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RESEARCH ARTICLE

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Digital technology adoption among smallholder farmers in Vietnam: Implications for digital agricultural extension strategies

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Abstract

This study explores the adoption of digital technology among smallholders in Quang Tri Province, Vietnam. Data were gathered by doing a survey of 455 farmers analysed by descriptive analysis and a Poisson Regression model. Key knowledge gaps include an incomplete understanding of farmers' digital technology adoption and insufficient empirical evidence supporting potential determinants in smallholders' digital adoption. Findings indicate active use of digital tools in agriculture, with factors such as education, farm size, digital experience, knowledge exchange frequency, access to digital information and internet costs positively influencing adoption. The study advocates for tailored training and targeted interventions to enhance adoption rates.

KEYWORDS
adoption, digital technology, smallholders, Vietnam

1 | INTRODUCTION

Vietnam is an agricultural nation, with 62.7% of its population living in rural areas where farming is their main source of livelihood (GSO, 2023). Moreover, approximately 40% of the country's workforce is associated with the agricultural sector (Burra et al., 2021). The farmers, who form the primary group in rural areas, experience low income and living standards as a salient feature of their lives. Farmers comprise a significant portion of the rural population, with 43.02% of households engaged in agriculture among a total of 10.2 million households (Vietnam Farmers' Union, 2022). However, their income and living standards are notably low, with rural people earning 1.54 times less than urban people (GSO, 2023). Therefore, to address this disparity and promote agricultural development,

digitization of the agricultural sector has become a crucial strategic task in Vietnam (Ha, 2021; Vo et al., 2021). Vietnam's plan for digital transformation until 2025 and its vision for 2030 identify agriculture as one of the key sectors for digitalization. As part of this program, the government has set a goal for "Every farmer to be a trader apply digital solutions by 2025". To achieve this goal, farmers are being encouraged to use digital technology in all aspects of agricultural production. The number of digital applications adopted by farmers is seen as a critical indicator of transformation progress since greater adoption offers more opportunities to access information and knowledge (MIC, 2021).

The COVID-19 pandemic has served as a catalyst for the extensive integration of digital technology, particularly internet-based applications, within Vietnam. This phenomenon has resulted in a substantial surge in online transactions, the prevalence of e-commerce and digital interactions. The adoption of digital devices, including smartphones, computers, laptops and digital televisions, has become increasingly widespread among the Vietnamese populace, a trend that has persisted beyond the pandemic period (Vietnamnet., 2022). According to the Statista Research Department (2021), 97.6% of internet users in Vietnam own a smartphone, while 64% use a laptop or desktop computer and 35.2% possess a tablet device. Remarkably, mobile phone ownership stands at 90% among Vietnamese farmers, with 10% of farm households having internet-accessible computers (Burra et al., 2021) and 68% of mobile phone users in rural areas of Vietnam own a smartphone (MMA, 2019). As a consequence, traditional daily services are increasingly shifting to online platforms in the era of digitalization (Nguyen et al., 2022), and digital technologies are being actively utilized in the agricultural sector (Drewry et al., 2019). As a result, farmers can employ a multichannel strategy to market their agricultural products via social media platforms and shopping online (MMA, 2019).

The digital transformation process in Vietnam is expected to require a significant amount of time to achieve full implementation. Therefore, the Ministry of Information and Communications (MIC) has emphasized that the initial step towards achieving digital transformation in the agricultural and rural sectors involves developing the necessary proficiency in utilizing smartphones and social platforms. However, recent studies in Vietnam suggest that accessing digital technology in rural areas remains a significant challenge. Hoang and Tran (2023) reveal that the adoption rate of digital devices among farmers for agricultural purposes is still relatively low. Meanwhile, Linh et al. (2015) found that the majority of Vietnamese farmers use digital devices primarily for social purposes rather than for agricultural-related activities.

There is a notable deficiency in recent studies on the adoption of digital technologies among smallholder farmers in Vietnam's agriculture. Recent research by scholars like Doanh et al. (2022), Hoang (2020a), Hoang (2020b), Hoang and Douglas (2021), Hoang and Nguyen (2021), Hoang (2020c), Hoang and Tran (2023), Van et al. (2022) and Do et al. (2023) contributes to this field, but there remains a lack of comprehensive insights into farmers' adoption of digital technology. For example, studies by Hoang (2020a), Hoang (2020b), Hoang and Douglas (2021), Hoang and Nguyen (2021), Hoang (2020c) and Do et al. (2023) primarily centre on mobile phones and conventional technologies without delving into specific platforms or applications. Hoang and Tran (2023) lack depth in exploring the purposes behind farmers' adoption of digital technology. Similarly, research by Hoang and Tran (2023) and, Van et al. (2022) only examines farmers' intentions to use digital platforms in agriculture rather than their actual usage. Furthermore, there is currently no research providing comprehensive insights into the purposes of using digital technology applications through modern devices by farmers. This research gap hinders agricultural extension agencies from crafting tailored digital agricultural extension solutions that cater to farmers' needs in Vietnam. Thus, targeted research is crucial to understand the current status and purposes of digital technology adoption among farmers, providing vital insights for effective digital agricultural extension strategies amidst the ongoing digital transformation in Vietnam.

The literature highlights the diverse and significant findings of recent studies in Vietnam regarding the factors influencing the adoption of digital technology in agricultural practices. For instance, Hoang and Douglas (2021), Hoang and Nguyen (2021), Hoang (2020c), Hoang and Tran (2023) and Do et al. (2023) primarily examined socio-economic factors as statistically significant determinants. They highlighted age, education level and farm size, among other factors, as influential in adoption rates. Conversely, Van et al. (2022) and Doanh et al. (2022) emphasized knowledge-experience and information barriers as the most impactful on farmers' intentions to use digital platforms

and applications. Obviously, the adoption of digital technology in agricultural activities by farmers was influenced by various factors, depending on the specific contexts in which farmers operate. Moreover, several factors discussed globally and in Vietnam lack strong supportive evidence. For instance, Hoang (2020b) and Mansour (2022) merely mentioned internet costs as a challenge to digital technology adoption without providing evidence to support this claim. Similarly, while Van et al. (2022) and Doanh et al. (2022) offered evidence to suggest that knowledge-experience barriers hinder farmers' intentions to use digital platforms, these studies only analysed determinants of intention rather than actual adoption. Hence, there is a need for more specific consideration of the impact of digital experience on the adoption of applications and functions by smallholders. Additionally, other scholars identified challenges of farmers' digital adoption but failed to provide empirical evidence, such as access to digital information sources (Chen, 2021), knowledge exchange (Blasch et al., 2022) and trust in exchanged knowledge (Korir et al., 2023). Therefore, further research is necessary to rigorously test such potential influencing factors beyond socioeconomic aspects.

