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Analysis of factors influencing the willingness to sell forest carbon sink products online: a case Study of Fujian Province, China

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Farmers' willingness to sell forest carbon sink products through the Internet is of great practical significance for achieving the goals of carbon peaking and carbon neutrality and promoting the sustainable development of forestry. Based on 300 sets of farmer survey data from Fujian Province, this study takes resource endowment as the core explanatory variable, and constructs a multiple ordered Logistic model by combining natural, human, and social resource endowments to empirically analyze the factors influencing farmers' willingness to sell carbon sink products through the Internet. The research results show that the per capita forest land area of the household, carbon knowledge training, whether the farmer is a village cadre, and awareness of Internet sales of forest carbon sinks all have a significant impact on farmers' willingness to sell through the Internet. In addition, control variables such as household forestry income and forestry operation activities also have varying degrees of influence on the willingness to sell through the Internet. This paper enriches the influence mechanism of resource endowment on the behavior of farmers in the carbon sink market and provides new empirical evidence for the formulation of carbon sink market policies. Based on this, it is necessary to rely on the advantages of natural resource endowments to provide targeted support for large-scale farmers, strengthen human resource empowerment by constructing a "knowledge empowerment + risk mitigation" dual-track mechanism, optimize the mobilization of social resources to give play to the demonstration effect of village cadres, and improve market infrastructure to reduce risks and operational thresholds. This will encourage farmers to actively participate, making the Internet sales of forest carbon sink products large-scale and normalized.

KEYWORDS

forest carbon sink, online sales, farmer resource endowment, logistic, willingness to participate

1 Introduction

In recent years, global warming has intensified, posing not just an environmental challenge but a multifaceted global crisis that impacts economies, societies, public health, and security. Tackling this issue demands urgent international action and innovative solutions (Scheffran and Battaglini, 2011). On 24 October 2021, China's central government promulgated a landmark policy document called Opinions on Fully and Accurately

Implementing the New Development Philosophy for Carbon Peaking and Carbon Neutrality. This announcement defined a concrete national development road map: To steadily cap carbon emissions over the 14th Five-Year Plan period, peak by 2030, and strive for carbon neutrality by 2060. These targets not only are critical to fulfilling China's obligations under climate commitments globally, but are also a bedrock for shifting to a high-quality, sustainable developmental mode (Wang et al., 2021). With their strong ability to absorb carbon, forest carbon sinks are a focal point in pursuing sustainable carbon neutrality, and their function is irreplaceable (Nunes et al., 2020). Trading of products of forest carbon sinks is the last link in releasing the full potential of forest systems. By converting forests' carbon sequestration service into tangible, tradable values, such markets not only make forest carbon sinks transparent, but also attract larger-scale social capital. With this, such markets optimize the ecological as well as the financial return on forest resources (Herr et al., 2019). With the arrival of information times, the internet has evolved into a vital medium for product transaction of forest carbon sinks. Farmers with forest resources are central in the product transaction of forest carbon sink commodities. Their decision to supply such commodities through net channels not only provides them tangible monetary benefits, but also introduces carbon market with increased liquidity, energizes trading, and stimulates more farmers toward participation in carbon sink projects, thereby propelling larger forest conservation initiatives.

