Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-025-04363-4 OPEN

Farmers' adoption of green prevention and control technology in China: does information awareness matter?

Ruifeng Liu[1], Jian Wang[1], Mengling Tian[1], Yefan Nian[2], Wei Ren[1], Hengyun Ma[1] & Fei Liang[1]✉

Green prevention and control technology (GPCT) represents an eco-friendly approach in agriculture, aimed at promoting sustainability by reducing farmers' excessive use of chemical pesticides. Despite the Chinese government having made a large effort to promote the technology, the farmers' utilization is still low in China, especially when no financial incentives are provided to farmers. This study took 642 farmer questionnaires in Hua county, China, to analyze the effect of information awareness on farmers' adoption of GPCT. Our findings indicate that farmers' information awareness is a significant factor in their decision to adopt GPCT. Furthermore, the underlying mechanisms of the influence of information awareness on farmers' GPCT adoption have been studied. Mechanism analysis shows that farmers' information awareness affects the adoption of GPCT mainly through social networks. Farmers' environmental values significantly reinforce the positive influence of information awareness on GPCT adoption. In addition, the regression results from the sub-sample indicate that information awareness has a more pronounced marginal effect on GPCT adoption for farmers with long years of schooling and larger wheat cultivation areas. These results offer insights for promoting GPCT in developing nations.

[1] College of Economics and Management, Henan Agricultural University, Zhengzhou 450046, China. [2] Department of Agricultural Sciences, Sandhill Research and Education Center, Clemson University, Clemson, SC 29229, USA. ✉email: liangfei@henau.edu.cn

Introduction

As the "guardian" of crops, chemical pesticides have played a key role in ensuring China's food security during the past few decades. From 1991 to 2022, chemical pesticide use in China's agricultural sector increased by 0.425 million tons, reaching 1.190 million tons compared to 0.765 million tons previously (China Rural Statistical Yearbook, 2023). It can annually recover losses accounting for 30% to 40% of the total crop yield (Zhang et al., 2015). However, the pervasive application of pesticides, together with the low average chemical pesticide utilization rate, has led to severe soil pollution problems in China (Li et al., 2023). As reported by the China Ministry of Agriculture and Rural Affairs (2023), China's utilization rate of chemical pesticides is only 41%. Many chemical pesticide particles volatilize or drift into the atmosphere and remain in water and soil, leading to substantial non-point source pollution in rural regions (Lai, 2017). Meanwhile, chemical pesticide residues on agricultural products can enter the human body directly or indirectly via the food chain or drinking water. The gradual accumulation of chemical residuals in human internal organs may pose long-term threats to human health (Mohd Nizam et al., 2023). Therefore, effectively reducing pesticide usage, minimizing ecological pollution, enhancing the quality of farm produce are crucial objectives for the Chinese agricultural sector to maintain its sustainability.

To develop agricultural sustainability, the Chinese government is dedicated to promoting GPCT to reduce farmers' overuse of pesticides. GPCT represents a pesticide substitution technology that combines Integrated Pest Management (IPM) with local practices in China. Differing from traditional single chemical pesticide control technology, GPCT comprehensively utilizes agricultural, biological, and physical methods to manage crop pest and disease problems, ultimately minimizing farmers' reliance on chemical pesticides. It follows the principle of "prioritizing prevention and implementing integrated control." Previous studies show that CPGT has the capacity to decrease chemical pesticide usage, boost farmers' net income, and ensure agricultural products' quality and safety (Midingoyi et al., 2019).

Although the Chinese government started promoting CPGT as early as 2006, the current farmers' utilization of CPGT is still relatively low. As of now, China has only established 203 demonstration counties for green prevention and control (China Ministry of Agriculture and Rural Affairs, 2021). The cumulative area of land utilizing GPCT across China totals 184 billion mu (1 mu ≈ 0.067 ha) (China National Agro-Tech Extension and Service Center, 2022). Many farmlands that currently use CPGT belong to so-called "demonstration" land for CPGT. Farmers tend to receive financial incentives from various projects to implement CPGT. However, this project-driven initiative and demonstration-oriented approach to promoting CPGT faces challenges in the long-term success of the technology. Many projects are facing obstacles due to insufficient support, making it hard to continue providing financial incentives to various farmers to adopt CPGT. Therefore, identifying factors that determine farmers' adoption of CPGT under the scenario of no financial incentives provided is crucial to the success of CPGT. It could help policymakers and industry personnel to develop better strategies to promote CPGT.

This study endeavors to explore the significance of information awareness as a pivotal determinant in promoting GPCT adoption in China. Considerable attention has been given by scholars to the examination of farmers' adoption decisions regarding GPCT. Current research investigates the influencing factors, including individual characteristics, land characteristics, and governmental subsidies (Tong et al., 2022; Sharifzadeh et al., 2023). Studies on the effect of information awareness are often substituted or assessed using information ability or a solitary indicator (Yue et al., 2023), which may result in misjudgment of an individual's information awareness. Information is pivotal in directing individual information activities (Reddy et al., 2022). Through alleviating information asymmetry, information awareness provides individuals with a basis for making informed decisions (Nikam et al., 2022). Cultivating farmers' information awareness can help them acquire and use green technology information in an effective manner and promote the acquisition of technical experience (Dzanku et al., 2022). Future research should intensify the examination of the role of information awareness in shaping farmers' decisions to adopt GPCT. Furthermore, earlier research has concentrated on the immediate motivational impacts of social networks and environmental values on technology adoption (Rezaei et al., 2020). Individual behavioral choices are influenced by both internal and external factors. Therefore, the study on farmers' technology adoption decisions needs to combine the internal factors with the external factors. Specifically, current research has not yet accounted for the reliance of farmers' information awareness on their environmental values (internal factors) and social networks (external factors) in shaping their decisions about GPCT adoption.

This research makes three significant contributions. First, based on scientific information theory, this study establishes an index system to assess farmers' information awareness and investigate its influence on their GPCT adoption. This system serves as a crucial reference for encouraging farmers' technology adoption from an information awareness perspective. Furthermore, this study delves into distinct farmer groups with varying characteristics, thereby improving the specificity of the research findings. Second, this study integrates information awareness, social networks, and environmental values into a cohesive analytical framework to investigate farmers' adoption of GPCT. Specifically, this study unravels the potential mechanism by which information awareness impacts on GPCT adoption, with a particular focus on the role of social networks in the process. Meanwhile, this research reveals the effect of the interaction between information awareness and environmental values in shaping GPCT adoption decisions. The results uncover the causal mechanism linking information awareness to farmers' GPCT adoption, offering insightful policy implications for promoting such technologies. Third, this study provides an empirical Chinese version for understanding farmers' information awareness and its impact on adopting environmentally friendly agricultural technology. Specifically, using data from wheat farmers in Hua county, a representative rural region in Henan province, China, we empirically investigate the influence of information awareness on GPCT adoption and its mechanisms. China's current agricultural production situation closely mirrors that of numerous other developing countries currently undergoing agricultural modernization. Therefore, the insights gained from GPCT adoption in China can serve as a valuable reference for other developing countries at a similar stage of development.

Literature review

Many studies have been conducted to investigate farmers' GPCT adoption. Some research primarily examines the relationship between the government's support and farmers' technology adoption at the macro level. Research indicates that government-provided financial subsidies, technology training programs, and regulations can effectively mitigate the risks of increased costs and applicability associated with GPCT, thereby exerting a positive influence on farmers' adoption (Ochieng et al., 2022; Sharifzadeh et al., 2023; Tambo, Liverpool-Tasie, 2024). At the micro level, farmers' adoption of GPCT is influenced by four key factors. First, individual farmer characteristics such as being male, younger, having higher education levels and being more risk-tolerant increase the probability of adopting GPCT (Wangithi et al., 2021; Tong et al., 2022). Second, farmers' cognitive characteristics are influential. Farmers unaware of the detrimental effects of pesticide usage exhibit random and disordered production behaviors (Hu et al., 2022). However, awareness of pesticide residues signifies that farmers acknowledge the risks associated with the overuse of pesticides, making them inclined to apply eco-friendly techniques (Madaki et al., 2024). Some researchers have suggested that increasing farmers' perception of the usefulness of GPCT can motivate them to adopt GPCT (Xiang and Guo, 2023). Third, researchers have discovered that household attributes, including family labor, family income, and participation in cooperatives, significantly affect the dissemination of GPCT (Yu et al., 2020; Ren et al., 2022; Zhang et al., 2023). Fourth, studies have indicated that operating at an appropriate scale facilitates farmers' adoption of GPCT (Lyu et al., 2024). Moreover, scholars found that the degree of farmland fragmentation may result in increased management costs, inhibiting the adoption of GPCT (Cui et al., 2022).

Scholars generally believe that awareness is regulatory in human behavior, while values serve as norms and guides for human conduct (Engelmann et al., 2014; Bissinger and Bogner, 2018). Regarding awareness, information awareness reflects the individual's sensitivity to information (Yue et al., 2023). The collection and processing of information can influence individual's behavioral intentions by adjusting their subjective perceptions (Fan and Salas, 2018). Differences in information awareness among individuals lead to variations in their reactions when confronted with the same information (Nikam et al., 2022). Farmers may exhibit different actions due to variations in their information awareness, even under similar resource endowment conditions (Phiri et al., 2019). Farmers who possess information awareness are capable of obtaining information promptly and efficiently, thereby facilitating the accumulation of technical experience (Campenhout, 2021). At the values level, environmental values are a profound factor guiding individuals in implementing environmental protection behaviors, reflecting the extent of importance individuals assign to the environment and related issues within their cognitive domain (Rezaei et al., 2020). Farmers who prioritize environmental values tend to exhibit positive attitudes toward ecological protection and proactively seek, acquire, and share information about environmentally friendly technologies (Lincoln and Ardoin, 2016). In addition, China is a traditionally relationship-oriented society, which makes the external interpersonal factor of social networks crucial in farmers' production decisions (Zhang and Fu, 2023). As a particular form of social capital, social networks can provide material capital, information resources, and emotional support for farmers and encourage farmers to adopt environment-friendly technology such as GPCT (Beaman and Dillon, 2018; Zheng and Luo, 2022).