Our study addresses the mentioned knowledge gaps by conducting a survey in Quang Tri Province, Central Vietnam. The study's primary objective is to provide valuable insights into the current status of digital technology adoption among smallholders and the underlying factors influencing this adoption. Additionally, the study aims to identify key considerations for developing digital extension strategies to promote digital technology adoption among smallholders in Vietnam and similar developing nations.

2 | LITERATURE REVIEW

The diverse range of research theories about the adoption of technology, particularly the well-known Diffusion of Innovation theory of Rogers (2010), has provided researchers with the flexibility to choose and apply suitable approaches in agricultural extension studies. However, the selection of an appropriate approach is contingent on the specific circumstances surrounding the technology adoption. Many researchers have adopted a rudimentary dichotomous variable technique to analyse farmers' decision-making related to the adoption of new technology (Doss, 2003). This approach enables researchers to investigate whether farmers accept or reject new technology, without delving into more complex categories (Challa & Tilahun, 2014; Mwangi & Kariuki, 2015; Udimal et al., 2017). In light of this, the current study considers farmers' adoption of digital technology as either adopters or non-adopters, due to the nascent nature of digital agriculture in our study area. In other words, the term "adoption of new technology" in this study can be defined as the process of accepting and utilizing a novel technological innovation, in which individuals or groups who use digital technologies are identified as adopters, while those who do not are labelled as non-adopters.

Scholars have discovered various factors that affect smallholder farmers' adoption of digital technology in agriculture, organizing them into specific categories. For example, Mwangi and Kariuki (2015) classified influencing factors into four groups: technology factors (e.g., characteristics of technology); economic factors (e.g., farm size, cost of using, off-farm income); institutional factors (e.g., belonging to social groups, access to information and extension services, access to credit) and household-specific factors (e.g., human capital). Similarly, in a study on adopting new technology, Shang et al. (2021) divided determinants of digital adoption into six groups, which include: farm characteristics (e.g., farm size, labour availability); operator characteristics (education, age, farming knowledge and experience); interactions (e.g., cooperation of farmers, participation of farmers in events); institutions (e.g., subsidy/credit approach, regulations); attributes of technology (e.g., relative advantage, complexity); psychological factors (e.g., attitude, subjective norm).

While various techniques exist for identifying determinants of technology adoption at the household level, and numerous determinants have been considered in prior studies, this research, drawing on the literature and the study's context, utilizes an analytical framework that classifies the influencing factors for the adoption of digital technology by smallholders into four groups: 1) farm operator characteristics; 2) farm characteristics; 3) digital technology

approach; and 4) farmer's social interactions (Figure 1). The following section discusses hypotheses related to these factors.

2.1 | Farm operator characteristics

Existing literature consistently demonstrates a negative relationship between age and the adoption of digital technology, as well as a positive correlation between education level and such adoption (Bounkham et al., 2022; Do et al., 2023; Kanjina, 2021; Khan et al., 2022). According to Michels et al. (2020), a plausible explanation for this pattern is that older farmers face challenges in adopting digital devices due to a lack of literacy compared to their younger counterparts. A similar finding was presented by Hoang and Tran (2023): farmers who are young and educated are more promising as potential early adopters of digital tools. Nonetheless, there are studies suggesting that age or education level may not significantly influence farmers' decisions regarding digital adoption (Abebaw & Cherinet, 2018; Michels & Musshoff, 2022). Considering these points, the following hypotheses will be tested:

H1. *Age has a negative effect on the level of digital technology adotion of smallholders (AGE).*

H2. *Farmers with higher levels of education are likely to adopt more digital technologies in agriculture activities (EDU).*

Payne and Willis (2021) found that women's ownership and use of digital devices are hindered by gender barriers, including economic factors and normative barriers such as societal perceptions and stereotypes. Similarly, Michels and Musshoff (2022) discovered that male farmers are more likely to adopt digital technology, contradicting previous findings by Bounkham et al. (2022) and Hoang and Tran (2023) that suggested gender does not influence digital device ownership and adoption. Despite mixed results in the literature, the following hypothesis is formulated:

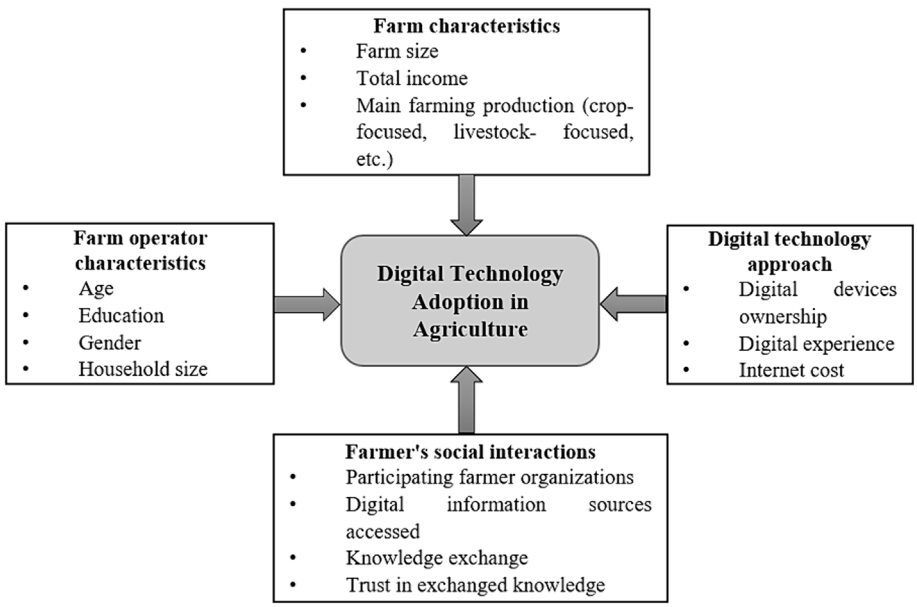

FIGURE 1 Conceptual framework of the study.