Authors have further investigated carbon sink trading in forests in recent studies. Yin et al. (2022) emphasized that one driver of the development of the carbon sink market in their study was the support of policies. Well-targeted policies, according to their study, can actively lead enterprises and individuals into the carbon sink trading and attract more capital investment in order to develop the projects and make publicity, thus driving the maturity of the carbon market. Churkina et al. (2020) confirmed that increased concentration on carbon neutrality by the global world, combined with enhanced environmental awareness by citizens and corporate societal responsibility, drove up demand for purchases of carbon sink products, impacting their trading quantity. Wang et al. (2017) provided information confirming that carbon tax policy, by imposing the cost of emissions on firms, enhances the attractiveness of carbon sinks, drives up further development of the market. Li et al. (2023) confirmed that the level of farmer education, number of members in the household, labor force proportion, and prior inclusion in carbon sink trade determine their intention to participate or continue in carbon trading. Applying the theory of planned behavior, Hou and Hou (2019) established that attitudes of forest farmers, subjective norms, and perceived behavior control are strong determinants of their willingness to participate in forest carbon sink trade. Chu et al. (2020) established that understanding of forest ecosystem services by farmers, as well as their family-owned forest area, play a strong role in determining their willingness to take part in forest carbon sink trade. Park and Savelyeva (2022) investigated three factors such as personal attributes, intrinsic motivation, and extrinsic factors, and their finding revealed that values on forest management such as environmental, economic, and bidirectional priorities, along with technological, policy factors, play an important role with a significant-positive effect on willingness to participate of farmers. Hui and Yong (2023) revealed that farmers with high risk tolerance are more likely to experiment with carbon sink trading, whereas risk-averse farmers tend to adopt a wait-and-see attitude due to market uncertainty. Lee (2017) stressed that farmers with high risk tolerance are more likely to experiment with carbon sink trading whereas risk-averse farmers tend to adopt a wait-and-see attitude due to market uncertainty. Lee (2017) stressed that farmersarmers tend to adopt a wait-and-see attitude due to markerole with a significant effect on their participation. Lack of training on carbon sinks along with poor knowledge may inhibit their participation in carbon trade. Wang and Wang (2020) noted that with an increase in non-agricultural labor members of a household and non-agricultural income in terms of percentage of total household income, farmers are less interested in participation in carbon sink markets.

Despite growing academic interest in forest carbon sink products both domestically and internationally, such limitations exist in micro-level factors, especially surveying farmers' intentions to sell sinks, which may result in policies and market incentives that are poorly targeted. In addition, studies on Internet sales channels remain scarce. Even though internet technology was brought in to forestry sink product trading, empirical studies focusing on factors that can influence farmers' willingness to trade using Internet channels are still rare. Based on gaps existing in previous studies, this study selected collective areas of forests in Fujian Province as the surveyed area. To ensure analytical rigor and effectiveness, this study follows the successful approach of scholars like Diao (2025) and Zhang et al. (2018), who applied multivariate ordered logistic regression to micro-level farmer behavior with stable explanatory results. This model was chosen not only because it accurately fits the clearly ordered but not equidistant five-point Likert scale data on farmersale del was chosen not only because it accurately fits the clearly ordered but not equidistant collective areas of forests in Fujian Province though intels. Therefore, it significantly enhances the theoretical soundness and explanatory power of the model. This methodology also overcomes the drawbacks common with generalized ordered models of logit in studies with comparatively small sample sizes, such as complicated parameter estimation, inefficient inference, and parameter instability. The results of this study are anticipated to contribute new insights and firm empirical evidence for grassroots-level studies on the willingness to participate in forest carbon sink transactions. Not only do they offer useful empirical evidence and policy recommendations for enhancing the online forest carbon sink market mechanism, but also for actively stimulating farmers' participation, promoting rural green development and transformation.

2 Materials and methods

2.1 Study area and data sources

The data for this study were obtained from a field survey conducted in July 2022 across 10 towns in Yongtai and Jiangle counties, Fujian Province. Yongtai and Jiangle counties, situated in the mountainous central region of Fujian Province, are typical collective forest ecological zones in southern China (Figure 1). Both have long been pilot areas for collective forest tenure reform and carbon sink policies, making them highly representative in