While existing research provides useful insights into farmers' GPCT adoption, it also has some limitations. First, existing research suggests that information awareness is a crucial factor influencing farmers' decisions to adopt technologies. However, previous studies have not scientifically measured the overall level of information awareness and empirically examined its impact on adopting GPCT. Second, social networks have the capacity to influence farmers' attitudes regarding environmentally friendly behaviors. Existing research has rarely considered the indirect effect of information awareness on GPCT adoption through social networks. Third, environmental values serve as the intrinsic motivation that drives individuals to engage in environmentally friendly behavior. Whether environmental values can reinforce the direct impact of information awareness on GPCT adoption remains to be further verified. Therefore, this study integrates information awareness, social networks, and environmental values into a comprehensive analytical framework for examining farmers' GPCT adoption. Specifically, this study examines the effect of information awareness on GPCT adoption. This study also delves into the indirect effect of information awareness on GPCT decisions through the expansion of social networks and examines the interactive effects between information awareness and environmental values in influencing GPCT adoption. The results of this study offer both theoretical and practical insights for promoting the adoption of GPCT by enhancing farmers' information awareness.

Institutional background

The Chinese government has strongly promoted GPCT. In 2011, the Opinions on Promoting Green Prevention and Control was issued, taking green prevention and control as a crucial aspect of advancing the construction of a modern plant protection system and implementing the "double reduction" action for pesticides and fertilizers. In 2017, the Opinions on Innovative Institutional Mechanisms for Promoting Green Agricultural Development were released, emphasizing the importance of reinforcing comprehensive green prevention and control measures. In 2019, the Strategy Plan for Revitalizing Quality-Oriented Agriculture (2018–2022) was issued, proposing to establish demonstration counties for pest management and control, with the objective of extending such practices to all counties. At the beginning of 2023, Central Document NO. 1 (2023), the most important government policy document of the year, emphasized the need for comprehensive green pest management strategies to facilitate the reduction and more efficient use of pesticides. These policy documents indicate that the Chinese government places significant emphasis on the promotion of GPCT.

The studying county, Hua county is situated in Henan province, China. It is a major wheat-producing county in China. In 2023, Hua county's wheat planting area reached 1.8120 million mu, with a yield of 1 million tons. Hua county is vigorously promoting the GPCT of wheat, aiming to accelerate the sustainable development of the wheat industry. In 2016, the Demonstration Zone of Wheat Green Prevention and Control was established in Hua county. Subsequently, Hua county has heavily promoted the application of methods such as light trapping, color board trapping, predatory wasps, and biological pesticides to carry out green prevention and control on crops such as corn, vegetables, peanuts, and cotton. Therefore, the damage caused by more than a dozen pests, such as corn borers, cotton bollworms, and yellow stem borers, has been effectively controlled. The demonstration zones of green prevention and control in Hua county have been increasing by over 10% annually. In 2023, the demonstration area for green prevention and control of major crops in Hua county reached 0.3528 million mu, with a radiating influence covering 1.1 million mu. The application level of green prevention and control measures for primary crops reached 47.9%, showing a 5 percentage point increase compared to 2022. In recent years, Hua county has summarized a series of green prevention and control technology models, including the "pear + lamp + chicken" model in Gaoping town, the "tomato + microbiological agents + color board" model in Wangzhuang town, and the "wheat + ladybugs + optimized combination of pesticide varieties" model in Laodian town. According to the statistics from the local agricultural and rural systems, in 2023, the comprehensive control effectiveness of the core demonstration area of green prevention and control in Hua

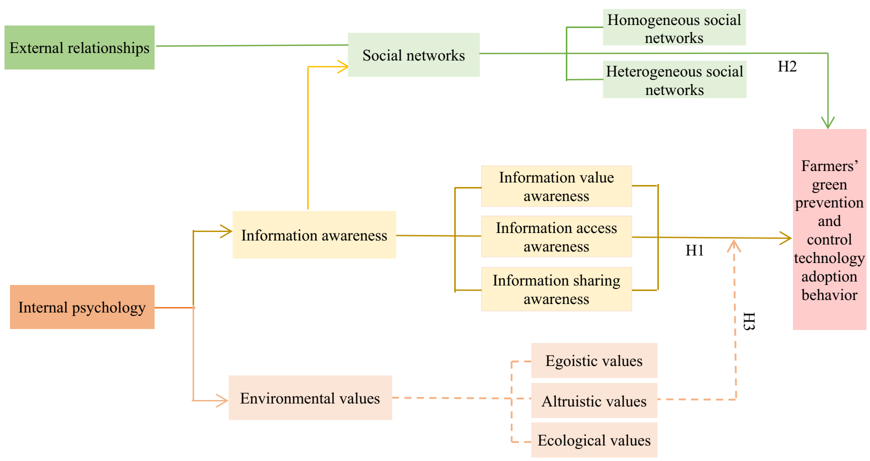


Fig. 1 Theoretical analysis framework.

county reached 94.6%. The per-mu usage of chemical pesticides was reduced by 2.26 times, and the per-mu prevention and control cost was reduced by 10%. The use of pesticides for wheat in Hua county has significantly decreased in recent years. In 2023, the amount of chemical pesticides used for wheat in Hua county was 110 g per mu, a decrease of 25 g per mu compared to the previous year.

Theoretical framework

This study reveals the mechanisms of farmers' information awareness on GPCT adoption. Figure 1 depicts the theoretical framework and research hypothesis.

Information awareness

The scientific information theory posits that information awareness can influence the demand expression of the information recipient, govern their information behavior, and determine the effectiveness of information utilization (Vande et al., 2004). Therefore, information awareness is a crucial factor influencing individual behavior diversification. Johnston and Webber (2003) characterize information awareness as the active response of the information recipients towards objectively existing information phenomena. Subsequently, scholars have refined and supplemented the definition of information awareness. For example, from the psychological perspective, Walsh (2009) pointed out that information awareness refers to the recipient's understanding of the function, value, and status of information transmission activities in society. Aubert et al. (2012) believed that possessing information awareness implies that individuals have a keen sensitivity and sustained attention to information, as well as a unique insight into the value of information. Following Machin-Mastromatteo (2021) and Tian et al. (2023), this study divides information awareness into three dimensions: information value awareness, information access awareness, and information sharing awareness. Specifically, information value awareness refers to the individual's awareness of making appropriate judgments about the role and value of external information to improve information utilization efficiency. Information access awareness involves the individual's awareness of defining the nature and scope of the information and actively collecting information through various channels. Information sharing awareness indicates the individual's proactive awareness of sharing and exchanging information with others.

Information awareness serves as a solution to the issue of farmers' hesitation to adopt technologies due to an incomplete grasp of technical information, thereby directly facilitating their adoption of GPCT. Specifically, farmers with strong information awareness are more inclined to actively acquire, comprehend, and analyze information related to GPCT (Nikam et al., 2022). Gaining more GPCT information allows farmers to better comprehend its fundamental principles and unique benefits, enhancing their trust in adopting GPCT (Ma et al., 2017). Farmers' trust is essential for the embrace of novel practices (Cofré-Bravo et al., 2019). Meanwhile, the stronger the information awareness, the greater farmers' capacity to access policy information, market intelligence, and production data, thereby mitigating market and environmental uncertainties encountered during technology adoption and promoting GPCT adoption (Naveed and Hassan, 2021). Furthermore, farmers with strong information awareness can derive satisfaction from sharing and exchanging information with others, thereby fostering a conducive environment for adopting GPCT (Dzanku et al., 2022). Based on the prior analysis, the hypothesis is formulated:

H1. Farmers' information awareness positively influences their adoption of GPCT.

Social networks

The high-tech nature of GPCT has increased the technical threshold for farmers to adopt it (Midingoyi et al., 2019). Information awareness is an internal factor that affects farmers' utilization of technologies (Engelmann et al., 2014). However, farmers will face obstacles in adopting GPCT if there is a lack of suitable pathways or supply-driven initiatives supported by organizations. Skaalsveen et al., 2020 pointed out that social networks, characterized by short communication channels and high impact, can effectively compensate for the deficiencies in technology extension. The social networks have become an important channel for the dissemination of agricultural technology information. Specifically, social networks encompass the formal and informal connections established through the exchange of resources among individuals engaged in various activities (Kekulandala et al., 2023). Farmers demonstrate two different kinds of social networks in adopting technologies: homogeneous and heterogeneous. Within homogeneous networks, individuals often perform similar tasks, fostering stronger connections and thus forming a cohesive social network group (Maertens, 2017). In heterogeneous networks, individuals originate from varied social backgrounds and hold distinct social statuses, contributing to the network's diversity (Skaalsveen et al., 2020). Homogeneous networks usually consist of familiar individuals like relatives, friends, and neighbors (Lonnqvist and Itkonen, 2016). Heterogeneous networks are often made up of professionals, including agrotechnical personnel, cooperatives, and village officials (Munshi, 2004). During the initial phase of agricultural technology dissemination, farmers' learning and communication on applying GPCT through the relationship networks can enhance their understanding and facilitate technology adoption (Chaudhuri et al., 2021).

Farmers' information awareness may indirectly affect their GPCT adoption through social networks. Typically, farmers possessing heightened information awareness generally exhibit larger social network sizes and superior network quality, leading to a more significant promotion of GPCT adoption. Specifically, farmers with strong information awareness can recognize the role of social networks as a conduit for information (Thuo et al., 2014; Skaalsveen et al., 2020). Therefore, these individuals are inclined to seek valuable production information through interactions with members within their networks (Ma et al., 2017). The interactions not only assist farmers in obtaining the requisite information but also foster deeper mutual connections and understanding, thereby facilitating the expansion of their social networks. Furthermore, trust relationships among farmers are forged through long-term interactions and shared interests (Cofré-Bravo et al., 2019). When farmers receive information from members of their social network, they are more inclined to believe in the reliability and efficacy of this information. Establishing trust relationships helps farmers strengthen their social networks, enabling them to easily access information support related to GPCT (Yu et al., 2020). Considering this, the hypotheses are suggested:

H2. Farmers' information awareness promotes their adoption of GPCT through social networks.

Environmental values

Values are an individual's overall view and evaluation of the significance and importance of objective things (Kanani and Ahmadvand, 2019). Values are fundamental guidelines that guide behavior and can have a lasting and stable impact on individual actions (Bissinger and Bogner, 2018). Stern (2000) extracted environmental values directly related to pro-environmental behaviors from the individual value system and introduced the theory of Value-Belief-Norm. The Value-Belief-Norm theory posits that an individual's value orientation toward the ecological environment shapes their environmental beliefs (Stern, 2000; Rezaei et al., 2020). Value orientation is categorized into egoistic, altruistic, and ecological values (Momenpour et al., 2024). Egoistic values imply that engaging in environmental protection practices may mitigate the adverse influence of various environmental issues on oneself. Altruistic values suggest that environmental issues pose a threat to others, necessitating environmental protection. Ecological values hold that humans should not harm the environment to meet their own needs.