H3. *Being a male farmer fosters the adoption of more digital technologies in agriculture-related tasks (GEND).*

The researchers noted a diminished adoption of digital technology among farmers with larger household sizes compared to those with smaller households. Kiarie (2020) corroborated this observation in Kenya, highlighting a negative correlation between household size and farmers' adoption of digital technologies. Similarly, Akudugu et al. (2023) reported comparable outcomes in Ghana, suggesting that farmers with larger households are less inclined to adopt digital technologies or services to address agricultural challenges.

H4. *Farmers with more family members are likely to adopt more digital technologies in agriculture-related activities (HHSIZ).*

2.2 | Farm characteristics

Farm size and household income emerge as crucial determinants of new technology adoption among smallholder farmers. Scholars have consistently found that smallholder farmers with larger farm sizes tend to adopt digital technologies more readily compared to those with smaller farms (Bounkham et al., 2022; Kanjina, 2021; Khan et al., 2022; Michels et al., 2020; Michels & Musshoff, 2022). Likewise, recent studies indicate that higher household income is associated with increased adoption of digital technology. This trend was observed in research conducted by Hoang and Douglas (2021), Hoang and Nguyen (2021) and Ma et al. (2023), which examined factors influencing the adoption of digital technologies in agricultural tasks across diverse regions. However, some studies present conflicting findings, indicating no significant relationship between digital technology adoption and either household farm size (Abebaw & Cherinet, 2018; Kanjina, 2021) or income (Hoang & Tran, 2023). Despite the differing results in the literature, the following hypotheses are formulated:

H5. *A larger farm size fosters the higher level of digital technology adoption among smallholders (FARMSIZ).*

H6. *Farmers with higher household income are more likely to adopt more digital technologies in agricultural activities (INCOME).*

Concentration on particular crops or specific livestock can be a determining factor in the adoption of digital technology (Barnes et al., 2019). In a study focusing on Swiss farmers, Groher et al. (2020) discovered that various farming systems exhibit distinct and statistically significant influences on the adoption of new digital technologies, with both positive and negative influences depending on the type of farm. Gabriel and Gandorfer (2023) similarly concurred, stating that the specialization of agricultural production on individual farms can affect the adoption rates of digital technologies within specific regions. Therefore, the hypothesis is formulated as follows:

H7a. *Farmers with a crop-focused farming have a positive or negative impact on the digital technology adoption level (FTYPE 1).*

H7b. *Farmers with a livestock-focused farming have a positive or negative impact on the digital technology adoption level (FTYPE 2).*

2.3 | Digital technology approach

The possession of digital devices such as smartphones and computers is promoting the adoption of digital applications (Li et al., 2023). However, recent research has primarily concentrated on examining the relationship between smartphone usage and the utilization of digital technology applications (Krell et al., 2020) or the influence of owning a laptop or PC, and the internet on the adoption of smartphones in agriculture (Ma et al., 2023; Michels & Musshoff, 2022). Consequently, to investigate whether owning multiple digital devices affects the adoption of digital applications and functions among farmers, this study hypothesized as follows:

H8. *Farmers who own more digital devices adopt more digital technologies in agricultural activities (DEVICE).*

Fox et al. (2021) emphasized that, following initial adoption, farmers' practical experience with digital applications becomes the primary factor influencing continued use. Studies by Van et al. (2022) and Doanh et al. (2022) in Vietnam revealed that digital knowledge and experience barriers hinder farmers' intentions to use the digital platforms of smallholders. Building on these insights, this study formulates the following hypothesis:

H9. *Experience years in using digital devices positively influences the adoption of digital technology in agriculture (DIGTEXP).*

Mansour (2022), in a study on factors influencing mobile phone usage in Egypt, concluded that high charges for internet services pose a constraint to farmers' adoption of ICT. Similarly, Hoang (2020b) and Payne and Willis (2021) asserted that the high cost of internet access is a challenge to farmers' digital adoption. Chen (2021) also affirmed that, for farmers who do use the internet, their usage is primarily constrained by high data costs. Ma et al. (2023) suggested that reducing costs by investing more in wireless internet facilities, such as WIFI, instead of broadband internet could be a potential solution to enhance digital technology adoption in rural China. However, the aforementioned studies only provide qualitative statements and conclusions. Therefore, there is a need for a more robust foundation to draw conclusions about the impact of internet costs on farmers' adoption of digital technology applications. Thus, the following is hypothesized:

H10. *Farmers who pay lower internet costs are more likely to adopt digital technology in agricultural tasks (INTCOST).*

2.4 | Farmer's social interactions

Membership in farmers' organizations, particularly cooperatives, fosters collaboration among individuals with shared interests and encourages the adoption of emerging technologies (Mendes et al., 2023). Exposure to new information and technologies within these organizations significantly influences farmers' decisions to adopt various digital agricultural solutions and the pace of adoption (Miine et al., 2023). Previous studies further support the notion that participation in farmer organizations is positively associated with farmers' adoption of digital technology in agriculture (Hoang, 2020a; Hoang & Douglas, 2021; Hoang & Nguyen, 2021; Mansour, 2022). This is stated in the following hypothesis:

H11. *Farmers are likely to use more digital technology in agriculture if they are involved in a farmer organization (ORGMEM).*

Information plays a crucial role in enhancing a farmer's daily decision-making regarding agricultural activities, as it improves their awareness of new technology (Mittal & Mehar, 2015). Diverse information sources enable farmers to access information more quickly and timely, aiding them in making more informed and better decisions (Aker, 2011; Mittal & Mehar, 2013). Supporting these perspectives, Chen (2021) empirical research presented evidence indicating that farmers with numerous close friends have a positive and statistically significant relationship with the utilization of digital platforms and applications. However, Chen's study is one of the few that addresses the impact of the number of information sources on farmers' adoption of digital technology. Therefore, we hypothesize that:

H12. *The number of digital-related information sources farmers access increases the likelihood of their adoption of digital technology in agricultural tasks (INFACCES).*

Scholars argue that the sharing of agricultural knowledge among farmers, facilitated through peer-to-peer interactions, significantly contributes to technology adoption (Adamaagashi et al., 2023; Weyessa, 2017). In the realm of digital technology adoption, Blasch et al. (2022) recommend that to enhance digital technology adoption, farmers should engage in more frequent knowledge exchanges with their peers. While recent studies have emphasized the importance of information sharing and its connection to the adoption of new technology, there is currently a lack of empirical research on how the frequency of knowledge and experience exchange influences farmers' adoption of new techniques. Therefore, this study hypothesizes that:

H13. *The frequency of knowledge and experience exchange positively influences the adoption of digital technology in agriculture by smallholders (KNOWEXC).*

Farmer adoption of digital technology can be influenced by trust in knowledge and experience exchanged with others. According to Weyessa (2017), trust among farmers plays a significant role in the adoption and diffusion of agricultural technologies, as concluded in a qualitative study. Additionally, Korir et al. (2023) studied the adoption of new technology among Ethiopian dairy farmers, finding that trust in information from other farmers was positive influence on the adoption of multiple technologies. Despite a non-statistically significant result, Korir et al.'s finding introduced a new factor with the potential to influence farmers' technology adoption. Considering these points, the following hypothesis will be tested:

H14. *Farmers with a high level of trust in exchanged knowledge and experience with others are likely to adopt more digital technology in agricultural activities (KNOWTRU).*

3 | METHODOLOGY

3.1 | Study area

This research was conducted in Quang Tri province, which is located in the central region of Vietnam. Quang Tri is an agricultural-based province with a population of 647,790 people, and 67.43% of its population lives in rural areas. According to Quang Tri Statistics Office (2022), the labour force in the rural area of the province will occupy 66.71% in 2022, and they mainly work in agriculture. With a natural area of 470,123 ha, of which agricultural land accounts for 88%, agriculture is identified as one of the three pillars of economic development of the province. However, the agricultural sector occupies only 21.42% of the province's gross regional domestic product (GRDP). Farmers in Quang Tri province mainly operate small farms (0.47 ha on average) with a multi-crop and livestock production system. To address the socioeconomic conditions of smallholder farmers in Quang Tri province, the Provincial People's

Committee approved the scheme "Application of 4.0 technologies in agricultural development in Quang Tri province in the period of 2021-2030" (Quang Tri DARD, 2021). This scheme focuses on three key pillars, including developing a digital government, fostering a digital economy and promoting a digital society in agriculture. A key target is to have 30% of farmers using smartphone apps for production and trade by 2030. To achieve this, the Provincial Agricultural Extension Center conducted digital transformation training courses for extension staff, empowering them with the necessary knowledge to train farmers (Agricultural Extension Center of Quang Tri Province, 2022). Moreover, the Provincial Farmers' Union and the Post Office have joined forces to plan and execute initiatives that aim to aid farmers in their pursuit of digital transformation, specifically in terms of agricultural product and commodity production and consumption (Farmers Association of Quang Tri Province, 2022). These are the efforts of the Quang Tri provincial government to contribute to promoting digital transformation in the agricultural sector in the province.

3.2 | Sample, instrumentation and data collection

Data collection took place in four selected communes across two districts in Quang Tri province, specifically Vinh Son and Vinh Tu (Vinh Linh district) and Trieu Trung and Trieu Thuong (Trieu Phong district), which are considered to possess the most advanced agricultural practices areas in the province.

The sample size was determined using the Yamane formula (1967). A total of 455 smallholder households were estimated to be selected from the 79,423 households in the province, with a sampling error of 5%. A snowball sampling technique was employed to select smallholders for interviews, as it allows for the recruitment of a large number of participants for the study (Cresswell, 2012). Initially, community leaders from four selected communes were contacted as entry points, and they facilitated the identification of smallholder households who owned internet-based digital devices such as smartphones, laptops, or digital TVs and held less than two hectares of land. From each commune entry point, an initial sample of 20 households was identified. Subsequently, each respondent in the initial sample referred another household for the subsequent sample, repeating this process until the desired sample size was reached. Participants were briefed on the anonymized utilization of survey data and privacy protection measures, adhering to the principle of informed consent.

Data were collected from both secondary and primary sources. Secondary data sources included the provincial statistical yearbook for 2022 and annual reports from provincial and district agencies such as the Department of Agriculture and Rural Development, Agricultural Extension, and Farmers' Association. Primary data were obtained through household surveys utilizing a structured questionnaire in two parts. The first part involved the socioeconomic characteristics of households, and the second part captured the information related to digital technologies adopted by smallholders. The majority of the statements in the questionnaire used Likert scales (1–5) with responses ranging from "strongly disagree" to "strongly agree". Age, gender, education, family size, farm size, farm income, etc. were among the socioeconomic characteristics examined in the study.

A structured interview schedule was utilized for the household surveys. To ensure the reliability of the instrument, a pre-test was conducted with 10 non-sample farmers randomly selected from the Trieu Phong district. Following validation of the questionnaire and training of enumerators, the surveys were administered by 5 enumerators. The survey took place between October and December 2022. It is important to note that this study only focused on the adoption of digital applications and functions for agricultural-related purposes of smallholders, without considering their adoption for other purposes such as social interaction and entertainment.

3.3 | Data analysis

The data were analysed using SPSS (for descriptive analysis) and Stata (for Poisson Regression). Percentage, mean, minimum, maximum and standard deviation were used. Multicollinearity among the variables was checked.

A Poisson Regression model was used to determine the effect of the independent variables on the dependent variable. The general form of the Poisson Regression model used in this research is expressed as follows:

$$\log(E(Y|X)) = \beta 0 + \beta 1X1 + \beta 2X2 + \ldots + \beta p^{*}Xp$$

Exponentiating both sides of the equation will provide the estimated count for Y. This will result in the following formula.

$$E(Y|X) = e^{\beta 0+\beta 1X1+\beta 2X2+\ldots+\beta p*Xp}$$

where:

E (Y|X) represents the expected value of Y given the values of the predictor variables X.is the expected value (i.e., mean) of the response variable Y.

log() is the natural logarithm function.

β0 is the intercept term.

β1, β2, ..., βp are the regression parameters corresponding to the predictor variables.

X1, X2, ..., Xp X1, X2, ..., Xp are the independent variables.

The dependent variable (Y) in this study is the total number of digital applications and functions adopted by smallholder farmers which takes the value from 1 to 8 as demonstrated in Figure 2.