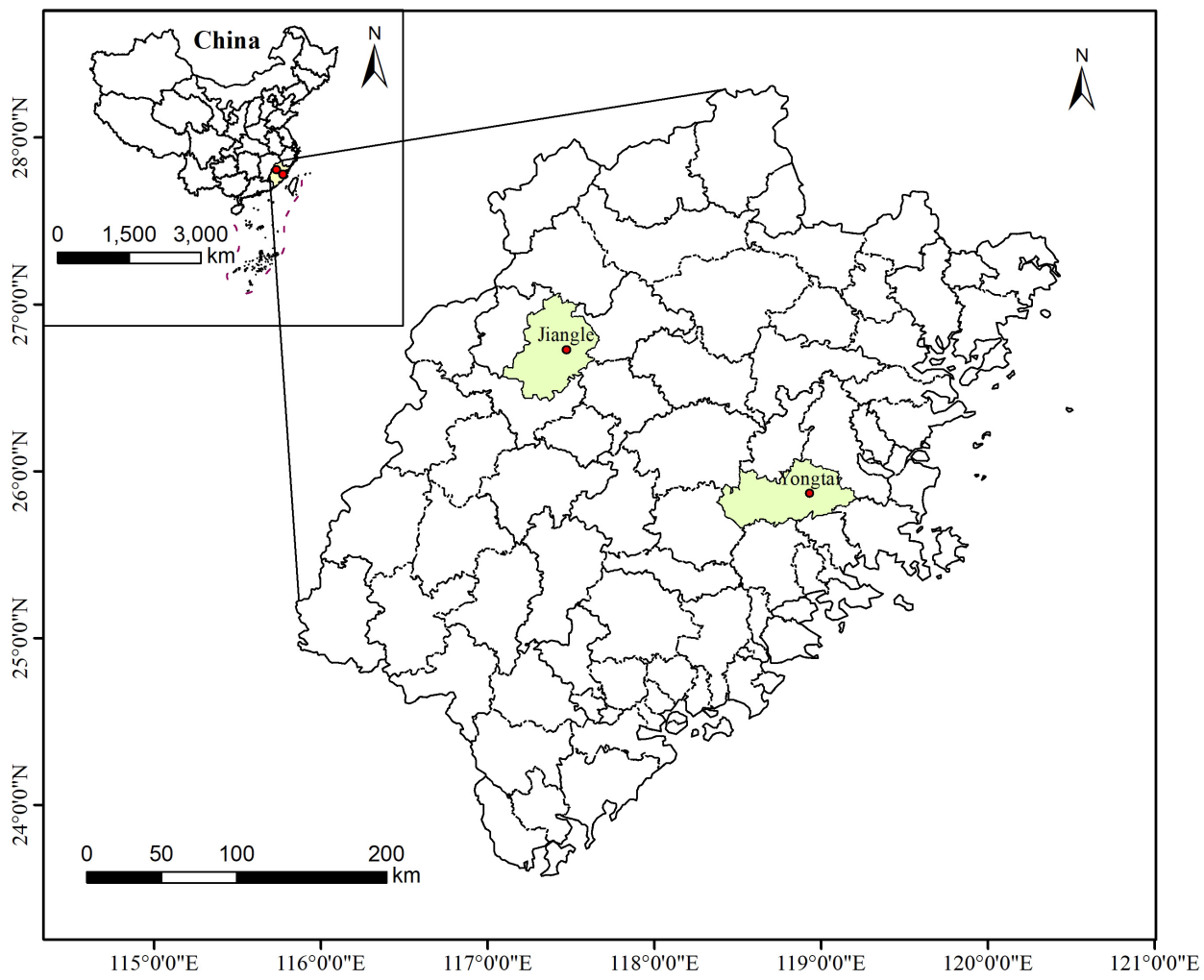

FIGURE 1
Study area location.

forestry management practices, resource endowments, and policy environments. With forest coverage rates of 69.37 and 80.80%, respectively, these counties significantly exceed the national average, aligning closely with the average forest coverage found in collective forest areas of other major southern forestry provinces like Zhejiang, Jiangxi, and Guangdong. In Yongtai, Jiangle, and other administrative villages in Fujian Province, 5G coverage has reached 93.4%, well above the national average and comparable to that of southeastern coastal provinces such as Zhejiang and Guangdong, reflecting the typical traits of digitally advanced areas. Moreover, farmers' forestry income in these counties is noticeably higher than the national average, highlighting their strong reliance on forestry. Consequently, the experiences of Yongtai and Jiangle provide valuable insights and practical reference for other low- to mid-mountainous regions in southern China, particularly those with relatively sound collective forest tenure systems and active forestry management. This study selected 173,403 households from different villages in ten towns as subjects, conducted a survey using random sampling, and collected data through a combination of field questionnaires and face-to-face interviews. A total of 300 questionnaires were distributed, and after screening and quality checks, 246 valid responses were obtained, providing reliable data support for the research.