Farmers' environmental values, as intrinsic motivators of individual behavior, may enhance the influence of information awareness on their GPCT adoption. Environmental values can stimulate farmers' information awareness to acquire the information and skills of GPCT, thereby reinforcing their understanding and adoption of this sustainable practice. Specifically, to achieve sustainable agricultural production, farmers with positive environmental values can be more acutely aware of information about environmental protection (Mills et al., 2017). Farmers, driven by their heightened information awareness, are motivated to seek out and acquire knowledge and skills related to environmental protection more efficiently (Yang et al., 2021). Furthermore, farmers with strong environmental values believe that everyone has a responsibility to protect the agricultural ecosystem (Momenpour et al., 2024). These farmers will share and disseminate agricultural information beneficial to environmental protection within the village area, aiming to create a favorable atmosphere for GPCT adoption and sustainable agriculture promotion. Therefore, Hypothesis 3 is proposed:

H3. Farmers' environmental values can enhance the positive impact of information awareness on their GPCT adoption.

Data, variables and methodologies

Data collection. Several reasons led to the choice of Hua county as the research site. First, wheat is a significant staple food crop in China, and this is equally true for Henan province. In Hua county, the trend is no different, with wheat occupying a substantial portion of the total sown area for grain crops. Second, the promotion of GPCT in Hua county is consistent with the broader promotional efforts undertaken in Henan province and throughout China. As a key county demonstrating the advancement of GPCT in Henan province, Hua county has attained notable accomplishments in fostering widespread adoption of GPCT, promoting healthy and sustainable agricultural development throughout the region. In 2022, Hua county accomplished a 1.1% reduction in its annual pesticide usage. Therefore, the scale of wheat sowing and the promotion of GPCT in Hua county represent China's key agricultural regions. Choosing Hua county as the research area also embodies a certain degree of typicality. Hua county stands as the foremost wheat-producing county in China. In 2023, Hua county's wheat-sown area accounted for 58.16% of the total, surpassing Henan province's 52.72% and China's 19.86%.

The study's survey was carried out in two phases. The initial phase involved a preliminary investigation. In August 2023, a selection of 40 wheat farmers in Hua county were interviewed to gain an initial insight into their GPCT adoption. According to preliminary survey results, we modified and improved the questionnaire (see Table A1). The second phase involved conducting a formal survey. Between October and December 2023, we utilized a mixed methodology of stratified and random sampling to select respondents. First, we selected representative townships as our research areas (Fig. 2) based on their geographical location and level of economic development. Next, we randomly chose two administrative villages from each township, taking into account their proximity to the town center. Finally, 20 respondents were chosen at random from every village administration. In total, 680 wheat growers from 34 administrative villages in 17 townships were interviewed in this study. Following the exclusion of questionnaires containing missing or invalid data, we obtained 642 valid responses.

Variable selection. This study aims to investigate how farmers' information awareness influences GPCT adoption. Table 1 and Table 2 present the definitions and measurements of variables.

Farmers' GPCT adoption behavior is seen as the outcome of selecting one or more specific sub-techniques from a broad and intricate technology set. This is due to the fact that GPCT is not a singular technology but rather a comprehensive technology set that includes ecological regulation, biological control, physicochemical inducement, and scientific medication (see Table A2). Building on the research by Creissen et al. (2021), as well as the practical application of GPCT in wheat production in Hua county, categorizes farmers' GPCT adoption as encompassing both biological control technology and physicochemical inducement technology. Biological control technology encompasses measures such as using biological pesticides and the artificial release of natural enemies by farmers to manage pests. On the other hand, physicochemical inducement technology pertains to pest control strategies employed by farmers, including trapping with insect-killing lamps and color traps. This study gives a score

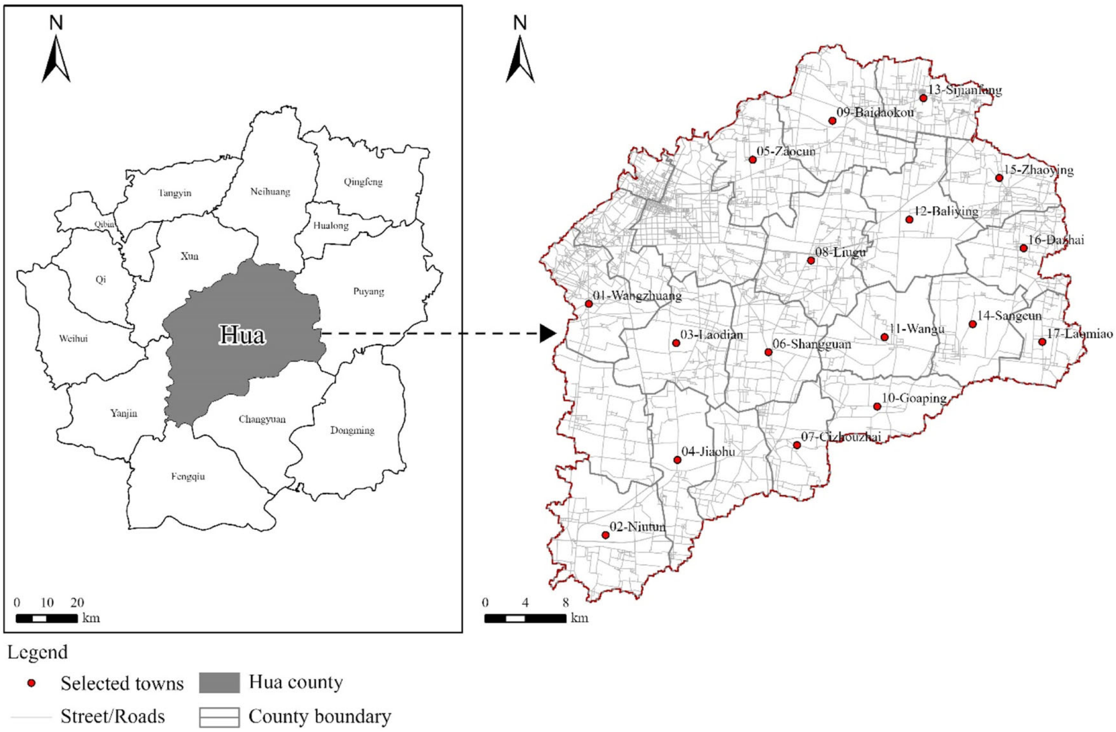


Fig. 2 The study/survey area.

of 1 to farmers who adopt one or more of the above-mentioned technologies and 0 to the others (see Table 1).

In terms of information awareness, to ensure the independence of measuring this variable, we aggregate the closely related factors to reduce the dimension. Specifically, we conduct a factor analysis on nine indicators to measure information awareness. Using principal component analysis, we identified three common factors with eigenvalues exceeding one, which together account for 76.4142% of the cumulative variance. Specifically, the variance contribution rates of Common Factor 1 to Common Factor 3 are 27.2706%, 25.2185%, and 23.9251. According to previous literature (Machin-Mastromatteo, 2021; Tian et al., 2023), we have named Common Factor 1 to Common Factor 3 as information value, information access, and information sharing awareness, respectively (see Table 2). Following Yang et al. (2021), we assess the level of information awareness among the samples. The formula to determine information awareness is as follows: information awareness = (27.2706% × information value awareness + 25.2185% × information access awareness + 23.9251% × information sharing awareness)/76.4142%. Furthermore, the KMO value of 0.8267 suggests a strong correlation between the items. Bartlett's test of sphericity yields an approximate chi-square value of 2907.3550 (sig <0.001), confirming the suitability of the data for factor analysis. The Cronbach'α value for each dimension measurement item is greater than 0.8000, indicating good representativeness of the common factors. All measurement items have factor loading values exceeding 0.7000, suggesting strong validity of the indicators.

Social networks consist of six measurement items, and the different items may be related to each other. Therefore, similar to the measurement of information awareness, this study uses factor analysis to comprehensively measure farmers' social networks. The KMO value of 0.7624 and Bartlett's test of sphericity with an approximate chi-square value of 1460.1495 (sig = 0.000) suggest that the social network evaluation index system is appropriate for factor analysis. Factor rotation yielded two common factors, with a cumulative variance contribution rate of 72.4988%. The variance contribution rates for Common Factor 1 and Common Factor 2 are 37.3418% and 35.1569%. In this study, according to the practice of Yang (2018), Common Factor 1 is named homogenous social networks, and Common Factor 2 is named heterogeneous social networks (see Table 2). The formula to determine information awareness is as follows: social networks = (37.3418% × homogeneous social networks + 35.1569% × heterogeneous social networks)/72.4988%. The Cronbach'α values for each dimension measurement item exceed 0.7000, indicating good representativeness of the common factors. All measurement items have factor loading values exceeding 0.7000, suggesting robust validity of the indicators.

The measurement for three distinct environmental values (i.e., egoistic values, altruistic values, and ecological values) is adapted from Rezaei et al. (2020). Respondents are asked items: "Protecting the environment is equivalent to protecting yourself," "Environmental pollution has a negative effect on public health," and "The ecosystem is fragile and hard to restore" (see Table 2). A 5-point Likert-type scale was utilized (from 1 = strongly disagree to 5 = strongly agree).

Existing literature on agricultural technology adoption offers insights into potential exogenous variables that could affect farmers' decisions to adopt. Ochieng et al. (2022) and Tong et al. (2022) found that younger, more educated male farmers exhibit a greater capacity for comprehending new practices and are more likely to use GPCT. Farmer households with a lower share of non-agricultural income and a larger agricultural labor force may exhibit a greater reliance on agricultural income, they are likely to be more inclined to continue using GPCT for long-term stable returns (Zhang et al., 2018; Yu et al., 2020). Furthermore, cooperatives have the potential to encourage farmers to adopt GPCT by standardizing production (Zhang et al., 2023). Characteristics related to land, such as the wheat planting area and the quantity of wheat plots, may impact farmers' decisions. Farmers possessing larger areas for wheat cultivation are more likely to adopt economically beneficial GPCT because they are more eager to achieve greater profits from wheat production (Sun

Table 1 Variables, definitions, and descriptive statistics.