According to the findings illustrated in Figure 2, the largest proportion of smallholders (22.64%) adopted three digital applications and functions, while the second highest percentage of adoption was observed for four applications and functions (16.70%). Conversely, the lowest ratio of users (7.03%) adopted only one application and function, slightly lower than the percentage of users who adopted the highest number of applications and functions (8), which amounted to 8.35%.

Table 1 provides the summary statistics for the variables used as independent variables in the regression model. In general, the independent variables exhibit a wide range of characteristics and attributes.

The majority of smallholders in the sample are middle-aged farmers (49.81 years old) with about 8.12 years of formal education (SD = 2.82 years). The average household size was approximately 4.54 people and ranged from two to nine members. Most of the household heads were male (85.05%).

The average farm size of farm households was found to be 11.83 sao (equivalent to 0.59 ha), and their annual average income was 261.98 million VND (11,148 USD). The farm size and income variation among farmer households were quite high, with 4.32 sao (0.22 ha) and 141.37 million VND (6,016 USD), respectively.

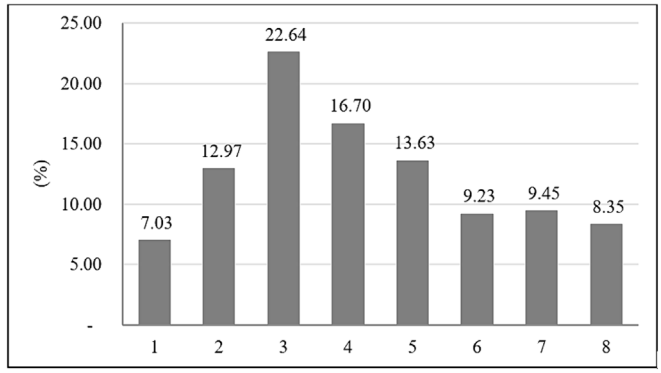

FIGURE 2 Distribution of digital applications and functions adopted by smallholders (n = 455).

TABLE 1 Summary statistics of variables used in the Poisson regression model (n = 455).

Type of variable	Variable description	Measurement and unit		
Dependent variable				
Digital technology adoption (Y)	Total number of digital applications and functions adopted by smallholder farmers	Taking the value from 1 to 8		
Independent variable				
Continuous and ordinal variable	***Variable description***	***Measurement and unit***	***Mean***	***SD***
Age (AGE)	Age of farmers	Year	49.81	8.53
Education (EDU)	Formal education measured by years in the school of farmers	Year	8.12	2.87
Household size (HHSIZ)	Number of people in the household	People	4.54	1.11
Farm size (FAMSIZ)	Total land area owned by households	Sao[a]	11.83	6.32
Total income (INCOME)	Total income of a household in a year	Million VND	261.98	141.37
Digital devices ownership (DEVICE)	Total digital devices (smartphones, laptops, digital TVs, …) owned by households	Device	4.24	2.01
Internet cost (INTCOST)	The total amount farmers pay for internet services in a month	Thousand VND	180.20	40.43
Digital experience (DIGIEXP)	Years of farmer's experience using digital devices	Year	4.53	1.91
Digital information sources accessed (INFACCES)	The number of digital-related information sources accessed by the farmers	Number of sources	2.45	1.21
Knowledge exchange (KNOWEXC)	Frequency of exchanging digital knowledge with fellow farmers	Likert scale, (1 = rarely, 2 = occasionally, 3 = sometimes, 4 = frequently, 5 = very frequently)	2.33	0.72
Trust in exchanged knowledge (KNOWTRU)	Levels of trust in the exchanged knowledge with fellow farmers	Likert scale, (1 = no trust, 2 = little trust, 3 = moderate, 4 = high trust, 5 = complete trust)	3.36	0.95
Binary variable	***Variable description***	***Measurement and unit***	***Number of cases***	***Percentage (%)***
Gender (GEND)	Gender of the farmers	1 = Male	387	85.05
		0 = Female	68	14.95
Participating farmer organizations (ORGMEB)	The involvement in farmer organizations of the farmers	1 = Member	387	85.05
		0 = Non-member	68	14.95
Crop-focused farming (FTYPE 1)[(*)]	Farmers with their main farming income comes from crop production	1 = Crop-focused production	128	28.13
		0 = Otherwise	327	71.87
Livestock-focused farming (FTYPE 2) [(*)]	Farmers with their main farming income comes from livestock production	1 = Livestock-focused production	150	32.97
		0 = Otherwise	305	67.03

[a]VND is Vietnamese Dong; 23,500 VND is equal to 1 USD.
[b]Sao is a unit of calculating land area in Vietnam; 20 sao equals one hectare.
[(*)]The aquaculture farm type is the base group.

Regarding the resources for digital adoption, on average, smallholder households owned 4.24 digital devices, including smartphones, laptops, PCs, digital televisions, etc. (SD = 2.01 devices), and they had around 4.53 years of digital experience adoption (SD = 2.01 years). The internet cost that households paid monthly was 180.20 thousand VND, with SD = 40.43 thousand VND (equivalent to 7.67 ± 1.72 USD).

Table 1 also reveals that 28.13% and 32.97% of households belonged to farm type 1 (crop farm) and farm type 2 (livestock farm), respectively. About 85.05% of surveyed households were members of at least one farmers' organization. In addition, on average, each farmer had 2.45 sources of information to get advice when they needed (SD = 1.21 sources). Moreover, smallholders engaged in the less frequent exchange of experiences with fellow farmers, with a mean score of 2.33 (SD = 0.72), and their trust level in the exchanged experience was moderate, scoring an average of 3.36 (SD = 0.95).

4 | RESULTS

4.1 | Smallholders' adoption of digital technologies in agricultural-related activities

4.1.1 | Internet connection and digital device ownership

Table 2 displays the proportion of smallholders who utilize digital devices, and their adopting experience. The primary digital means and devices used by smallholders were the internet, smartphones and digital television, with farmers exhibiting more experience in utilizing these devices. Particularly, almost all smallholders possessed a smartphone and had access to an internet connection in their homes, while digital television was utilized by 80% of users. In contrast, laptops, personal computers (PCs) and tablets were not as widely used by smallholder households. On average, smallholders had over 4.5 years of experience with internet usage, PCs, smartphones and digital television (with a standard deviation of approximately 2.00 years). On the contrary, farmers had the lowest level of experience with tablets (only 2.67 years of usage).