2.2 Variable design and research hypotheses

Factor endowment represents the resources owned by farmers. Farmers with advantageous factor endowments are more competitive in participating in the carbon sink product market. These resources provide the necessary support and security for farmers to engage in market transactions. This study defines the "farmer's willingness to sell forest carbon sink products online" as the dependent variable (y), and the "the dependent variable (y), and the ine" defines the "farmer's wink product market. These resesponses were obtained, providing res focuses on three dimensions: natural resource endowment, human resource endowment, and social resource endowment, to explore how these factors influence farmers' willingness to engage in online sales of carbon sink products. Natural resource endowment is represented by the per capita forest land area of the farmer's household; human

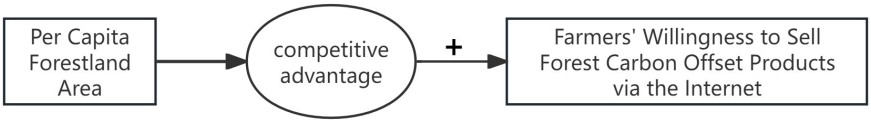

FIGURE 2
Natural resource endowment theoretical framework.

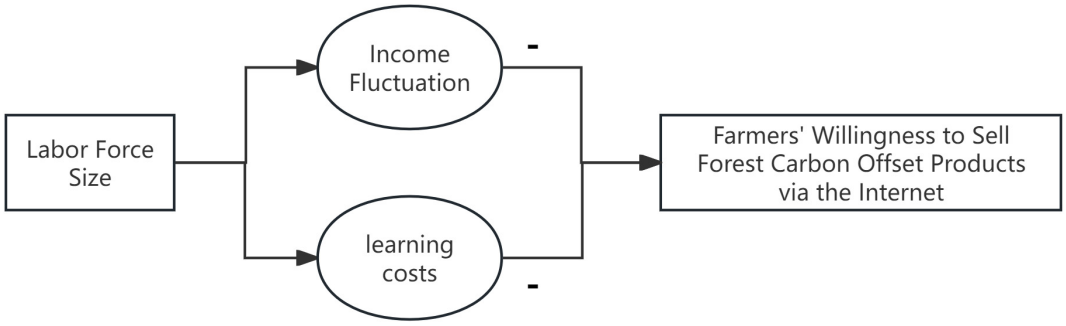

FIGURE 3
Human resource endowment theoretical framework.

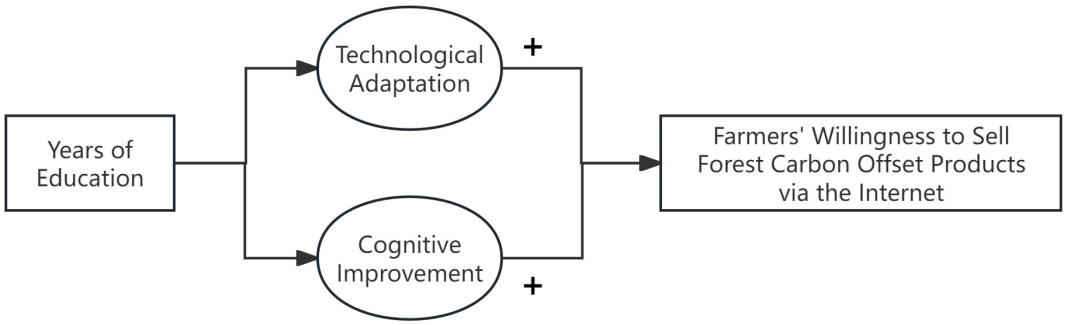

FIGURE 4
Human resource endowment theoretical framework.

resource endowment is measured by the number of laborers, years of education, and participation in carbon knowledge training; social resource endowment is represented by the non-agricultural employment rate of the farmer's household, whether the farmer holds a village leadership position, and the farmer's awareness of forest carbon sink product online sales.

Farm households with a larger per capita forest land area are likely to have a competitive advantage, which can positively influence their attitudes toward online carbon sink products sales. In brief, farmers with a larger per capita area of forestland will be more willing to make internet sales of forest carbon sink products (White et al., 2018). Hypothesis 1: Farmers with a resource advantage are more willing to provide forest carbon sink products for internet sales, *i.e.*, a household's per capita forestland area is positively related to a farmer's willingness to provide internet sales of forest carbon sink products (Figure 2).