Variables	Definition	Mean	Standard deviation	Min	Max
Dependent variable					
GPCT adoption behavior (Adopt)	Whether the farmers adopt GPCT (1 = yes; 0 = no)	0.3255	0.4689	0	1
Independent variable					
Information Awareness (Inf_awa)	Calculated from factor analysis	0	0.5782	−1.3007	1.5947
Information value awareness (Inf_val_awa)	Calculated from factor analysis	0	1	−2.3043	2.9864
Information access awareness (Inf_acc_awa)	Calculated from factor analysis	0	1	−2.0541	2.9529
Information sharing awareness (Inf_sha_awa)	Calculated from factor analysis	0	1	−2.5982	2.9296
Mechanism variable					
Social networks (Soc_net)	Calculated from factor analysis	0	0.7074	−1.8469	1.6292
Homogenous social networks (Hom_soc_net)	Calculated from factor analysis	0	1	−2.7521	1.8789
Heterogeneous social networks (Het_soc_net)	Calculated from factor analysis	0	1	−1.8483	3.3067
Environmental values (Env_val)					
Egoistic Values (Ego_val)	Protecting the environment is equivalent to protecting yourself: 1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree.	3.3411	1.0256	1	5
Altruistic Values (Altr_val)	Environmental pollution has a negative effect on public health: 1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree.	3.2118	1.0064	1	5
Ecological Values (Eco_val)	The ecosystem is fragile and hard to restore: 1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree.	3.4065	0.9874	1	5
Control variable					
Personal					
Gender	Gender of respondent:1 = male; 0 = female	0.5592	0.4969	0	1
Age	Age of respondent (years of age)	54.8193	7.8620	32	69
Education	Years of schooling of respondent (year)	5.8598	3.1319	0	13
Household family					
Income %	Share of non-agricultural income: 1 = less than 20%; 2 = 20%-40%; 3 = 40%-60%; 4 = 60%-80%; 5 = more than 80%	3.0405	1.4279	1	5
Laborers	Number of agricultural labor force	3.1791	1.2022	1	9
Cooperative	Whether to join the cooperatives: 1 = yes; 0 = no	0.3318	0.4712	0	1
Land					
Area	Wheat planting area (mu)	5.2397	1.9302	0.5	16
Plots	Number of wheat plots	2.1075	1.2081	1	6

et al., 2020). Khanna and Kaur (2023) found that farmers with fewer wheat plots tend to have lower technology adoption costs, increasing their likelihood of using new technologies. In our study, the characteristics of the respondents, characteristics of the household family, and characteristics of land are controlled in our models (see Table 1).

Empirical models. The behavior of farmers adopting GPCT is represented as a binary variable, taking on values of 0 or 1. Therefore, we choose the Binary Probit model for estimation. The simplified model is as follows:

$$\Pr(Adopt_i = 1) = \Phi(\alpha_1 + \beta_1 Inf\_awa_i + \theta_1 Control_i + \varepsilon_1) \quad (1)$$

where $Adopt_i$ is a dummy variable indicating whether the i-th farmer adopts GPCT, with 1 signifying adoption and 0 signifying non-adoption. Inf_awa_i denotes information awareness. $Control_i$ denotes a collection of control variables, as specified in Table 1. α_1, β_1 and θ_1 are coefficients that need to be estimated, and ε_1 is disturbance term. Furthermore, we utilize a hierarchical regression approach to examine whether farmers' information awareness affects their adoption of GPCT through social networks. The model is specified as follows:

$$Soc\_net_i = \alpha_2 + \alpha_1 Inf\_awa_i + \theta_2 Control_i + \varepsilon_2 \quad (2)$$

where Soc_net_i represents farmers' social networks. α_2, a_1 and θ_2 are coefficients. ε_2 is the disturbance term. The other variables retain their meanings as defined in Eq. (1). Following Fang et al. (2017), if a_1 is significant, it is considered that information awareness affects farmers' GPCT adoption through social networks.

To investigate the effect of the interaction between information awareness and environmental values on GPCT adoption, we introduce both the separate term for environmental values and the interaction term between information awareness and environmental

Table 2 Description of the information awareness and results of reliability and validity testing.

Variable	Definition	Measurement	Mean	Standard deviation	Factor loading	Cronbach'α
Env_val						
Information value awareness (Inf_val_awa)	I can realize the importance of information for agricultural production	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.7570	1.1339	0.8527	0.8845
	I am eager for useful agricultural information	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.7866	1.0191	0.8767	
	I am willing to pay for agricultural information at a reasonable price	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.6122	1.1091	0.8164	
Information access awareness (Inf_acc_awa)	I can describe the scope of the information I need based on the agricultural problems encountered	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.5467	1.0738	0.8631	0.8120
	When I encounter agricultural problems, I immediately think of surf the Internet to find solutions	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.4844	1.0674	0.7961	
	I can take the initiative to pay attention to the agricultural information I need and understand the changing trend in the information	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.5779	1.0514	0.8297	
Information sharing awareness (Inf_sha_awa)	I believe that effective agricultural information exchange can lead to common prosperity	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.4798	0.9978	0.8045	0.8031
	I am willing to share valuable agricultural information with others	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.5639	0.9445	0.8386	
	I believe that the value of agricultural information can be fully utilized through communication	1 = strongly disagree; 2 = not quite agree; 3 = generally agree; 4 = somewhat agree; 5 = strongly agree	2.5249	0.9740	0.7456	
Soc_net						
Homogenous social networks (Hom_soc_net)	The frequency of daily interactions with relatives	1 = never; 2 = occasionally; 3 = usually; 4 = often; 5 = very often	4.0530	1.3988	0.8691	0.7837
	The frequency of daily interactions with friends	1 = never; 2 = occasionally; 3 = usually; 4 = often; 5 = very often	3.5000	0.6915	0.7416	
	The frequency of daily interactions with neighbors	1 = never; 2 = occasionally; 3 = usually; 4 = often; 5 = very often	3.4081	1.0853	0.9020	
Heterogeneous social networks (Het_soc_net)	The frequency of daily interactions with agrotechnical personnel	1 = never; 2 = occasionally; 3 = usually; 4 = often; 5 = very often	2.3754	0.9918	0.8262	0.7994
	The frequency of daily interactions with agricultural cooperatives	1 = never; 2= occasionally; 3 = usually; 4 = often; 5 = very often	2.2212	1.0075	0.8365	
	The frequency of daily interactions with village official	1 = never; 2 = occasionally; 3 = usually; 4 = often; 5 = very often	2.4533	1.2258	0.7892	

values into Eq. (1). The detailed form is provided below:

$$\Pr(Adopt_i = 1) = \Phi(\alpha_3 + b_1 Inf\_awa_i + c_1 Env\_val_i + d_1 Inf\_awa_i \times Env\_val_i + \theta_3 Control_i + \varepsilon_3) \tag{3}$$

where Env_val_i is environmental values (i.e., egoistic values, altruistic values, ecological values). $Inf\_awa_i \times Env\_val_i$ represents the interaction terms between information awareness and environmental values (i.e., information awareness × egoistic values, information awareness × altruistic values, information awareness × ecological values). α_3, b_1, c_1, d_1 *and* θ_3 are coefficients. ε_3 is the disturbance term. The other variables retain their meanings as defined in Eq. (1). Following Nguyen et al. (2024), if d_1 is significantly positive, it indicates that farmers' environmental values can reinforce the influence of information awareness on GPCT adoption.

Table 3 Demographic characteristics of the sample.

Variable	Category	Frequency	Percentage	Cumulative percentage
Gender	Male	359	55.9	55.9
	Female	283	44.0	99.9
Age	<55 years old	305	47.5	47.5
	≥55 years old	337	52.5	100
Education	≤9 years	602	93.8	93.8
	10–12 years	24	3.7	97.5
	≥13 years	16	2.5	100
Income % (share of non-agricultural income)	<20%	147	22.9	22.9
	20%–40%	80	12.5	35.4
	40%–60%	135	21.0	56.4
	60%–80%	160	24.9	81.3
	>80%	120	18.7	100
Laborers (size of labor force)	≤2 people	178	27.7	27.7
	3people	218	34.0	61.7
	4people	182	28.3	90.0
	≥5 people	64	10.0	100

Results and discussion

Sample description. Table 3 presents the demographic data collected from the surveyed farmers. Of the respondents, 55.9% were male, and 52.5% were aged 55 and above. 93.8% of the respondents had less than 9 years of education. The range of non-agricultural income from 60–80% is the most prevalent, accounting for 24.9% of the respondents. Concerning the size of labor force, 62.3% of respondent's households had 3–4 laborers. The demographic characteristics of the respondents closely correspond to the findings reported in the Third Agricultural Census of China (see Table A3), suggesting the respondent's representativeness.

Farmers' adoption of GPCT. We used a multicollinearity test before the regression. The maximum variance inflation factor is 1.0148, indicating that there is no multicollinearity problem among the variables.

Table 4 shows the results of the analysis examining the impact of information awareness on GPCT adoption. Model 1 shows the regression results of farmers' information awareness affecting their GPCT adoption without controlling any other variables. We introduce control variables in Model 2. The chi-square test results

Table 4 Basic regression results.

Variable	Model 1 (Probit)		Model 2 (Probit)		Model 3 (OLS)	Model 4 (Probit)	
	Coefficient	*dy/dx*	Coefficient	*dy/dx*	Coefficient	Coefficient	*dy/dx*
Inf_awa	0.4722*** (0.0904)	0.1640	0.4500*** (0.0929)	0.1489	0.1560*** (0.0309)	—	—
Inf_val_awa	—	—	—	—	—	0.1418*** (0.0533)	0.0468
Inf_acc_awa	—	—	—	—	—	0.1188** (0.0531)	0.0392
Inf_sha_awa	—	—	—	—	—	0.1966*** (0.0544)	0.0649
Gender	—	—	0.0403 (0.1084)	0.0133	0.0098 (0.0360)	0.0341 (0.1086)	0.0112
Age	—	—	−0.0118* (0.0068)	−0.0039	−0.0039* (0.0023)	−0.0111* (0.0068)	−0.0037
Education	—	—	0.0305* (0.0171)	0.0101	0.0108* (0.0057)	0.0298* (0.0172)	0.0098
Income %	—	—	−0.0980*** (0.0375)	−0.0324	−0.0333*** (0.0126)	−0.0980*** (0.0376)	−0.0323
Laborers	—	—	0.0164 (0.0446)	0.0054	0.0050 (0.0148)	0.0161 (0.0447)	0.0053
Cooperative	—	—	0.1250 (0.1127)	0.0413	0.0386 (0.0381)	0.1219 (0.1129)	0.0402
Area	—	—	0.0339 (0.0279)	0.0112	0.0128 (0.0093)	0.0358 (0.0280)	0.0118
Plot	—	—	−0.1962*** (0.0481)	−0.0649	−0.0596*** (0.0148)	−0.1980*** (0.0482)	−0.0653
Observations	642		642		642	642	
LR chi^2 (*n*)	27.87***		62.89***		—	64.40***	
Pseudo R^2	0.0344		0.0776		—	0.0795	
F-value	—		—		7.29***	—	
R^2	—		—		0.0940	—	

Notes: *P<0. 10, **P<0. 05, ***P<0. 01; Values in parentheses are standard errors.

for each equation are all significant, indicating a relatively good overall fit for each model. Model 3 uses OLS estimation for the robustness test. The results across Model 1 to Model 3 demonstrate that coefficient signs and significance levels of each variable remain unchanged, suggesting robustness in the estimation results. The subsequent analyses primarily utilize the results from Model 2.