4.1.2 | The smallholders' adoption of digital applications and functions

Table 3 presents the digital applications and functions utilized by smallholder farmers and the extent of their usage. Generally, the smallholders in the study area adopted various applications and functions for their farm-related activities, with more focus on bidirectional and multidirectional platforms. In particular, Facebook, YouTube and weather

TABLE 2 Digital device ownership and utilization experience of smallholders (n = 455).

		Utilization experience (year)	
Device	**Percentage of users (%)**	**Mean**	**SD**
Internet connection(*)	99.78	4.84	2.02
Smartphone	99.56	4.58	2.45
Digital TV	80.00	4.61	1.94
Laptop	27.25	3.80	2.42
PC	10.11	4.74	2.76
Tablet	2.86	2.67	1.21

(*)*wireless or wired connections*.

forecast apps were the most commonly used applications and functions among smallholders, with 81.28%, 80.84% and 70.99% of users, respectively. Audio and video calls and interaction in Zalo were followed by 62.20% and 45.49% of farmers adopted. Meanwhile, the Web, search engines and Online shopping apps were the least adopted, with less than 30% of smallholders reporting their use.

Table 3 also indicates that smallholder farmers use digital applications and functions for agricultural-related purposes to a limited extent. The most frequently utilized applications and functions are typically accessed between 2 and 3 times per week, followed by usage of 4–5 times per week. Of which, weather forecast apps, Facebook, YouTube and Zalo were used with a higher frequency.

4.1.3 | The main purposes of digital adoption of smallholders

Table 4 illustrates the purposes for which smallholder farmers adopted digital applications and functions. Overall, smallholders in the region used digital tools for multi-purposes related to agriculture. Specifically, a substantial percentage of smallholder farmers (82.42%) adopted digital applications and functions for obtaining farm practice advisories, followed by those who utilized these tools to receive weather information (77.14%). Contacting and selling farm products, as well as obtaining and exchanging output price information, were the next most popular purposes, with adoption rates of 65.05% and 61.76%, respectively.

Table 4 also reports that over 50% of farmers employed digital tools to contact and purchase inputs, as well as to obtain and exchange input price information. In addition, a significant percentage of smallholders (47.91%) used digital technologies for marketing their farm products. Notably, the adoption rates for hiring labour or seeking financial assistance through digital applications and functions were relatively low, with fewer than 10% of smallholders utilizing these tools for these purposes.

TABLE 3 Digital applications and functions adopted by smallholders (n = 455).

Applications and functions	Percentage of users (%)	Extent of use (%)				
		< 2 times/ week	2–3 times/ week	4–5 times/ week	6–7 times/ week	> 7 times/ week
A. Unidirectional Platforms						
Weather forecast Apps	70.99	3.10	16.72	29.10	26.32	24.77
Web and search engines	29.67	25.74	36.76	23.53	10.29	3.68
B. Bidirectional Platforms						
Audio and video calls	62.20	24.73	42.76	26.15	4.24	2.12
Instant messaging	38.24	25.86	32.76	24.14	12.64	4.60
Online shopping Apps	15.82	72.22	18.06	9.72	0.00	0.00
C. Multidirectional Platforms						
Facebook	81.28	20.81	29.73	21.08	17.03	11.35
YouTube	80.84	16.62	29.16	31.06	13.62	9.54
Zalo	45.49	13.27	33.67	26.53	16.67	9.86

TABLE 4 The purposes of digital applications and functions adoption (n = 455).

Purpose of use of digital technologies	Number of cases	Percent of cases (%)
Getting farming knowledge and practice advisories	375	82.42
Receiving weather information	351	77.14
Contacting and selling farm products	296	65.05
Obtaining and exchanging output price information	281	61.76
Contacting and purchasing inputs	245	53.85
Getting and exchanging input price information	231	50.77
Marketing farm products	218	47.91
Exchanging farming experience and information	178	39.12
Post-harvest practice advisory	99	21.76
Seeking other farm services	99	21.76
Hiring labour	44	9.67
Seeking financial assistance	23	5.05
Others	3	0.66

4.2 | Factors influencing smallholders' digital technology adoption

Table 5 presents the results of the multicollinearity test and Poisson regression. The Variance Inflation Factor (VIF) for each explanatory variable was below 5 suggesting that all of the explanatory variables were suitable for inclusion in the Poisson regression model.

The Poisson regression model produced a Pseudo R2 value of 0.1252, indicating that approximately 12.52% of the variance in the response variable could be explained by the explanatory variables in the model. The LR chi-square value of 238.01 with 16 degrees of freedom and a p-value of 0.000 suggested that the model as a whole was statistically significant and that at least one of the explanatory variables was associated with the response variable.

Table 5 reports that among 15 exploratory variables, 10 were found to be statistically significant and influencing smallholders' digital technology adoption for agricultural-related purposes. At a 5% significance level, factors such as education (EDU), farm size (FAMSIZ), digital information sources accessed (INFACCES), knowledge exchange (KNOWEXC), Internet cost (INTCOST) and digital experience (DIGEXP) were found to have a positive influence on the number of digital application and function adoption. On the other hand, variables such as age (AGE) and trust in exchanged knowledge (EXPTRU) were identified as having a negative influence ($P < 0.05$). Additionally, at a significance level of 10%, participating in farmer organizations (ORGMEB) was found to be a positive influence factor, while crop-focused farming (FTYPE 1) had a negative influence ($P < 0.1$).

5 | DISCUSSIONS

5.1 | Smallholders' digital device ownership and their adoption of digital applications and functions for agricultural-related purposes

Our analysis indicates that nearly all smallholders in the study region have access to the internet and own smartphones. This is consistent with the findings of Nguyen et al. (2023), which show that most smallholders in Vietnam's rural households use smartphones with an internet connection as their primary digital devices. It was found that smallholders owned a variety of digital devices, such as digital televisions, laptops, computers and tablets,

TABLE 5 Multicollinearity test and Poisson regression results.