Households with more workers may depend more on traditional business models because of greater income changes and higher learning costs, making them less likely to choose online sales. On the other hand, higher education helps farmers adapt to technology better and understand the forest carbon sink products market more, which increases their confidence and willingness to sell forest carbon sink products online (Yang et al., 2024). Carbon knowledge training helps farmers see the benefits and future potential of online sales channels, while also offering technical support and risk management advice, which boosts their interest in online sales (Cammarata et al., 2024). Therefore, Hypothesis 2 is proposed: Among human resources, the number of workers in a household negatively affects farmers' willingness to sell forest carbon sink products online, while years of education and participation in carbon knowledge training have a positive effect. Specifically, the higher the farmer's education or the more they have participated in carbon knowledge training, the more likely they are to sell forest carbon sink products online. In contrast, the more workers in a household, the less likely they are to engage in online sales of forest carbon sink products (Figures 3–5).

Farmers with additional non-farm occupations or those in a village leadership status are most likely to obtain information

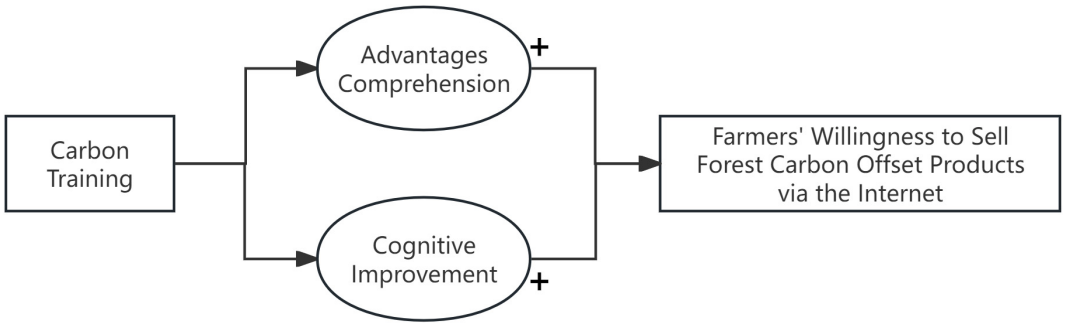

FIGURE 5
Human resource endowment theoretical framework.

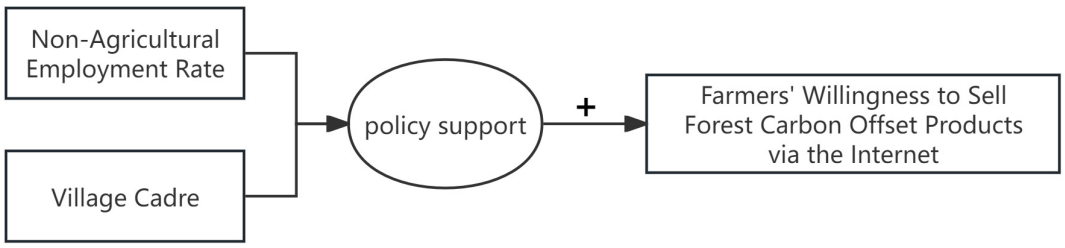

FIGURE 6
Social resource endowment theoretical framework.

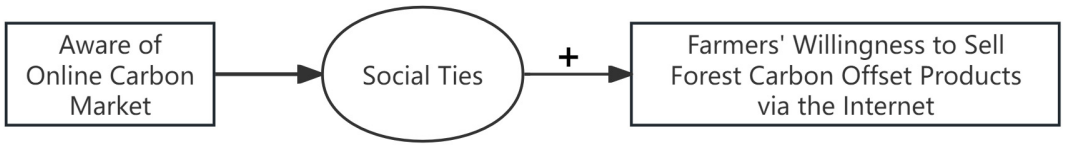

FIGURE 7
Social resource endowment theoretical framework.

regarding forest carbon sink product selling policies. They also possess a solid social network, thus have a better opportunity to obtain assistance and aid from social connections. Because of this, they are more inclined toward selling forest carbon sink products over the internet (Lin and Yang, 2023). Those farmers who know about online selling of forest carbon sink products tend to have wider social networks, more knowledge about the market, as well as better information access. These make them better aware of the prospective and advantages of selling online and, therefore, more inclined to take part (Håbesland et al., 2016). Hence, Hypothesis Hence, Hypothesis 3 is developed as follows: Social resources have a positive influence on farmersnagement advice, which boosts their interest in tion and participation in carbon knowledge training have a positi leaders, and those who know how to sell forest carbon sink products online are more inclined toward this (Figures 6, 7).

