A TOE-Based Analysis of Modern Agricultural Technology Adoption in the Agri-Food Supply Chain

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Abstract
This study examines the key determinants influencing the adoption of modern agricultural technologies in the Agri-Food Supply Chain (AFSC) through the lens of the Technology-Organization-Environment (TOE) framework. By integrating scholarly literature and empirical evidence, the research explores how technological, organizational, and environmental factors such as cost, perception, access to extension services, credit availability, government support, and external pressures affect technology adoption. A sample of 145 respondents was selected using convenience sampling, and data were analyzed through descriptive analysis, correlation analysis, and multiple regression analysis using SPSS. The findings indicate that technological factors, particularly farmers' perceptions of cost-effectiveness and utility, play a crucial role in adoption. Additionally, organizational factors, including access to credit and extension services, serve as essential enablers, while environmental factors, such as government policies and market pressures, significantly impact adoption trends. Multiple linear regression results highlight perception as the most influential factor driving technology adoption. By offering empirical insights, this study contributes to enhancing agricultural productivity, strengthening food security, and promoting economic sustainability within the AFSC, ultimately fostering a more competitive and resilient agricultural sector.
Keywords: Modern Technologies, TOE Theory, Technological, Organizational, Environmental, Agri-Food Supply Chain

Introduction
The agri-food sector, a blend of industrial commodities and smallholder-driven cultivation, plays a pivotal role in sustaining the country's resources and economic well-being (Hassan et al., 2018). As the sector evolves, the integration of modern agricultural technologies is reshaping traditional practices, promising efficiency, sustainability, and resilience (Abbasi et al., 2022). Malaysia's agricultural industry encompasses both industrial commodities and agri-

food. Large-scale cultivation is dedicated to industrial commodities like palm oil, rubber, and cocoa. On the other hand, agri-food, primarily cultivated by smallholders often categorized as Small Medium Enterprises (SMEs), includes rice, fruits, vegetables, fisheries, and livestock. These commodities are distributed to traders, hypermarkets, and local sundry shop owners. The economic growth of a country is highly dependent on the agricultural sector. The application of technology in agriculture can perform various functions and play an important role in various aspects. According to the Second Edition Student Dictionary, technology is referred to as science related to how to create goods in business, that is, technology related to the acquisition, storage, processing, and dissemination of information electronically. Modern agricultural technology refers to the use of advanced tools, equipment and systems in agriculture and agricultural practices to increase efficiency, productivity, and sustainability in food production. Therefore, for long-term food security and economic growth, modern agricultural technologies that improve sustainable food and fibre production are essential. Due to this, there has been a lot of research done on the dynamics of technical change in agriculture since the early 20th century (Loevinsohn et al., 2013). The agri-food supply chain (AFSC) stands at the nexus of a complex and interconnected system that spans the entire journey of agricultural products from farm to table. As a critical component of the global food ecosystem, the AFSC encompasses various stages, including production, processing, distribution, and consumption. AFSC refers to the production and delivery of agri-produce from production to the point of consumption through a series of stages (Yadav et al., 2021). Despite these advances, the adoption of modern agricultural technologies in the agri-food supply chain remains uneven, particularly among smallholders and SMEs who face structural, organizational, and social barriers. This raises a critical research problem: why, despite the proven benefits of modern technologies, do adoption rates vary significantly across different stakeholders within the AFSC? Addressing this problem is not only a technical issue but also a social one, as it relates to broader debates in the social sciences about innovation diffusion, rural inequality, and sustainability transitions. Contemporary scholarship emphasizes that technological change in agriculture must be understood within its socio-economic and institutional context, where factors such as access to credit, trust in institutions, cultural perceptions of risk, and government policies shape decision-making (Smidt & Jokonya, 2021; Ntshangase et al., 2018). Moreover, technology adoption is deeply intertwined with pressing global concerns, including the United Nations Sustainable Development Goals (SDGs), especially those targeting zero hunger (SDG 2), decent work and economic growth (SDG 8), and responsible consumption and production (SDG 12) (Abbasi et al., 2022). Therefore, the significance of this research lies in its potential to bridge technical perspectives with social science debates by using the Technology-Organization-Environment (TOE) framework as an analytical lens. By explicitly examining how technological, organizational, and environmental factors converge to shape adoption behavior, this study contributes to ongoing discussions about the resilience of food systems, the role of digital technologies in reducing rural inequalities, and the policy pathways needed for inclusive agricultural transformation. Hence, the objective of this research is to explore the factors of technological, organizational, and environmental factors such as cost, perception, access to extension services, credit availability, government support, and external pressures exerting a positive impact on technology adoption in agri-food supply chain.