Variable	VIF	Coefficient	SD Err.	P > z	Marginal effect
Age (AGE)	1.334	−0.0128***	0.0031	0.000	−0.0543
Gender (GEND)	1.136	0.0197^{ns}	0.0678	0.771	0.0836
Education (EDU)	1.481	0.0264***	0.0100	0.008	0.1120
Household size (HHSIZ)	1.152	−0.0090^{ns}	0.0384	0.815	−0.0382
Farm size (FARMSIZ)	1.405	0.0193***	0.0038	0.000	0.0818
Crop-focus farming (FTYPE 1)	1.578	−0.1168*	0.0639	0.068	−0.4955
Livestock-focus farming (FTYPE 2)	2.236	−0.1023^{ns}	0.0698	0.143	−0.4341
Total income (INCOME)	1.677	−0.0001^{ns}	0.0002	0.727	−0.0003
Digital devices ownership (DEVICE)	1.316	0.0043^{ns}	0.0178	0.811	0.0181
Internet cost (INTCOST)	1.195	0.0013**	0.0006	0.032	0.0054
Digital experience (DIGTEXP)	1.317	0.0274**	0.0132	0.038	0.1162
Participating farmer organizations (ORGMEM)	1.190	0.1189*	0.0713	0.096	0.5043
Digital information sources accessed (INFACCES)	1.241	0.1110***	0.0191	0.000	0.4710
Knowledge exchange (KNOWEXC)	1.364	0.1000***	0.0366	0.006	0.4243
Trust in exchanged knowledge (KNOWTRU)	1.447	−0.0740**	0.0289	0.011	−0.3139
Constant		1.1701	0.2926	0.000	
Number of observation			**455**		
Pseudo R^2			**0.1252**		
LR Chi-square (16)			**238.01**		
Prob > Chi-square			**0.000**		

*p ≤ 0.1.
**p ≤ 0.05.
***p ≤ 0.01.

which provided them with multiple ways to access information and engage with the internet. Therefore, while most studies have focused on employing the smallholders' utilization of mobile phones or conventional ITC technologies in agricultural practices in Vietnam (Hoang, 2020a; Hoang, 2020b; Hoang & Nguyen, 2021; Uy et al., 2023), our study suggests that smallholder farmers could potentially benefit from owning a variety of modern digital devices such as computers, laptop, digital televisions, etc.

Smallholders in the region commonly used multidirectional platforms such as Facebook and Zalo for social interaction and YouTube as primary sources for farming-related purposes. This research outcome is consistent with the discoveries of Kanjina (2021) in Thailand, where LINE, Facebook and YouTube are frequently used by farmers, and with the findings of Mansour (2022) in Egypt, which identified Facebook and WhatsApp as the primary applications used by farmers to access agricultural information. The study also found that a significant ratio of farmers relied on smartphone apps for accessing daily weather information and took advantage of internet-based digital devices and apps to make bidirectional interactions like video or audio calls and instant messaging for agricultural-related purposes, indicating a shift towards increased digital technology adoption in agriculture of the smallholders. However, the current study reveals that farmers primarily utilized simple and ubiquitous features and applications of digital devices. Advanced digital applications, such as crop and livestock management, mobile money apps, agribusiness apps, etc., were not identified in this study.

Smallholder farmers in the study also widely adopted digital applications and functions for various purposes related to their agricultural production and marketing, with some similarities to previous studies (Drewry et al., 2019;

Kansiime et al., 2021; Kaske et al., 2018; Mansour, 2022; Nikola et al., 2019; Priya et al., 2021). Our study found that a significant proportion of farmers used digital means to obtain weather information, and farming knowledge and advisories, which aligns with the findings of Drewry et al. (2019), Kaske et al. (2018), Priya et al. (2021) that digital tools have become the primary source of agricultural information for farmers. These studies highlight the increasing significance of digital technology applications in the acquisition of weather and agricultural knowledge, and extension advisories by farmers. The study also revealed that smallholder farmers extensively utilized digital tools to access information on market prices and sell their produce, demonstrating their rapid adaptation to the transition towards a 4.0 society. These findings support the conclusion of Hoang and Douglas (2021), Khan et al. (2022) and Nikola et al. (2019) that digital technologies have become vital tools for smallholder farmers in seeking assistance with output markets.

5.2 | Factors influencing digital technology adoption by smallholders

The study's findings shed light on various determinants influencing smallholders' adoption of digital applications and functions in agriculture. Regarding operator characteristics, the age of smallholder farmers (*AGE*) exhibited a significant negative association with digital adoption, indicating that older smallholders are less likely to utilize digital technologies. This supports hypothesis H1. Conversely, farmers' education level (*EDU*) showed a positive and statistically significant effect on the adoption of digital applications and functions, corroborating hypothesis H2. These findings are consistent with recent empirical studies (Bounkham et al., 2022; Do et al., 2023; Hoang & Tran, 2023; Kanjina, 2021; Khan et al., 2022). However, the empirical findings did not support hypothesis H3, indicating that gender (*GEND*) was not a significant factor in digital technology adoption. This is consistent with previous studies (Bounkham et al., 2022; Hoang & Tran, 2023), suggesting that both male and female farmers have equal opportunities to adopt digital technologies in agriculture. Furthermore, household size (*HHSIZ*) did not significantly influence the adoption of digital applications and functions among farmers. Therefore, hypothesis H4 was not supported, although previous studies have reported conflicting findings (Akudugu et al., 2023; Kiarie, 2020). It is plausible that digital technologies do not necessarily require extensive labour or involvement from household members for adoption, thereby minimizing the impact of household size on farmers' adoption decisions regarding digital technology.

In terms of farm characteristics' influences, the model validates hypothesis H5, revealing a positive and statistically significant relationship between farm size (*FAMSIZ*) and the adoption of digital applications and functions by smallholders. This finding is consistent with previous studies by Bounkham et al. (2022), Kanjina (2021), Khan et al. (2022), Michels et al. (2020), Michels and Musshoff (2022), which found that farmers operating larger farms are more likely to adopt digital technologies to improve productivity and profitability. However, hypothesis H6 is not supported by the model, suggesting that higher household income (*INCOME*) does not significantly increase the likelihood of adopting digital technologies in agriculture. This contradicts previous research by Barnes et al. (2019), Hoang and Douglas (2021), Hoang and Nguyen (2021), Ma et al. (2023), but aligns with the findings of Abebaw and Cherinet (2018), Kanjina (2021). Additionally, among farming systems, only crop-focused farming (*FTYPE 1*) had a significant negative effect on the adoption of digital applications and functions by smallholders, supporting hypothesis H7a. This could be because crop-based households often prioritize family consumption over-commercialization, leading to lower demand for digital tools for connectivity and market monitoring compared to other farming-based systems.

