complex interactions among variables. Additionally, long-term secondary data may contain inconsistencies or estimation modifications from a few data sources. Moreover, the ARI is constructed nationally and does not reflect sub-national differences, such as disparities between Peninsular Malaysia and East Malaysia. Future research should incorporate spatial econometric techniques and qualitative fieldwork to capture more granular insights. Similarly, incorporating variables related to institutional quality, farmer perception, and agro ecological diversity could enrich the ARI framework.

In conclusion, this study contributes to the growing body of literature on agricultural resilience by providing a detailed assessment of Malaysia's agricultural sector and offering practical recommendations for enhancing its resilience. As global and local challenges continue to evolve, the insights gained from this research can guide policymakers, researchers, and stakeholders in developing strategies to ensure the sustainability and resilience of Malaysia's agriculture for future generations. This study makes a novel contribution by constructing a comprehensive and longitudinal Agricultural Resilience Index (ARI) specific to Malaysia. By integrating technological, economic, labour, policy, and market dimensions, this study presents a replicable framework for resilience assessment in other developing countries. Unlike prior studies that focused on short-term shocks or single factors, this research provides a multi-dimensional and temporal analysis, revealing the drivers of resilience across nearly three decades. It offers empirical evidence that resilience is not static but can be cultivated through sustained policy support, innovation, and investment.

References

Abdullah, N., Ahmad, S., & Ayob, M. (2016). Labour force participation of rural youth in plantation sector of Northern Peninsular Malaysia. Doi: 10.17576/jem-2016-5002-07.

Abson, D. J., Dougill, A. J., & Stringer, L. C. (2012). Using principal component analysis for information-rich socio-ecological vulnerability mapping in Southern Africa. *Applied Geography*, *35*(1-2), 515-524. Doi: 10.1016/j.apgeog.2012. 08.004.

Adger, W. N., Quinn, T., Lorenzoni, I., Murphy, C., & Sweeney, J. (2020). Changing social contracts in climate-change adaptation. *Nature Climate Change*, *3*(4), 330-333. Doi: 10.1038/nclimate1751.

Akbari, M., Sabouri, H., Sajadi, S. J., Yarahmadi, S., & Ahangar, L. (2024). Classification and prediction of drought and salinity stress tolerance in barley using GenPhenML. *Scientific Reports*, *14*(1), 1-16. Doi: 10.1038/s41598-024-68392-w.

Akerlof, G.A., & Yellen, J.L. (1986). Efficiency Wage Models of the Labour Market. *Southern Economic Journal*, *54*, 1068.

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Alston, J. M., Andersen, M. A., James, J. S., & Pardey, P. G. (2011). The economic returns to U.S. public agricultural research. *American Journal of Agricultural Economics*, *92*(5), 1257-1277. Doi: 10.1093/ajae/aar044.

Altieri, M. A., & Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *The Journal of Peasant Studies*, *47*(5), 881-898. Doi: 10.1080/03066150.2020.1782891.

Bahta, Y. T., & Myeki, V. A. (2021). Adaptation, coping strategies, and resilience of agricultural drought in South Africa: Implications for the sustainability of the livestock sector. *Heliyon*, *7*(11), e08280. Doi: 10.1016/j.heliyon.2021.e08280.

Binswanger-Mkhize, H. P., McCalla, A. F., & Patel, P. (2009). *Agricultural and rural development in developing countries*. World Bank.

Boahen, S., Oviroh, P. O., Austin-Breneman, J., Miyingo, E. W., & Papalambros, P. Y. (2023). Understanding resilience of agricultural systems: A systematic literature review. *Proceedings of the Design Society*, *3*, 3701-3710.

BusinessToday (July 26, 2021). *Nurturing the next generation of young agropreneurs*. -- https://www.businesstoday.com.my/2021/07/26/nurturing-the-next-generation-of-young-agropreneurs/.

BusinessToday (October 2, 2023). *Redesigning, repurposing agriculture, food systems to increase youth engagement, inclusivity*. -- https://www.businesstoday.com.my/2023/10/02/redesigning-repurposing-agriculture-food-systems-to-increase-youth-engagement-inclusivity/.