To analyze the factors influencing farmersre more inclined noforest carbon sink products online. That is, farmers with more sts their ins from three aspects: personal characteristics, family characteristics, and forestry production characteristics. The personal characteristic variables include age, gender, and occupation. Older farmers are often more strongly influenced by traditional values and accustomed to conventional business methods, making them less adaptable to new sales models. Furthermore, they generally exhibit lower stress resistance and weaker abilities to adapt to emerging technologies (Altieri and Nicholls, 2017). In contrast, women, compared to men, tend to engage more in family and external communications, which increases their access to the Internet and social media, thus making them more likely to adapt to online sales models (Macqueen et al., 2020). Farmers who engage in non-agricultural jobs tend to have stable incomes or are less reliant on forest carbon sink products, which reduces their willingness to participate in the online carbon sink product market (Fujimori et al., 2022). The household characteristic variables include household size and forestry income. Families with a larger population size are more likely to use Internet sales channels, as they have higher economic needs and are thus more inclined to seek ways to increase income and reduce transaction costs (Baiocchi et al., 2010). Farmers with higher forestry income tend to have stronger economic capacity, allowing them to afford the initial costs and potential risks of online sales, as well as expand their sales channels with the advantage of

greater funds (Deichmann et al., 2016). The forestry production characteristics include forestry business activities, subsidies, and production expenditures. Farmers engaged in forestry operations are likely to prioritize traditional operations and may be less familiar with Internet technologies, leading to a lower willingness to sell carbon sink products online. Forestry subsidies offer financial support, easing the economic pressure on farmers and making them more likely to engage in online sales (Yin, 2021). Farmers with higher forestry production expenses are more attuned to the dynamics of the carbon sink product market, have higher income expectations, and are therefore more willing to experiment with new online sales channels. Based on the variables described above, Table 1 presents their definitions and descriptive statistics.

TABLE 1 Variable definitions and descriptive statistics.

Variable type	Conceptual variable	Variable name	Definition and coding	Mean	SD	Min	Max
Dependent variable		Willingness to sell forest carbon products online (Y)	Willing = 5; somewhat willing = 4; neutral = 3; slightly unwilling = 2; unwilling = 1	3.64	1.32	1	5
Key explanatory variables	Natural resource endowment	Per capita forestland area (X_1)	Forestland area per capita in the household (mu)	2.02	2.01	0.11	14.29
	Human resource endowment	Labor force size (X_2)	Number of working-age laborers in the household	3.03	1.48	1	12
		Years of education (X_3)	Years of education received by the household head	6.96	3.56	1	15
		Carbon knowledge training (X_4)	Yes = 1; No = 0	0.39	0.49	0	1
	Social resource endowment	Non-agricultural employment rate (X_5)	Proportion of household members engaged in non-agricultural employment	0.56	0.2	0.1	1
		village cadre (X_6)	Yes = 1; No = 0	0.27	0.44	0	1
		Awareness of forest carbon product online sales (X_7)	Yes = 1; No = 0	0.67	0.47	0	1
Control variables	Personal characteristics	Age (X_8)	Actual age of the household head	56.74	10.77	21	86
		Gender (X_9)	Male = 1; Female = 0	0.87	0.34	0	1
		Occupation (X_{10})	Farming = 1; Farming-dominant sideline = 2; Non-farming-dominant sideline = 3; Non-farming = 4; other = 5	1.93	1.15	1	5
	Household characteristics	Household size (X_{11})	Total number of household members	5.17	2.04	2	12
		Forestry income (X_{12})	Forestry income of the household (10,000 yuan)	1.42	4.26	0	50
	Forestry production characteristics	Forestry operation experience (X_{13})	Participated = 1; Not participated = 0	0.67	0.47	0	1
		Forestry subsidy (X_{14})	Yes = 1; No = 0	0.61	0.49	0	1
		Forestry production expenditure (X_{15})	Forestry-related expenditure (10,000 yuan)	0.55	2.72	0	38