The study findings did not corroborate hypothesis H8 regarding the determinants related to the digital technology approach of smallholders. While there was a positive correlation, it was not statistically significant, suggesting that owning more digital devices (*DEVICE*) did not significantly increase the likelihood of adopting more digital technologies in agriculture. However, hypothesis H9 was validated, indicating that farmers with greater experience in using digital devices (*DIGTEXP*) are more inclined to adopt digital technology in agriculture. Difference from the prior qualitative assertions by Fox et al. (2021), our study established a statistically significant relationship between years of farmers' digital experience and their adoption of digital applications and functions for agricultural activities. This

finding offers more nuanced insight into the impact of digital experience on smallholder adoption of digital technologies in Vietnam, an aspect not fully explored in prior research (Doanh et al., 2022; Van et al., 2022). This suggests that as farmers become more familiar with digital devices, they are more likely to explore additional applications and functions to apply in agricultural tasks. Additionally, the findings refute hypothesis H10, as they indicate a positive relationship between the rise in monthly internet expenses and the adoption of more digital tools (*INTCOST*). This finding also contradicts the qualitative conclusions drawn from prior investigations by Chen (2021), Hoang (2020b), Mansour (2022), Payne and Willis (2021) and Ma et al. (2023), which posited that exorbitant internet costs hindered the acceptance of digital tools. The results suggest that farmers who invest more in internet costs are motivated to maximize their technology usage by adopting multiple applications and functions.

This study uncovered significant findings regarding the impact of farmers' social interactions on the adoption of digital technology. Participation in farmer organizations (*ORGMEM*) was found to have a positive and statistically significant relationship with smallholders' adoption of digital applications and functions, confirming hypothesis H11. This aligns with previous research (Hoang, 2020a; Hoang & Douglas, 2021; Hoang & Nguyen, 2021; Mendes et al., 2023; Miine et al., 2023), indicating that involvement in such organizations fosters digital technology adoption among smallholders. Additionally, access to digital-related information sources (*INFACCES*) was positively associated with digital adoption, supporting Hypothesis H12. This corresponds with findings by Chen (2021), suggesting that farmers with extensive social networks are more likely to adopt internet-based digital tools. Moreover, increased frequency of knowledge exchange regarding digital technology among farmers (*KNOWEXC*) positively correlated with greater adoption of digital applications and functions, validating hypothesis H13. This finding contributes to providing evidence that supports previous conclusions by scholars (Adamaagashi et al., 2023; Akudugu et al., 2023; Blasch et al., 2022; Weyessa, 2017) regarding the potential influence of knowledge exchanges among farmers on technology adoption. However, the study contradicted hypothesis H14, as it found that decreased trust in knowledge shared by other farmers (*KNOWTRU*) was associated with higher digital applications and functions adoption. This finding contradicts previous observations (Korir et al., 2023; Wang et al., 2020), suggesting that trust in shared knowledge among farmers enhances technology adoption. This discrepancy may be attributed to the novelty of digital technology, where farmers may prefer independent experimentation or seek reliable information sources rather than relying solely on peer knowledge.

6 | CONCLUSIONS AND IMPLICATIONS

The adoption of digital technologies by smallholders is a topic attracting a lot of attention in Vietnam. From the findings of this study, it can be concluded that Vietnamese smallholders had a good foundation for digitalization with almost all of them accessing the internet and owning smartphones as well as other digital devices. Smallholders used many kinds of applications and functions for agricultural-related purposes. Among these applications, bidirectional and multidirectional platforms, especially social media platforms, are more commonly utilized compared to one-way platforms. This suggests that digital extension strategies should prioritize the development and utilization of these types of platforms to effectively support smallholders. Furthermore, the study revealed that smallholders have not adopted complex applications and functions, underscoring the importance of introducing and training farmers on the usage of advanced digital applications that are necessary for day-to-day farming activities such as crop and livestock management, mobile money apps, agribusiness apps, etc., which being used quite popular in developed countries. In addition, digital extension services should adopt a multi-modal approach, as farmers have access to various digital channels and applications.

Farmers use digital applications and functions for multi-purposes in which, the majority are for getting farming knowledge and practice advisories, receiving weather information and getting output information, as well as contacting and selling farm products. Thus, digital extension services need to pay more attention to developing farming tutorials as well as forming platforms that can integrate and provide daily farming-related information for

smallholders. The study findings also highlighted the value of digital applications that provide integrated features encompassing weather updates, market information and tailored guidance for specific crops and livestock, as they effectively cater to farmers' needs.

This study makes a significant contribution to the existing literature by identifying key factors that drive the adoption of digital applications and functions among smallholders in Vietnam. Young age, higher education and digital experience, larger farm size and frequent digital knowledge exchange smallholders should consider emerged as pioneering forces in the adoption of digital technologies. The primary focus of training efforts to cultivate a group of digital farmers should be on these farmer groups, as they are considered the leading forces in adopting digital technologies. Models such as the "new farmers" or "smart farmers" should be taken into account to leverage the expertise and experiences of farmers within these groups. By targeting these specific groups, it is possible to build a strong foundation for digital farming and accelerate the adoption of digital technologies in the agricultural sector in Vietnam. Specialized training programs are essential for older individuals, those with limited education and low digital experience, small-scale, crop-focused farmers, etc. These efforts are vital to enhance their digital skills and facilitate the widespread adoption of digital technologies in the agricultural sector.

The study suggests that internet costs do not serve as a significant barrier to digital technology adoption among farmers. Instead, increased investment in internet expenses motivates farmers to maximize technology usage by adopting multiple applications and functions. This finding contradicts previous concerns raised by some scholars regarding the potential inhibitory effect of internet costs on farmers' digital tool usage. Furthermore, the research indicates that a lack of trust in knowledge and experiences shared by fellow farmers enhances the likelihood of digital technology adoption. This finding challenges the notion that trust in knowledge exchanged among farmers fosters their capacity to adopt new techniques. As a result, the study suggests that direct training programs are crucial for effectively disseminating knowledge, rather than solely relying on the trust in exchanged knowledge among farmers. Finally, the findings from this research also underscore the importance of involving farmer organizations to drive the adoption of digital technologies among smallholders. Collaboration with these organizations is instrumental in advancing strategies to expand digital extension services.

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CONFLICT OF INTEREST STATEMENT

The authors are solely responsible for any errors in this paper and declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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