Cassey, A., Lee, K., Sage, J., & Tozer, P. (2018). Assessing post-harvest labour shortages, wages, and welfare. *Agricultural and Food Economics*, *6*. Doi: 10.1186/s40100-018-0112-6.

Chavas, J. P. (2024). Economic resilience: Measurement and assessment across time and space. *Research in Economics*, *78*(2), 100953.

Chandio, A., Akram, W., Du, A., Ahmad, F., & Tang, X. (2025). Agricultural transformation: Exploring the impact of digitalization, technological innovation and climate change on food production. *Research in International Business and Finance*. Doi: 10.1016/j.ribaf.2025.102755.

Coelli, T., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis* (2nd ed.). Springer.

Cramb, R., & Curry, G. N. (2012). Oil palm and rural livelihoods in the Asia-Pacific region: An overview. *Asia Pacific Viewpoint*, *49*(3), 223-239. Doi: 10.1111/j.1467-8373.2012.01495.x.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approach* (5th ed.). SAGE Publications.

Cruz, M. D. (2023). Labour productivity, real wages, and employment in OECD economies. *Structural Change and Economic Dynamics*, *66*, 367-382. Doi: 10.1016/j.strueco.2023.05.007.

Department of Fisheries Malaysia (2022). *Annual Report 2022*. Ministry of Agriculture and Food Industries Malaysia.

Diao, X., Hazell, P., Resnick, D., & Thurlow, J. (2007). *The role of agriculture in development: Implications for Sub-Saharan Africa*. International Food Policy Research Institute.

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Dorairaj, D., & Govender, N. T. (2023). Rice and paddy industry in Malaysia: Governance and policies, research trends, technology adoption and resilience. *Frontiers in Sustainable Food Systems*, *7*, 1093605. Doi: 10.3389/fsufs.2023.1093605.

Filmer, D., & Pritchett, L.H (2001). Estimating Wealth Effects Without Expenditure Data – Or Tears: An Application to Educational Enrolments in States Of India. *Demography*, *38*, 115-132. Doi: 10.1353/dem.2001.0003.

Firdaus, R., Tan, M., Rahmat, S., & Gunaratne, M. (2020). Paddy, rice and food security in Malaysia: A review of climate change impacts. *Cogent Social Sciences*, *6*. Doi: 10.1080/23311886.2020.1818373.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2016). Resilience thinking: Integrating resilience, adaptability, and transformability. *Ecology and Society*, *15*(4), 20. Doi: 10.5751/ES-03610-150420.

Food and Agriculture Organization of the United Nations (FAO) (2020). *The state of food security and nutrition in the world 2020: Transforming food systems for affordable healthy diet*s. FAO.

Fuglie, K. O. (2018). R&D capital, R&D spillovers, and productivity growth in world agriculture. *Applied Economic Perspectives and Policy*, *40*(3), 421-444. Doi: 10.1093/aepp/ppx045.

Furr, N. R., & Eisenhardt, K. M. (2021). Strategy and uncertainty: Resource-based view, strategy-creation view, and hybrid. *Journal of Management*, *47*(7), 1915-1935. Doi: 10.1177/01492063211011760.

Gomez Ayalde, D., Giraldo Londono, J. C., Quiroga Mosquera, A., Luna-Melendez, J.L., Gimode, W., Tran, T., Zhang, X., Selvaraj, M. G. (2024). AI-powered detection and quantification of Post-harvest Physiological Deterioration (PPD) in cassava using YOLO foundation models and K-means clustering. *Plant Methods*, *20*, 178.

Hamid, S., Arzaman, A., Razali, M., Yasin, N., Masrom, N., Sabri, N., & Margono, M. (2024). The deployment of the Malaysian sustainable palm oil standard in the agriculture sector. *Multidisciplinary Science Journal*. Doi: 10.31893/multiscience.2024115.