In Model 2, the information awareness shows a positive marginal effect, statistically significant at the 1% level, highlighting its crucial role in encouraging farmers' adoption of GPCT. Specifically, one unit increase in the strength of information awareness significantly raises the probability of farmers adopting GPCT by 14.89%. Thus, Hypothesis 1 is verified. Furthermore, our findings align with previous research by Thuo et al. (2014), Nikam et al. (2022), and Yue et al. (2023), which underscored the significance of information awareness for technology extension. Technology adoption's early characteristic is enhancing technological cognition through information access (Dzanku et al., 2022). Farmers with stronger information awareness have an advantage in mastering informational resources (Bukchin and Kerret, 2020). Specifically, these farmers can access and utilize GPCT information at a lower cost, leading to increased accessibility of GPCT. Furthermore, the widespread use of various information platforms and applications provides an opportunity for farmers with strong information awareness to learn, share, and imitate practical applications of GPCT, thereby contributing to the accumulation of GPCT knowledge (Cole and Fernando, 2021).

Model 4 in Table 4 delineates the impacts related to the three distinct dimensions of information awareness. Model 4's results show that the marginal effects of information value awareness, information access awareness, and information sharing awareness are all positively significant at the 1%, 5%, and 1% levels, further confirming H1. Furthermore, out of the three dimensions of information awareness, information sharing awareness exhibits a more profound influence on farmers' adoption of GPCT, surpassing both information value and information access awareness. The reason for the aforementioned situation can be attributed to the fact that information-sharing awareness inclines farmers towards exchanging experiences, impacts, and potential challenges encountered during the application of GPCT (Yu et al., 2021). Therefore, through information sharing, farmers can gain a more profound understanding and acceptance of GPCT, increasing their likelihood of adopting GPCT more extensively. However, due to the absence of efficient sharing and application mechanisms, the potential values of information value awareness and information access awareness remain constrained.

Additionally, age, years of schooling, share of non-agricultural income, and number of wheat plots have a statistically significant effect on farmers' GPCT adoption. The results are consistent with the findings of Zhang et al. (2018), Ochieng et al. (2022), and Li et al. (2023). The marginal effect of the age is −0.0039, which means that younger farmers have a higher likelihood of adopting GPCT compared to older farmers. Older farmers tend to be more conservative, which can hinder their understanding and adoption of innovative technologies. The marginal effect of years of schooling exhibits a positive trend. Farmers who have greater education are better able to recognize the comparative advantages of GPCT and are, therefore, more inclined to adopt it. The marginal effect of the share of non-agricultural income is negative, suggesting that farmers with a higher proportion of such income are less likely to adopt GPCT. A high share of non-agricultural income reduces farmers' dependence on agricultural production, thereby diminishing their interest in new technologies. The marginal effect of the number of wheat plots is −0.0649, which indicates that farmers with more wheat plots are less inclined to adopt GPCT. An increase in the number of wheat plots corresponds to a higher degree of plot dispersion. The dispersed plots increase the cost of agricultural production, thereby hindering farmers from adopting GPCT.

To prove the reliability of the conclusion, we conducted a robustness test by excluding the sample of farmers who are members of cooperatives. In fact, most farmers in cooperatives have been mandated to use GPCT. Model 1 in Table 5 shows that information awareness significantly promotes farmers' GPCT adoption. Furthermore, farmers across various age brackets may exhibit disparities in information awareness, influencing their adoption of GPCT. Therefore, we employ grouping regression to re-examine the robustness. Specifically, with reference to the elderly population categorization established by the World Health Organization, the respondents aged 60 and above are defined as "farmers in older age groups," and those under 60 are defined as "farmers in other age groups." We then perform group regression according to the age of the farmers. In comparison to the results in Table 4, the influence direction and significance of regression results are basically the same. Therefore, the results of this study are robust to a large extent.

Endogeneity test. This study endeavors to examine the causal link between information awareness and farmers' GPCT adoption. However, this relationship could potentially be influenced by endogeneity, as the farmers' GPCT adoption may lead to an elevated level of information awareness by enhancing their recognition of the significance of information. To address potential estimation bias caused by endogeneity, this study utilizes an IV-Probit model for estimation, with the highest years of schooling among farmers' parents (Par_hig_sch) as an instrumental variable for information awareness. The IV reflects the innate upbringing environment of the family. The importance farmers place on information, and their learning abilities are influenced by their parents. Therefore, the schooling years of farmers' parents have a direct impact on farmers' information

Table 5 Results of robustness test.

Variable	Model 1 (Limited samples)		Model 2 (Other farmers)		Model 3 (Elderly farmers)	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Inf_awa	0.3910*** (0.1164)	0.1249	0.5044*** (0.1258)	0.1727	0.3911*** (0.1397)	0.1231
Control variable	Controlled		Controlled		Controlled	
Observations	429		353		289	
LR chi^2 (n)	42.96***		35.41***		25.53***	
Pseudo R^2	0.0816		0.0770		0.0736	

Notes: ***P<0. 01; Values in parentheses are standard errors.

awareness. Additionally, the schooling years of farmers' parents do not exhibit a direct association with farmers' GPCT adoption.

Table 6 presents the results of the IV-Probit two-stage regression model. Drawing from the findings of Model 1 and Model 2 in Table 6, the Wald statistic indicates significance at the 5% level for assessing exogeneity, proving the necessity of employing instrumental variables. The F-value obtained from the first-stage exceeds 10, suggesting that the chosen instrumental variable meets the relevance criterion. The AR and Wald statistics, which serve as indicators for assessing weak instrumental variables, have passed the significance tests, suggesting no weak instrumental variable issue exists. The second-stage regression results of Model 2 indicate that information awareness positively and significantly influences the adoption of GPCT, suggesting that increased information awareness raises the probability of GPCT diffusion. The results underscore the robustness and reliability of the study's findings.

Indirect mechanism of information awareness. Table 7 reports the indirect mechanism of information awareness. Specifically, the coefficient for information awareness is notably positive at the 1% significance level (see Model 1 in Table 7). The result implies that information awareness effectively augments farmers' opportunities to expand social networks, which aligns with the findings of Beaman and Dillon (2018) in Mali. Therefore, Hypothesis 2 is validated. For farmers, the GPCT information is minimal. Therefore, it is challenging for farmers to form a comprehensive and objective cognition of GPCT. By enhancing farmers' subjective initiative to comprehend, access, and share information, information awareness improves the efficacy of information dissemination and expands their social networks, ultimately providing information support for their GPCT adoption.

We further discuss the impacts of information awareness on various dimensions of social networks, with the results present in Table 7. Upon examining Model 2 and Model 3, the coefficients for information awareness at the 5% and 10% significance levels are 0.1484 and 0.1163, respectively, suggesting a positive impact on both homogeneous and heterogeneous social networks. Farmers primarily access and share technical information through homogenous and heterogeneous networks (Tulin et al., 2021). Therefore, to obtain more information resources, farmers with strong information awareness will actively expand both homogenous and heterogeneous social networks. However, information awareness has a more significant marginal impact on homogenous social networks. Strong relationships in homogeneous social networks make information dissemination among farmers more frequent, efficient, and reliable (Kinnan and Townsend, 2012; Zheng and Luo, 2022). Thus, farmers who possess a high level of information awareness are more inclined to expand their homogeneous social networks, as opposed to heterogeneous ones.

We reassess the indirect mechanism of social networks by employing the indicator of the number of relatives visiting for the Spring Festival. The strongest relational network for farmers is their kinship networks (Zheng and Luo, 2022). Prior research has demonstrated that the "New Year's visit network" is a reliable method for assessing the strength of kinship networks (Lei et al., 2015). Therefore, we have selected the number of relatives visiting for the Spring Festival as a proxy indicator to conduct a robustness test on the indirect mechanism of social networks. As presented in Model 4 of Table 7, the coefficient of the number of relatives visiting for the Spring Festival is positive and significant at the 10% level, supporting the notion that farmers' information awareness facilitates GPCT adoption through social networks. Therefore, Hypothesis 2 is reinforced.

Reinforcing effect of environmental values. As shown in Table 8, $Inf\_awa_i \times Ego\_val_i$, $Inf\_awa_i \times Alt\_val_i$, and $Inf\_awa_i \times Eco\_val_i$ exhibit statistical significance at the 5%, 5%, and 10% levels with marginal effects of 0.0696, 0.0743, and 0.0514. As expected, a higher level of farmers' environmental values corresponds to a greater positive impact of information awareness on GPCT adoption. The result aligns with the discoveries made by Bolderdijk et al. (2013) and Nguyen et al. (2024). Thus, Hypothesis 3 is verified. Farmers with environmental values possess a strong sense of responsibility and mission, believing that protecting the environment is an unshirkable duty (Bissinger and Bogner, 2018). Therefore, these farmers will exert their subjective initiative in information awareness, thereby actively seeking, positively

Table 6 Endogeneity test of information awareness.

Variable	Model 1 (First stage: Inf_awa) Coefficient	Model 2 (Second stage: Adopt) Coefficient
Par_hig_sch	0.1040*** (0.0077)	—
Inf_awa	—	0.7865*** (0.1935)
Control variable	Controlled	Controlled
Observations	642	642
First stage F-value	21.85***	—
Exogeneity test (Wald statistic)	—	4.10**
Weak-instrument test (AR statistic)	—	16.72***
Weak-instrument test (Wald statistic)	—	16.53***

Notes: **$P<0.05$, ***$P<0.01$; Values in parentheses are standard errors.

Table 7 Indirect mechanism of information awareness.

Variable	Model 1 (Soc_net) Coefficient	Model 2 (Hom_soc_net) Coefficient	Model 3 (Het_soc_net) Coefficient	Model 4 (Soc_net) Coefficient
Inf_awa	0.1328*** (0.0477)	0.1484** (0.0682)	0.1163* (0.0683)	0.3757** (0.2197)
Control variable	Controlled	Controlled	Controlled	Controlled
Observations	642	642	642	642
F-value	3.84***	2.38**	2.16**	0.90
R^2	0.0519	0.0327	0.0233	0.0126

Notes: *$P<0.10$, **$P<0.05$, ***$P<0.01$; Values in parentheses are standard errors.