Materials and Methods

To achieve the study's objectives, a survey method was employed to effectively describe the characteristics of the target population. A self-administered questionnaire was developed to assess stakeholders' perspectives on blockchain adoption in agri-food supply chain management, considering various blockchain applications such as tokens, smart contracts, and traceability systems. The questionnaire was designed in both English and Punjabi to ensure accessibility and inclusivity. The measurement scales were adapted from previous empirical studies related to the Unified Theory of Acceptance and Use of Technology (UTAUT) to ensure validity and reliability. Key indicators included performance expectancy (PE), effort expectancy (EE), facilitating conditions (FC), social influence (SI), inter-firm trust (IT), transparency (T), and behavioral intention (BI) to adopt blockchain technology. A preliminary questionnaire was distributed to a pilot group of 20 academicians and agri-food supply chain experts to refine the survey instrument based on their feedback. The final data was collected from 200 stakeholders across Punjab, India, using face-to-face interactions. Given that the respondents had not previously deployed blockchain technology, an introductory session on blockchain applications in the agri-food supply chain was conducted before the survey. All constructs were measured using a 5-point Likert scale ranging from "strongly disagree" to "strongly agree," ensuring a standardized evaluation of blockchain adoption determinants.

The Technology-Organization-Environment model, introduced by Tornatzky and Fleischer in 1990, represents a comprehensive framework for understanding the adoption of technological innovations within organizations. Building upon Everett Rogers' diffusion of innovation theory, the TOE model emphasizes the importance of considering three main dimensions: technology, organization, and environment (Tornatzky, 1990). The technology dimension focuses on the characteristics of the technology itself, including its complexity, compatibility, and relative advantage. The organization dimension examines internal factors such as organizational structure, culture, and resources, assessing how well the technology aligns with organizational goals and the readiness of the organization for change. The environment dimension considers external factors like regulatory requirements, market competition, and technological trends, recognizing the broader socio-economic and political context in which the organization operates. By analyzing how these dimensions interact, the TOE model provides a structured approach to understanding the complex factors influencing technology adoption decisions and outcomes within organizations. It has been widely used across various domains within information systems to identify barriers and facilitators to adoption and develop strategies for successful technology.
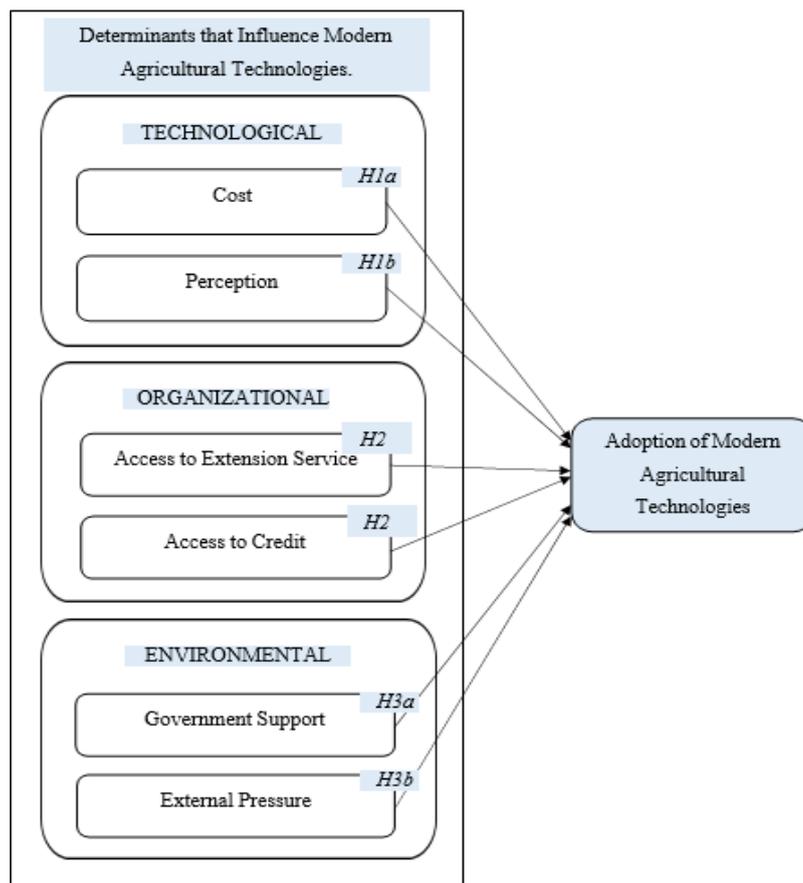
Figure 1: Conceptual Framework