Hamidu, Z., Oppong, P., Asafo-Adjei, E., & Adam, A. (2022). On the Agricultural Commodities Supply Chain Resilience to Disruption: Insights from Financial Analysis. *Mathematical Problems in Engineering*. Doi: 10.1155/2022/9897765.

Hallegatte, S. (2014). *Economic resilience: definition and measurement*. World Bank Policy Research Working Paper, (6852). -- https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2432352.

He, X., Fang, Y., Wang, B., & Huang, X. (2024). Assessment of the spatial and temporal dynamics of food system resilience and its response to natural hazards. *International Journal of Disaster Risk Reduction*. Doi: 10.1016/j.ijdrr.2024.104781.

Hoang-Khac, L., Tiet, T., To-The, N., & Nguyen-Anh, T. (2022). Impact of human capital on technical efficiency in sustainable food crop production: a meta-analysis. *International Journal of Agricultural Sustainability*, *20*(4), 521-542. Doi: 10.1080/14735903.2021.1949880.

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No Derivatives License. For terms and conditions of usage please see: http://creativecommons.org

Howell, P. (December 9, 2022). *Skills mismatch a continuing problem in Malaysia, expert says*. -- https://chiefofstaff.asia/news-and-insights/skills-mismatch-a-continuing-problem-in-malaysia-expert-says/.

Huffman, W. E., & Orazem, P. F. (2007). Agriculture and human capital in economic growth: Farmers, schooling and nutrition. *Handbook of agricultural economics*, *3*, 2281-2341. doi:10.1016/s1574-0072(06)03043-x

Hassanat, A. B., Alqaralleh, M. K., Tarawneh, A. S., Almohammadi, K., Alamri, M., Alzahrani, A., Altarawneh, G. A., & Alhalaseh, R. (2023). A Novel Outlier-Robust Accuracy Measure for Machine Learning Regression Using a Non-Convex Distance Metric. *Mathematics*, *12*(22), 3623. Doi: 10.3390/math12223623.

Institute of Strategic and International Studies Malaysia (ISISM) (2024). *Malaysian palm oil industry performance 2023*. ISISM.

Ismail, K. H. (2024). *Revolutionising palm oil: How drones are driving sustainable plantations in Malaysia*. -- https://bernardbc.com/revolutionising-palm-oil-how-drones-are-driving-sustainable-plantations-in-malaysia/.

Jiang, X., Zhang, W., Zhang, X., & Yang, L. (2018). Application of principal component analysis in agricultural monitoring and assessment. *Environmental Monitoring and Assessment*, *190*(7), 404.

Jolliffe, I. T. (2002). *Principal component analysis* (2nd ed.). Springer.

Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *374*(2065), 20150202. Doi: 10.1098/rsta.2015.0202.

Joffre, O., Poortvliet, P., & Klerkx, L. (2019). To cluster or not to cluster farmers? Influences on network interactions, risk perceptions, and adoption of aquaculture practices. *Agricultural Systems*. Doi: 10.1016/J.AGSY.2019.02.011.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, *39*(1), 31-36. Doi: 10.1007/BF02291575.

Khanjani, M., Da Silva, L., Fóes, G., Vieira, F., Poli, M., Santos, M., & Emerenciano, M. (2023). Synbiotics and aquamimicry as alternative microbial-based approaches in intensive shrimp farming and biofloc: Novel disruptive techniques or complementary management tools? A scientific-based overview. *Aquaculture*. Doi: 10.1016/j.aquaculture.2023.739273.

Latruffe, L. (2010). *Competitiveness, productivity and efficiency in the agricultural and agri-food sectors*. OECD.

Li, H., Liu, Z., Zheng, L., & Lei, Y. (2011). Resilience analysis for agricultural systems of north China plain based on a dynamic system model. *Scientia Agricola*, *68*, 8-17.

Lin, Y., Wan, C., Li, S., Xie, S., Gan, Y., & Lu, Y. (2023). Prediction of women and Children's hospital outpatient numbers based on the autoregressive integrated moving average model. *Heliyon*, *9*(4), e14845. Doi: 10.1016/j.heliyon.2023. e14845.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., … Hottle, R. (2020). Climate-smart agriculture for food security. *Nature Climate Change*, *4*(12), 1068-1072. Doi: 10.1038/nclimate2437.