Table 8 Reinforcing effect of environmental values.

Variable	Model 1		Model 2		Model 3	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Inf_awa	0.3606*** (0.0970)	0.1172	0.3929*** (0.0953)	0.1281	0.3036*** (0.0995)	0.0918
Ego_val	0.1478*** (0.0553)	0.0481	—	—	—	—
Alt_val	—	—	0.1008* (0.0544)	0.0329	—	—
Eco_val	—	—	—	—	0.4213*** (0.0583)	0.1274
Inf_awa × Ego_val	0.2142** (0.0961)	0.0696	—	—	—	—
Inf_awa × Alt_val	—	—	0.2276** (0.0912)	0.0743	—	—
Inf_awa × Eco_val	—	—	—	—	0.1700* (0.0946)	0.0514
Control variable	Controlled		Controlled		Controlled	
Observations	642		642		642	
LR chi^2 (n)	74.61***		74.15***		123.04***	
Pseudo R^2	0.0921		0.0891		0.1519	

Notes: *P <0. 10, **P <0. 05, ***P <0. 01; Values in parentheses are standard errors.

evaluating, and properly utilizing information on GPCT to attain environmental protection objectives. Furthermore, under the influence of the prevailing environmental protection atmosphere in rural communities, farmers are more inclined to continuously acquire environmental information and take actions that are beneficial to environmental protection, including adopting GPCT.

To present more intuitively the interactive effects of information awareness and environmental values, a simple slope analysis was used to calculate the slope (Fig. 3), that is, one standard deviation above and below the average value of environmental values to plot the interaction. Figure 3A–C shows the interaction effects. Compared to low egoistic values, the effect of information awareness on GPCT adoption is more obvious under high egoistic values. Compared with low altruistic values, information awareness under high altruistic values has a more significant impact on farmers' adoption of GPCT. Compared to low ecological values, farmers' adoption of GPCT is more significantly influenced by their information awareness when ecological values are high. These results suggest that as environmental values strengthen, the positive influence of farmers' information awareness on their adoption of GPCT is enhanced.

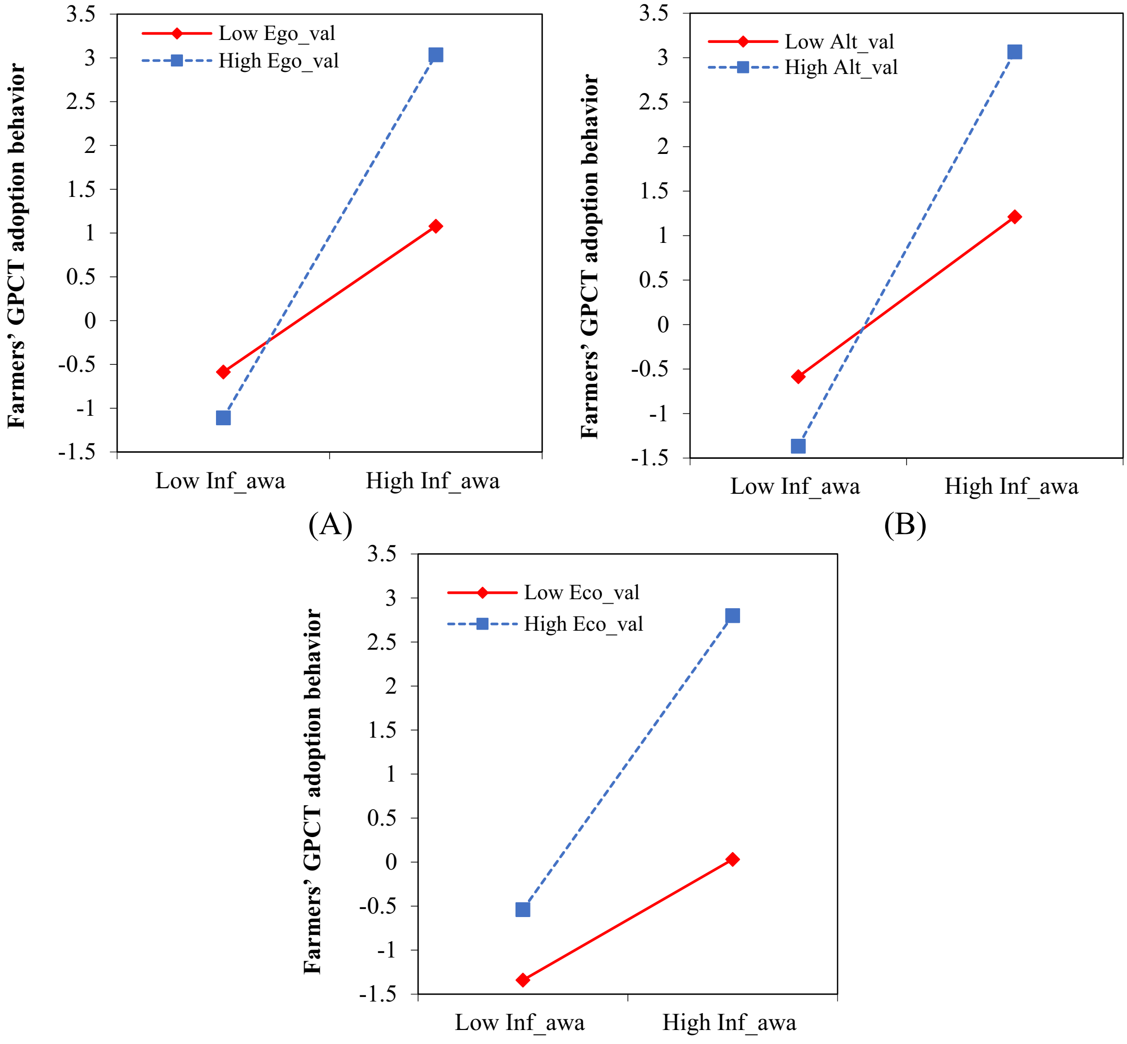
Heterogeneity analysis. Farmers with varying years of schooling and wheat planting areas exhibit differences in terms of their business orientations, production inputs, mastery of technology, family characteristics, and social capital. These differences may affect how information awareness influences farmers' choices about adopting GPCT. Therefore, this study groupes farmers' years of schooling and wheat planting areas to explore the varying impacts of information awareness on GPCT adoption. Specifically, according to whether farmers have completed nine years of compulsory education, we divide the years of schooling into a low-educated group (<9 years) and a high-educated group (≥9 years). Futhermore, we divide farmers into small-scale group (<5.24 mu) and large-scale group (≥5.24 mu), based on if their wheat planting area exceeds the average of 5.24 mu.

Observing the results in Table 9, we find significant group differences among farmers with different years of schooling and wheat planting areas. Specifically, the marginal effect of information awareness on GPCT adoption is greater in the highly educated group. One possible reason is that farmers with a higher level of education tend to have a stronger capacity to comprehend and accept technical information. Therefore, farmers in the highly educated group are more susceptible to the influence of information awareness. Regarding the wheat planting area, the marginal effect of information awareness is greater for farmers with large wheat planting areas. There are economies of scale in GPCT adoption, and farmers in the large-scale group often gain more benefits from GPCT adoption. Therefore, information awareness can motivate large-scale farmers to adopt GPCT to a greater extent.

Conclusions

This study empirically analyzes the effects and underlying mechanisms of information awareness on GPCT adoption. The findings reveal that information awareness positively influences GPCT adoption, suggesting that improving farmers' information awareness can increase their likelihood of adopting GPCT. Further mechanism analysis highlights that information awareness promotes farmers' GPCT adoption by broadening social networks, emphasizing the significance of social network expansion in promoting technology adoption among farmers. In addition, environmental values are found to strengthen the positive effect of information awareness on GPCT adoption, indicating that the combination of these two factors is particularly effective in persuading farmers to adopt GPCT. Heterogeneity analysis further uncovers that information awareness has a more pronounced impact on motivating highly educated and large-scale farmers to adopt GPCT. This suggests that tailored strategies targeting these specific farmer groups could be particularly fruitful in promoting the adoption of GPCT.

Theoretical implications. This study comprehensively assesses farmers' information awareness across three pivotal dimensions: information value awareness, information access awareness, and information sharing awareness. Furthermore, we delve into the ramifications of farmers' information awareness on their GPCT adoption. The findings emphasize the pivotal role of information



(C)

Fig. 3 Reinforcing effect of environmental values. A Reinforcing effect of egoistic values. **B** Reinforcing effect of altruistic values. **C** Reinforcing effect of ecological values.

Table 9 Heterogeneity analysis.

Variable	Model 1 (Low-educated farmers)		Model 2 (High-educated farmers)		Model 3 (Small-scale farmers)		Model 4 (Large-scale farmers)	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Inf_awa	0.3749*** (0.1059)	0.1249	0.7418*** (0.2117)	0.2126	0.1783 (0.1154)	0.0603	0.9920*** (0.1755)	0.2910
Control variable	Controlled		Controlled		Controlled		Controlled	
Observations	513		129		412		230	
LR chi^2 (n)	47.85***		29.86**		18.81**		60.54***	
Pseudo R^2	0.0737		0.1851		0.0269		0.2020	

Notes: **P<0. 05, ***P<0. 01; Values in parentheses are standard errors.

awareness in promoting GPCT adoption, offering new empirical perspectives to the field of farmers' technology adoption research. This study reveals that the impact of information awareness on GPCT adoption varies among groups with different years of schooling and wheat planting areas. The result underscores the significance of acknowledging the diversity of farmer groups in future research endeavors. The study additionally elucidates the distinct types of farmers' social networks and their respective levels of environmental values, thereby enriching the existing scholarship on social networks and environmental values. This study aims to improve the breadth and depth of studies on GPCT adoption. Specifically, this study explores the direct effect of information awareness on GPCT adoption and investigates the indirect pathways of information awareness through the perspective of social networks. This study also examines the interaction between information awareness and environmental values. Consequently, this study offers a new perspective for comprehending the intricacies of farmers' technology adoption behavior, thereby stimulating further exploration into the underlying motives and influence mechanisms behind their GPCT adoption. This study lays a theoretical foundation for enhancing information awareness, enlarging social networks, nurturing environmental values, and augmenting their acceptance of GPCT. Furthermore, this study investigates farmers' adoption of GPCT by incorporating information awareness, social networks, and environmental values into a cohesive analytical framework. Therefore, the study not only enriches and expands the theoretical framework of farmers' adoption of GPCT but also establishes a new foundational framework for future related research.