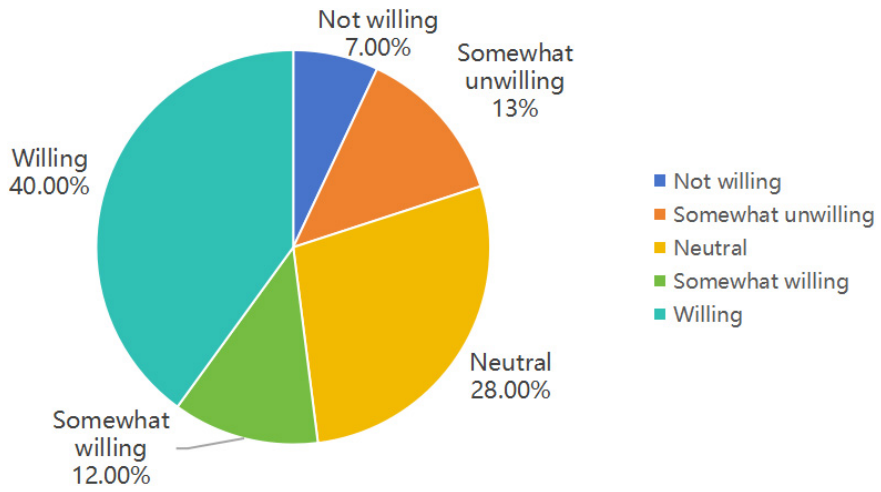

FIGURE 8
Farmers' willingness to sell forest carbon sink products online.

Overall, 52% of farmers expressed willingness or relative willingness to engage in online sales of forest carbon sink products, indicating a certain foundation for promotion. However, nearly half remained uncertain or unwilling, suggesting that further efforts are needed to enhance participation, as shown in Figure 8.

2.3 Model construction

Since the dependent variable in this study, products, indicating a certain foundation for promotion. sure on fs a discrete variable with three or more categories and is ordered, we choose a multinomial ordered Logistic model to conduct an econometric analysis of the factors influencing farmers' willingness to sell forest carbon sink products online.

Let y* denote the latent variable representing farmers' willingness to sell forest carbon sink products online. This variable is divided into five categories: "Unwilling," "Slightly unwilling," "Neutral," "Somewhat willing," and "Willing," with corresponding values of "1, 2, 3, 4, 5," respectively. It is assumed that y follows the equation below:

$$y* = \partial + \beta X + \theta Z + \varepsilon \quad (1)$$

In this equation, X denotes the key explanatory variables, i.e., resource endowments (including natural resource endowments, human resource endowments, and social resource endowments). ∂ is the constant term, β is the coefficient of the key explanatory variables to be estimated, θ is the coefficient of the control variables to be estimated, and Z represents the control variables, including personal characteristics, household characteristics, and forestry production characteristics. ε is the error term, assumed to be independently distributed. Let c denote the threshold values that divide the latent variable y* into distinct levels of willingness. The relationship between y* and y can then be expressed as follows:

If $y* < c_1$, then y = 1, meaning the farmer is unwilling to sell forest carbon sink products online;

If $c_1 \leq y* < c_2$, then y = 2, indicating the farmer is slightly unwilling;

If $c_2 \leq y* < c_3$, then y = 3, indicating a neutral;

If $c_3 \leq y* < c_4$, then y = 4, indicating the farmer is somewhat willing;

If $c_4 \leq y* < c_5$, then y = 5, meaning the farmer is willing to adopt online sales of forest carbon sink products.