Lucas, R. E. (1980). Methods and problems in business cycle theory. *Journal of Money, Credit and banking*, *12*(4), 696-715. -- https://www.jstor.org/stable/1992030.

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Low, C. (2017). A Strategy of Attrition through Enforcement: The Unmaking of Irregular Migration in Malaysia. *Journal of Current Southeast Asian Affairs*, *36*, 101-136. Doi: 10.1177/186810341703600204.

Madhani, P. M. (2009). *Resource Based View (RBV): Concepts and Practices*. -- https://ssrn.com/abstract=1966810.

Malay Mail (2024, June 22). *Agriculture minister urges Fama to boost durian kampung exports to China*. -- https://www.malaymail.com/news/malaysia/2024/06/22/agriculture-minister-urges-fama-to-boost-durian-kampung-exports-to-china/31349.

Malay Mail (June 11, 2023). *Malaysian Cocoa Board to open 200 hectares of land for cultivation this year, says Plantation Industries Ministry*. -- https://www.malaymail.com/news/money/2023/06/11/malaysian-cocoa-board-to-open-200-hectares-of-land-for-cultivation-this-year-says-plantation-industries-ministry/73768.

Malaysian Investment Development Authority (MIDA) (2020). *Ratification of CPTPP can help Malaysia be more competitive*. -- https://www.mida.gov.my/mida-news/ratification-of-cptpp-can-help-malaysia-be-more-competitive-says-ideas/.

Malaysian Investment Development Authority (MIDA) (September 15, 2023). *Malaysia as a global leader in the halal industry*. -- https://www.mida.gov.my/mida-news/malaysia-as-a-global-leader-in-the-halal-industry/.

Martin, W., & Mitra, D. (2001). Productivity growth and convergence in agriculture and manufacturing. *Economic Development and Cultural Change*, *49*(2), 403-422. Doi: 10.1086/452509.

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., De Mey, Y., … & Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656. Doi: 10.1016/j.agsy.2019.102656.

Ministry of Finance Malaysia (2023). *Govt provides RM2.6 billion for subsidies, incentives for paddy farmers, fishermen*. -- https://www.mof.gov.my/portal/en/news/press-citations/govt-provides-rm2-6-billion-for-subsidies-incentives-for-paddy-farmers-fishermen.

Micheels, E. T., & Gow, H. R. (2008). *Market Driven Entrepreneurship: The Convergence of Market Orientation and the Resource Based View*. -- https://ageconsearch.umn.edu/record/44276/?v=pdf.

Moseley, W. G. (2017). Agricultural development and change in Sub-Saharan Africa. *Journal of Agrarian Change*, *17*(3), 593-597.

Nguyen, M., Renaud, F., & Sebesvari, Z. (2019). Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. *Environmental Science & Policy*. Doi: 10.1016/J.ENVSCI.2018.10.016.

Nikoloski, D. (2023). *The Role of Efficiency Wages in Determining the Inter-Industry Wage Differentials: Evidence from North Macedonia*. -- https://eprints.uklo.edu.mk/id/eprint/9242/

Pardey, P. G., Alston, J. M., & Piggott, R. R. (2006). *Agricultural R&D in the developing world: Too little, too late?*. International Food Policy Research Institute.

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Pingali, P. L. (2019). Agricultural mechanization: Adoption patterns and economic impact. *Agricultural Economics*, *43*(1), 13-26.

Praveenkumar, A., Jha, G.K., Madival, S.D. *et al.* (2024). Deep Learning Approaches for Potato Price Forecasting: Comparative Analysis of LSTM, Bi-LSTM, and AM-LSTM Models. *Potato Res.* Doi: 10.1007/s11540-024-09823-z.

Prasad, S. (2017). *Shortages in Agriculture Labour Market and Changes in Cropping Pattern*, 181-204. Doi: 10.1007/978-981-10-6014-4_11.