Results

The data in Table 1 demonstrated that the majority of respondents were female, accounting for 68.5% (267 out of 384), while males made up 30.5% (117 respondents). Most participants (66.4%) were between 20 and 29 years old, with Malays representing the largest ethnic group at 78.6% (302 respondents). Regarding occupation, students formed the largest category at 44.5% (171 respondents), followed by full-time employees at 29.4% (113 respondents), and the majority were single. In terms of income, 54.7% of respondents earned less than RM 1500, while 23.7% fell within the RM 1500–RM 3000 range. All respondents were consumers of agricultural products, with perceived quality being the most influential purchasing factor for 59.6% of them. Supermarkets emerged as the preferred purchasing channel, chosen by 56.8% of respondents. Additionally, 51.3% of respondents reported spending less than RM 50 per month on agricultural products, highlighting affordability as a key consideration in their purchasing behavior.

Table 1
Demographic profile of the respondents

Items	Details	Frequency N =384	Percent (%)
Gender	Male	117	30.5
	Female	267	69.5
Age	< 20 years old	29	7.6
	20 – 29 years old	255	66.4
	30 – 39 years old	42	10.9
	40 – 49 years old	55	14.3
	> 50 years old	3	0.8
Employed Status	Employed full time	113	29.4
	Employed part time	30	7.8
	Unemployed	13	3.4
	Self-employed	56	14.6
	Retired	1	0.3
	Student	171	44.5
Race	Malay	302	78.6
	Indian	48	12.5
	Chinese	30	7.8
	Others	4	1.0
Marital status	Single	266	69.3
	Married	118	30.7
Monthly income	< RM 1500	210	54.7
	RM 1500 – RM 3000	91	23.7
	RM 3001 - RM 6000	83	21.6
What are your main factors for buying agricultural products? (e.g., fruits)	Brand Awareness	56	14.6
	Perceived Quality	229	59.6
	Brand trust	99	25.8
Channel to purchase agricultural products? (e.g., fruits)	Food market	74	19.3
	Online store	52	13.5

	Supermarket	218	56.8
	Direct ordering from farmers	40	10.4
Monthly expenses for agricultural products? (e.g., fruits)	< RM 50	197	51.3
	RM 50 – RM 100	131	34.1
	RM 101 – RM 200	45	11.7
	> RM200	11	2.9

The results indicate significant positive correlations between factors influencing consumer preferences in purchasing agricultural products. Brand awareness ($r = 0.592$, $p < 0.01$) and brand trust ($r = 0.607$, $p < 0.01$) show strong positive correlations, while perceived quality ($r = 0.424$, $p < 0.01$) demonstrates a moderate positive correlation with consumer preferences as shown in Table 2.