Policy implications. The results of this study provide new perspectives on facilitating the extensive adoption of GPCT. Specifically, government departments should take the lead in guiding farmers to enhance their information awareness, broaden their social networks, and foster positive environmental values. Furthermore, many countries, including China, are facing the issue of low enthusiasm among farmers for adopting GPCT. Therefore, both China and various other countries should motivate farmers to adopt GPCT. In fact, the findings of this study hold policy implications for various countries and regions grappling with the challenge of low farmer enthusiasm for adopting GPCT. This section offers practical suggestions to facilitate the implementation of the study's findings in real-world scenarios.

This study underscores the pivotal role of information awareness in driving farmers' GPCT adoption. Therefore, nurturing farmers' information awareness must be a top priority in the GPCT promotion process. The government should establish and enhance rural information infrastructure, encompassing broadband networks and smart devices, lowering the threshold for farmers to access information. Government departments can also regularly organize specialized training sessions on enhancing information awareness, inviting experts and scholars to educate farmers on the basics and application skills of information technology, as well as the importance of information, thereby increasing farmers' understanding and emphasis on information. Policymakers should also devise strategies to mitigate the limited dissemination of agricultural technology information by broadening farmers' social networks. The local government can designate farmers who have successfully implemented GPCT as exemplars and benchmarks, encouraging other farmers to engage in robust exchanges of experience with these model farmers. The government should actively support agricultural technology experts or enthusiasts in becoming internet influencers, leveraging their social media platforms to disseminate agricultural technology information and harnessing their influence to boost the efficiency of information dissemination. The next finding highlights the critical importance of environmental values in promoting GPCT adoption. Relevant government departments should prioritize the development of the village environment, fostering environmentally friendly practices among farmers in their daily production and life. Furthermore, the government should provide basic knowledge about environmental issues and specific guidance on green agricultural practices to farmers through training sessions, lectures, and other forms. This will help farmers comprehend and cultivate environmental values that resonate with the shared future for all humanity. The insights derived from heterogeneous analyses are invaluable. Policymakers ought to develop tailored policies for farmers with different years of schooling and different areas of wheat planting. For instance, policymakers ought to prioritize highly educated and large-scale farmers, as they will likely be the most receptive to adopting GPCT.

Limitations and future research. This study has some limitations that can inspire future research. First, the process of farmers' decision-making regarding GPCT adoption is multifaceted. Therefore, future research may need to collect data at other places in Hua county to see if other factors may hinder or motivate farmers to adopt GPCT. Second, Information awareness, social networks, and environmental values are all unobservable latent variables. As China's digital village and beautiful village construction continue to advance, the extensions of information awareness, social networks, and environmental values continue to enrich. Therefore, further research necessitates refining the measurement items for the variables listed above, taking into account the differences in research objects and methods.

Data availability

The data underpinning the findings of this study can be obtained from the corresponding author, Fei Liang, upon reasonable request.

Received: 6 May 2024; Accepted: 7 January 2025;
Published online: 14 January 2025

References

Aubert BA, Schroeder A, Grimaudo J (2012) IT as enabler of sustainable farming: an empirical analysis of farmers' adoption decision of precision agriculture technology. Decis Support Syst 54(1):510–520. https://doi.org/10.1016/j.dss.2012.07.002

Beaman L, Dillon A (2018) Diffusion of agricultural information within social networks: evidence on gender inequalities from Mali. J Dev Econ 133:147–161. https://doi.org/10.1016/j.jdeveco.2018.01.009

Bissinger K, Bogner FX (2018) Environmental literacy in practice: education on tropical rainforests and climate change. Environ Dev Sustain 20:2079–2094. https://doi.org/10.1007/s10668-017-9978-9

Bolderdijk JW, Gorsira M, Keizer K, Steg L (2013) Values determine the (in) effectiveness of informational interventions in promoting pro-environmental behavior. PLoS ONE 8(12):e83911. https://doi.org/10.1371/journal.pone.0083911

Bukchin S, Kerret D (2020) The role of self-control, hope and information in technology adoption by smallholder farmers–a moderation model. J Rural Stud 74:160–168. https://doi.org/10.1016/j.jrurstud.2020.01.009

Campenhout BV (2021) The role of information in agricultural technology adoption: experimental evidence from rice farmers in Uganda. Econ Dev Cult Change 69(3):1239–1272. https://doi.org/10.1086/703868

Chaudhuri S, Roy M, McDonald LM, Emendack Y (2021) Reflections on farmers' social networks: a means for sustainable agricultural development? Environ Dev Sustain 23:2973–3008. https://doi.org/10.1007/s10668-020-00762-6

China National Bureau of statistics (2023) China rural statistical yearbook—2023. China Statistics Press, Beijing

China Ministry of Agriculture and Rural Affairs of China (2021) The National Agricultural Technology Extension and Service Center has released the list of the second batch of "Demonstration Counties for Green Prevention and Control of Crop Diseases and Pests" nationwide. http://www.moa.gov.cn/xw/zxfb/202104/t20210401_6365078.htm. Accessed 26 Dec 2023

China Ministry of Agriculture and Rural Affairs of China (2023) Positive progress was made in green agricultural development. http://www.moa.gov.cn/xw/zwdt/202312/t20231222_6443326.htm. Accessed 26 Dec 2023

China National Agro-Tech Extension and Service Center (2022) The National Agro-Tech Extension and Service Cente organized a summary of the national crop disease and pest control work in 2022 and a green prevention and control video meeting. https://www.natesc.org.cn/news/des?id=813392fc-ba1b-4d50-878d-38a9da3cf744&Category. Accessed 26 Dec 2023

Cofré-Bravo G, Klerkx L, Engler A (2019) Combinations of bonding, bridging, and linking social capital for farm innovation: how farmers configure different support networks. J Rural Stud 69:53–64. https://doi.org/10.1016/j.jrurstud.2019.04.004

Cole SA, Fernando AN (2021) Mobile'izing agricultural advice technology adoption diffusion and sustainability. Econ J 131(633):192–219. https://doi.org/10.1093/ej/ueaa084