Qun, W., Ranran, C., Jingsuo, L., & Khan, N. (2024). Toward a sustainable agricultural system in China: exploring the nexus between agricultural science and technology innovation, agricultural resilience and fiscal policies supporting agriculture. *Frontiers in Sustainable Food Systems*, *8*, 1390014.

Reardon, T., Echeverria, R., Berdegue, J. A., Minten, B., Liverpool-Tasie, L. S. O., Tschirley, D., & Zilberman, D. (2019). Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. *Agricultural Systems*, *172*, 47-59. Doi: 10.1016/j.agsy.2018.01.022.

Rumanti, I., Hairmansis, A., Nugraha, Y., N., Susanto, U., Wardana, P., Subandiono, R., Zaini, Z., Sembiring, H., Khan, N., Singh, R., Johnson, D., Stuart, A., & Kato, Y. (2018). Development of tolerant rice varieties for stress-prone ecosystems in the coastal deltas of Indonesia. *Field Crops Research*. Doi: 10.1016/J.FCR.2018.04.006.

Siregar, A. P., Siregar, H., & Supriana, T. (2024). The trend of agricultural sector resilience in Indonesia during 2008-2020. *The Journal of Agricultural Sciences - Sri Lanka*, *19*(2), 336-357. Doi: 10.4038/jas.v19i2.10154.

South China Morning Post (2023). *China looks to Malaysia to satisfy national durian craving as import talks accelerate*. -- https://www.scmp.com/economy/china-economy/article/3237575/china-looks-malaysia-satisfy-national-durian-craving-import-talks-accelerate.

Stigler, G. J. (1958). The Economies of Scale. *Journal of Law and Economics*, *1*, 54-71. Doi: 10.1086/466541.

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., … Six, J. (2015). Food system resilience: Defining the concept. *Global Food Security*, *6*, 17-23. Doi: 10.1016/j.gfs.2015.08.001.

Thornton, P. K., Schuetz, T., Förch, W., Cramer, L., Abreu, D., Vermeulen, S., & Campbell, B. M. (2021). Is agricultural research focusing on the right goals?. *Global Food Security*, *10*, 1-8.

Timmer, C. P. (2002). Agriculture and economic development. *Handbook of agricultural economics*, *2*, 1487-1546. Doi: 10.1016/S1574-0072(01)10010-1.

Tittonell, P. (2020). Assessing resilience and adaptability in agroecosystems: Critical insights from a French case study. *Agricultural Systems*, *176*, 102652. Doi: 10.1016/j.agsy.2020.102862.

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2018). Climate change and food systems. *Annual Review of Environment and Resources*, *37*(1), 195-222. Doi: 10.1146/annurev-environ-020411-130608.

Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*, *5*(2), 171-180. Doi: 10.1002/smj.4250050207.

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World Bank (2020). *World development report 2020: Trading for development in the age of global value chain*s. World Bank.

Yang, Y., Cai, Y., Jiang, Z., & Fang, X. (2019). Assessing the resilience of agricultural production systems in China. *Agricultural Systems*, *173*, 324-334.

Yang, Q., Zhang, P., Z., Liu, D., & Guo, Y. (2022). Agricultural Economic Resilience in the Context of International Food Price Fluctuation – An Empirical Analysis on the Main Grain – Producing Areas in Northeast China. *Sustainability*. Doi: 10.3390/su142114102.

Zahari, Z., Rosly, N., Zaik, N., Rusli, M., Ahmad, G., Al-Sharqi, F., Al-Quran, A., & Awad, A. (2024). A DEMATEL Analysis of The Complex Barriers Hindering Digitalization Technology Adoption in the Malaysia Agriculture Sector. *Journal of Intelligent Systems and Internet of Things*. Doi: 10.54216/jisiot.130102.

Zampieri, M., Weissteiner, C. J., Grizzetti, B., Toreti, A., van den Berg, M., & Dentener, F. (2020). Estimating resilience of crop production systems: From theory to practice. *Science of the Total Environment*, *735*, 139378.

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