Table 2
Correlation Coefficient Analysis

		Brand Awareness	Perceived Quality	Brand Trust	Consumer's Preferences
Consumer's Preferences	Pearson Correlation	0.592**	0.424**	0.607**	1
	Sig. (2-tailed)	0.000	0.000	0.000	
	N	384	384	384	384

**. Correlation is significant at the 0.01 level (2-tailed).

Meanwhile, Table 3 shows that brand awareness, perceived quality, and brand trust all have significant relationships with consumer preferences in purchasing agricultural products, as their p-values are below 0.05. Among these factors, brand trust is the most dominant, with the highest R-value of 0.396.

Table 3
Summary of Multiple Regression Analysis

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.416	0.238		1.745	0.082
Brand Awareness	0.372	0.042	0.380	8.900	0.000
Perceived Quality	0.145	0.061	0.106	2.357	0.019
Brand Trust	0.396	0.055	0.355	7.190	0.000

a. Dependent Variable: Consumer's preferences

The Multiple Regression Model:

$$Y = \beta 0 + \beta 1 X1 + \beta 2 X2 + \beta 3 X3 + \varepsilon i$$

Y = Consumer's preferences in purchasing agricultural products.
X1 = Brand awareness
X2 = Perceived quality X3 = Brand trust
$$Y = 0.416 + 0.372 X1 + 0.145 X2 + 0.396 X3 + \varepsilon i$$

The coefficient interpretation reveals that brand trust is the most influential factor in shaping consumer preferences for purchasing agricultural products. Among the variables analyzed, brand trust ($\beta 3 = 0.396$) has the highest impact, followed by brand awareness ($\beta 1 = 0.372$) and perceived quality ($\beta 2 = 0.145$). This suggests that consumers prioritize trust and reliability in a brand over mere awareness or perceived quality when making purchasing decisions. The findings indicate that strengthening brand trust can significantly enhance consumer preference for agricultural products.

Discussion
The study highlights that brand awareness, perceived quality, and brand trust significantly influence consumer preferences in purchasing agricultural products. Brand awareness (p-value = 0.000) plays a crucial role in consumer decision-making, as consumers are more likely to choose well-known and familiar brands (Ismail et al., 2023). Brand awareness has a positive effect on purchasing behavior, with well-recognized brands being preferred due to their reputation and familiarity (Ntshangase et al., 2018). Additionally, women demonstrate higher brand awareness than men, as they tend to seek more information before making purchasing decisions, aligning with the study's findings that 69.5% of respondents were female. Th perceived quality (p-value = 0.019) is another key determinant, as consumers associate high-quality agricultural products with safety, effectiveness, and value. When products meet or exceed expectations in freshness, taste, and appearance, consumer trust and preference increase. Prior research supports that perceived quality has a direct positive relationship with purchase intention (Cuong Dam, 2020). In addition, brand trust (p-value = 0.000, r = 0.396) emerges as the most dominant factor in influencing consumer preferences. Trust is particularly crucial when consumers are unfamiliar with a brand, as it shapes their expectations and purchasing decisions. Previous studies confirm that brand trust significantly influences purchase intention, particularly for regional public brand agricultural products (Mat et al., 2020). Trust impacts both initial purchases and future buying behavior, as consumers rely on past experiences to guide their decisions. Overall, the findings reinforce that enhancing brand awareness, ensuring high product quality, and building strong brand trust are essential strategies for influencing consumer preferences in the agricultural product market.

Conclusions
The study found that consumer preferences for agricultural products are generally high, with significant relationships between brand awareness, perceived quality, and brand trust. Brand awareness showed a strong positive correlation with consumer preferences (r = 0.592, p = 0.000), indicating that increased awareness leads to higher preferences, with women being more brand-aware than men. Perceived quality had a moderate positive correlation (r =

0.424, p = 0.000), reinforcing consumer trust and confidence in agricultural products. Brand trust was the most dominant factor (r = 0.607, p = 0.000), highlighting its crucial role in influencing purchase decisions. The study suggests that marketers should focus on building brand trust, ensuring quality consistency, and using targeted strategies, particularly for female consumers, to enhance brand awareness and perceived quality.

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