Creissen HE, Jones PJ, Tranter RB, Girling RD, Jess S, Burnett FJ, Kildea S (2021) Identifying the drivers and constraints to adoption of IPM among arable farmers in the UK and Ireland. Pest Manag Sci 77(9):4148–4158. https://doi.org/10.1002/ps.6452
Cui S, Li Y, Jiao X, Zhang D (2022) Hierarchical linkage between the basic characteristics of smallholders and technology awareness determines Small-Holders' willingness to adopt green production technology. Agriculture 12(8):1275. https://doi.org/10.3390/agriculture12081275
Dzanku FM, Osei RD, Nkegbe PK, Osei-Akoto I (2022) Information delivery channels and agricultural technology uptake: experimental evidence from Ghana. Eur Rev Agric Econ 49(1):82–120. https://doi.org/10.1093/erae/jbaa032
Engelmann T, Kolodziej R, Hesse F (2014) Preventing undesirable effects of mutual trust and the development of skepticism in virtual groups by applying the knowledge and information awareness approach. Int J Comput-Supported Collaborative Learn 9:211–235. https://doi.org/10.1007/s11412-013-9187-y
Fan Q, Salas GVB (2018) Information access and smallholder farmers' market participation in Peru. J Agric Econ 69(2):476–494. https://doi.org/10.1111/1477-9552.12243
Fang J, Wen ZL, Zhang MQ (2017) Mediation analysis of categorical variables (in Chinese). J Psychol Sci 02:217–223
Hu H, Cao A, Chen S, Li H (2022) Effects of risk perception of pests and diseases on tea farmers' green control techniques adoption. Int J Environ Res Public Health 19(14):8465. https://doi.org/10.3390/ijerph19148465
Johnston B, Webber S (2003) Information literacy in higher education: a review and case study. Stud High Educ 28(3):335–352. https://doi.org/10.1080/03075070309295
Kanani E, Ahmadvand M (2019) Explaining environmental behavior of wheat farmers: application of value-belief-norm theory. Environ Educ Sustain Dev 7(3):35–46. https://doi.org/10.30473/ee.2019.5806
Khanna A, Kaur S (2023) An empirical analysis on adoption of precision agricultural techniques among farmers of Punjab for efficient land administration. Land Use Policy 126:106533. https://doi.org/10.1016/j.landusepol.2022.106533
Kekulandala B, Cunningham R, Jacobs B (2023) Exploring social networks in a small tank cascade system in Northcentral Sri Lanka: First steps to establishing adaptive governance. Environ Dev 46:100847. https://doi.org/10.1016/j.envdev.2023.100847
Kinnan C, Townsend R (2012) Kinship and financial networks, formal financial access, and risk reduction. Am Econ Rev 102(3):289–293. https://doi.org/10.1257/aer.102.3.289
Lai W (2017) Pesticide use and health outcomes: evidence from agricultural water pollution in China. J Environ Econ 86:93–120. https://doi.org/10.1016/j.jeem.2017.05.006
Li H, Wang C, Chang WY, Liu H (2023) Factors affecting Chinese farmers' environment-friendly pesticide application behavior: a meta-analysis. J Clean Prod 409:137277. https://doi.org/10.1016/j.jclepro.2023.137277
Lincoln NK, Ardoin NM (2016) Cultivating values: Environmental values and sense of place as correlates of sustainable agricultural practices. Agri Hum Values 33:389–401. https://doi.org/10.1007/s10460-015-9613-z
Lonnqvist JE, Itkonen JVA (2016) Homogeneity of personal values and personality traits in Facebook social networks. J Res Personal 60:24–35. https://doi.org/10.1016/j.jrp.2015.11.001
Lyu X, Peng W, Qu Y, Li M, Wang Q, Solodovnikov SY, Serhiyevich TV (2024) The differentiated adoption of green planting technology by farmers and its influencing factors: the case from Juxian County, China. Environ Dev Sustain 1–30. https://doi.org/10.1007/s10668-024-05370-2
Lei X, Shen Y, Smith JP, Zhou G (2015) Do social networks improve Chinese adults' subjective well-being? J Econ Ageing 6:57–67. https://doi.org/10.1016/j.jeoa.2015.07.001
Mohd Nizam SN, Haji Baharudin NS, Ahmad H (2023) Application of pesticide in paddy fields: a Southeast Asia case study review. Environ Geochem Health 45(8):5557–5577. https://doi.org/10.1007/s10653-023-01668-8
Mills J, Gaskell P, Ingram J, Dwyer J, Reed M, Short C (2017) Engaging farmers in environmental management through a better understanding of behaviour. Agri Hum values 34:283–299. https://doi.org/10.1007/s10460-016-9705-4
Ma W, Ma C, Su Y, Nie Z (2017) Organic farming: does acquisition of the farming information influence Chinese apple farmers' willingness to adopt? China Agric Econ Rev 9(2):211–224. https://doi.org/10.1108/CAER-05-2016-0070
Machin-Mastromatteo JD (2021) Information and digital literacy initiatives. Inf Dev 37(3):329–333. https://doi.org/10.1177/02666669211031695. https://doi/abs/
Maertens A (2017) Who cares what others think (or do)? Social learning and social pressures in cotton farming in India. Am J Agric Econ 99(4):988–1007. https://doi.org/10.1093/ajae/aaw098
Midingoyi SG, Kassie M, Muriithi B, Diiro G, Ekesi S (2019) Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. J Agric Econ 70(2):452–470. https://doi.org/10.1111/1477-9552.12306
Momenpour Y, Sadighi H, Choobchian S, Lebailly P, Dogot T, Viira AH, Azadi H (2024) Towards predicting the pro-environmental behaviour of wheat farmers by using the application of value-belief-norm theory. Environ Dev Sustain. 1–31. https://doi.org/10.1007/s10668-024-04865-2
Munshi K (2004) Social learning in a heterogeneous population: Technology diffusion in the Indian Green Revolution. J Dev Econ 73(1):185–213. https://doi.org/10.1016/j.jdeveco.2003.03.003
Madaki MY, Lehberger M, Bavorova M, Igbasan BT, Kächele H (2024) Effectiveness of pesticide stakeholders' information on pesticide handling knowledge and behaviour of smallholder farmers in Ogun State, Nigeria. Environ Dev Sustain 26(7):17185–17204. https://doi.org/10.1007/s10668-023-03332-8
Naveed MA, Hassan A (2021) Sustaining agriculture with information: an assessment of rural Citrus farmers' information behaviour. Inf Dev 37(3):496–510. https://doi.org/10.1177/0266666920932994. https://doi/abs/
Nguyen HV, Thanh DL, Thu LMT (2024) From environmental values to pro-environmental consumption behaviors: the moderating role of environmental information. Curr Psychol 43(4):3607–3620. https://doi.org/10.1007/s12144-023-04569-2
Nikam V, Ashok A, Pal S (2022) Farmers' information needs, access and its impact: evidence from different cotton producing regions in the Maharashtra state of India. Agric Syst 196:103317. https://doi.org/10.1016/j.agsy.2021.103317
Ochieng J, Afari-Sefa V, Muthoni F, Kansiime M, Hoeschle-Zeledon I, Bekunda M, Thomas D (2022) Adoption of sustainable agricultural technologies for vegetable production in rural Tanzania: trade-offs, complementarities and diffusion. Int J Agric Sustain 20(4):478–496. https://doi.org/10.1080/14735903.2021.1943235
Phiri A, Chipeta GT, Chawinga WD (2019) Information behaviour of rural smallholder farmers in some selected developing countries: a literature review. Inf Dev 35(5):831–838. https://doi.org/10.1177/0266666918804861
Reddy P, Sharma B, Chaudhary K, Lolohea O, Tamath R (2022) Information literacy: a desideratum of the 21st century. Online Inf Rev 46(3):441–463. https://doi.org/10.1108/OIR-09-2020-0395
Ren Z, Fu Z, Zhong K (2022) The influence of social capital on farmers' green control technology adoption behavior. Front Psychol 13:1001442. https://doi.org/10.3389/fpsyg.2022.1001442
Rezaei MK, Vatankhah N, Ajili A (2020) Adoption of pro-environmental behaviors among farmers: application of value–belief–norm theory. Chem Biol Technol Agri 7:1–15. 10.1186/s40538-019-0174-z
Sharifzadeh MS, Abdollahzadeh G, Damalas CA (2023) Farmers' behaviour in the use of integrated pest management (IPM) practices: perspectives through the social practice theory. Int J Pest Manag 2023:1–14. https://doi.org/10.1080/09670874.2023.2227607
Skaalsveen K, Ingram J, Urquhart J (2020) The role of farmers' social networks in the implementation of no-till farming practices. Agric Syst 181:102824. https://doi.org/10.1016/j.agsy.2020.102824
Stern PC (2000) New environmental theories: toward a coherent theory of environmentally significant behavior. J Soc Issues 56(3):407–424. https://doi.org/10.1111/0022-4537.00175
Sun S, Zhang C, Hu R (2020) Determinants and overuse of pesticides in grain production: a comparison of rice, maize and wheat in China. China Agric Econ Rev 12(2):367–379. https://doi.org/10.1108/CAER-07-2018-0152
Tambo JA, Liverpool-Tasie LSO (2024) Are farm input subsidies a disincentive for integrated pest management adoption? Evidence from Zambia. J Agric Econ 75(2):740–763. https://doi.org/10.1111/1477-9552.12582
Thuo M, Bell AA, Bravo-Ureta BE, Lachaud MA, Okello DK, Okoko EN, Puppala N (2014) Effects of social network factors on information acquisition and adoption of improved groundnut varieties: the case of Uganda and Kenya. Agri Hum Values 31:339–353. https://doi.org/10.1007/s10460-014-9486-6
Tian X, Sun RY, LI Z (2023) Effects of information literacy on farmers' transition to green production. Appl Ecol Environ Res 21(4):3445–3463. https://doi.org/10.15666/aeer/2104_34453463
Tong R, Wang Y, Zhu Y, Wang Y (2022) Does the certification of agriculture products promote the adoption of integrated pest management among apple growers in China? Environ Sci Pollut Res 29:29808–29817. https://doi.org/10.1007/s11356-022-18523-5
Tulin M, Volker B, Lancee B (2021) The same place but different: How neighborhood context differentially affects homogeneity in networks of different social groups. J Urban Aff 3(1):57–76. https://doi.org/10.1080/07352166.2019.1578176
Vande BLR, Wenner LA, Gronbeck BE (2004) Media literacy and television criticism: enabling an informed and engaged citizenry. Am Behav Sci 48(2):219–228. https://doi.org/10.1177/0002764204267266
Walsh A (2009) Information literacy assessment: where do we start? J Librariansh Inf Sci 41(1):19–28. https://doi.org/10.1177/0961000608099896
Wangithi CM, Muriithi BW, Belmin R (2021) Adoption and dis-adoption of sustainable agriculture: a case of farmers' innovations and integrated fruit fly management in Kenya. Agriculture 11(4):338. https://doi.org/10.3390/agriculture11040338
Xiang P, Guo J (2023) Understanding farmers' intentions to adopt pest and disease green control techniques: comparison and integration based on multiple models. Sustainability 15(14):10822. https://doi.org/10.3390/su151410822

Yang W, Qi J, Arif M, Liu M, Lu Y (2021) Impact of information acquisition on farmers' willingness to recycle plastic mulch film residues in China. J Clean Prod 297:126656. https://doi.org/10.1007/s11356-020-09724-x
Yang ZH (2018) Ageing, social network and the adoption of green production technology: evidence from farm households in six provinces in the Yangtze River basin (in Chinese). China Rural Surv 4:44–58
Yu L, Chen C, Gao Y (2020) Confucian values, trust, and family farm adoption of green control techniques. Environ Sci Pollut Res 27:35099–35111. https://doi.org/10.1007/s11356-020-09724-x
Yu Y, He Y, Zhao X (2021) Impact of demand information sharing on organic farming adoption: an evolutionary game approach. Technol Forecast Soc Change 172:121001. https://doi.org/10.1016/j.techfore.2021.121001
Yue S, Xue Y, Lyu J, Wang K (2023) The effect of information acquisition ability on farmers' agricultural productive service behavior: an empirical analysis of corn farmers in northeast China. Agriculture 13(3):573. https://doi.org/10.3390/agriculture13030573
Zhang B, Fu S (2023) Do market pressure and social network affect farmers' adoption of low-carbon fertilization practices? Evidence from China. Environ Sci Pollut Res 30(18):51804–51815. https://doi.org/10.1007/S11356-023-25664-8
Zhang L, Li X, Yu J, Yao X (2018) Toward cleaner production: what drives farmers to adopt eco-friendly agricultural production? J Clean Prod 184:550–558. https://doi.org/10.1016/j.jclepro.2018.02.272
Zhang Y, Lu Q, Yang C, Grant MK (2023) Cooperative membership, service provision, and the adoption of green control techniques: evidence from China. J Clean Prod 384:135462. https://doi.org/10.1016/j.jclepro.2022.135462
Zheng W, Luo B (2022) Understanding pollution behavior among farmers: exploring the influence of social networks and political identity on reducing straw burning in China. Energy Res Soc Sci 90:102553. https://doi.org/10.1016/J.ERSS.2022.102553
Zhang C, Guanming S, SHEN Jian, Hu RF (2015) Productivity effect and overuse of pesticide in crop production in China. J Integr Agri 14(9):1903–1910. https://doi.org/10.1016/S2095-3119(15)61056-5

Acknowledgements

This research was funded by the National Natural Science Foundation of China (Grant No. 72173037), the Humanities and Social Science Research Project of the Ministry of Education of China (Grant No. 21YJA790039), the Philosophy and Social Science Planning Project of Henan Province (Grant No. 2021BJJ046), the Humanities and Social Science Research Project for Colleges and Universities of Henan Province (Grant No. 2023-ZDJH-368), and the Key Project of Higher Education Teaching Reform Research and Practice of Henan Province (Grant No. 2024SJGLX0060).

Author contributions

Conceptualization: Ruifeng Liu, Jian Wang, Mengling Tian, Fei Liang; Validation: Ruifeng Liu, Jian Wang, Yefan Nian; Formal Analysis: Ruifeng Liu, Jian Wang, Hengyun Ma, Fei Liang; Data Curation: Ruifeng Liu, Jian Wang, Fei Liang; Writing—Original Draft Preparation: Ruifeng Liu, Jian Wang; Writing—Review, Editing: Ruifeng Liu, Jian Wang, Mengling Tian, Yefan Nian, Wei Ren, Fei Liang, Hengyun Ma; Project Administration: Ruifeng Liu, Hengyun Ma; Funding Acquisition: Ruifeng Liu, Hengyun Ma. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

Approval was obtained from the ethics committee of the College of Economics and Management, Henan Agricultural University, before beginning data collection (24th July 2023, Approval ID is HAU20230724012). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent

Informed consent was obtained from all participants in this study. Participants accept and voluntarily participate in this study. The study does not reveal the personal information of the respondents.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-025-04363-4.

Correspondence and requests for materials should be addressed to Fei Liang.