The probability of each level of willingness is modeled using the cumulative distribution function of the error term ε, and is expressed as:

$$\text{Prob}(y = 1) = \text{Prob}(\partial + \beta X + \theta Z + \varepsilon < c_1) = \frac{1}{1 + e^{-c_1 + \partial + \beta X + \theta Z}} \quad (2)$$

$$\text{Prob}(y = 2) = \text{Prob}(c_1 \leq \partial + \beta X + \theta Z + \varepsilon < c_2) = \frac{1}{1 + e^{-c_2 + \partial + \beta X + \theta Z}} - \frac{1}{1 + e^{-c_1 + \partial + \beta X + \theta Z}} \quad (3)$$

$$\text{Prob}(y = 3) = \text{Prob}(c_2 \leq \partial + \beta X + \theta Z + \varepsilon < c_3) = \frac{1}{1 + e^{-c_3 + \partial + \beta X + \theta Z}} - \frac{1}{1 + e^{-c_2 + \partial + \beta X + \theta Z}} \quad (4)$$

$$\text{Prob}(y = 4) = \text{Prob}(c_3 \leq \partial + \beta X + \theta Z + \varepsilon < c_4) = \frac{1}{1 + e^{-c_4 + \partial + \beta X + \theta Z}} - \frac{1}{1 + e^{-c_3 + \partial + \beta X + \theta Z}} \quad (5)$$

$$\text{Prob}(y = 5) = \text{Prob}(c_4 \leq \partial + \beta X + \theta Z + \varepsilon < c_5) = \frac{1}{1 + e^{-c_5 + \partial + \beta X + \theta Z}} - \frac{1}{1 + e^{-c_4 + \partial + \beta X + \theta Z}} \quad (6)$$

3 Results

Prior to regression analysis, a multicollinearity diagnostic was performed to ensure the robustness of the model. The results indicate that all Variance Inflation Factor (VIF) values are below the commonly accepted threshold of 10, with an average of 1.66, suggesting no significant multicollinearity among the variables. Accordingly, the regression analysis proceeded using a multivariate ordered logistic model. The empirical results are presented in Table 2. To more intuitively present the effect sizes and confidence intervals of each influencing factor, a forest plot was generated (Figure 9) to visualize the results, which helps clarify the direction and significance of each factor's impact on farmers' willingness to sell forest carbon sink products online.

TABLE 2 Empirical results of factors influencing farmers' willingness to sell forest carbon products online.

Variables	Regression coefficients
Per capita forestland area	0.2103*** (2.8173)
Labor force size	−0.0576 (−0.3529)
Years of education	0.0077 (0.1782)
Carbon knowledge training	0.7851*** (2.7566)
Non-agricultural employment rate	0.1115 (0.1147)
Village cadre	0.8523*** (2.7012)
Awareness of forest carbon product online sales	−0.8484*** (−2.7676)
Age	−0.0137 (−1.0146)
Gender	−0.0642 (−0.1657)
Occupation	−0.0613 (−0.5423)
Household size	0.1500 (1.4446)
Forestry income	0.0793* (1.6526)
Forestry operation experience	−0.9850*** (−3.0407)
Forestry subsidy	−0.1914 (−0.6628)
Forestry production expenditure	0.0845 (1.5887)
Sample size	246

*$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$ indicate statistical significance at the 10, 5, and 1% levels, respectively.

3.1 Analysis of regression results for key explanatory variables

Natural resource endowment: The results show that per capita forestland area has a significant positive impact on farmers' willingness to sell forest carbon sink products online, at the 1% level of significance. This indicates that farmers with greater forestland holdings are more inclined to adopt online channels for carbon sink products sales. Farmers with greater natural resource endowments are more likely to engage in forest carbon sink activities, as these resources provide them with a competitive edge. Additionally, farmers with larger per capita forestland areas can effectively leverage the internet to expand their market reach, thereby increasing carbon sink sales revenue and reducing transaction costs. Consequently, they are more inclined to participate in online sales of forest carbon sink products, which supports the validity of Hypothesis 1.

Human resource endowments: Both the years of education and the labor force size of farmers have no significant impact on their willingness to sell carbon sink products online. This may be attributed to the generally low and concentrated distribution of education levels among the sample farmers, where small differences in education are insufficient to significantly influence their willingness to adopt online sales. Additionally, although households with a larger labor force can dedicate personnel to skill acquisition, their stronger reliance on traditional practices may counteract this benefit. These counterbalancing effects may offset one another, resulting in an overall insignificant influence on the dependent variable. Carbon knowledge training has a significant positive impact on farmers' willingness to sell carbon sink products online at the 1% significance level. This suggests that farmers who have received training in carbon-related knowledge are more likely to utilize online sales channels. Such training typically includes technical guidance and risk management strategies, which help farmers enhance their skills in Internet usage and alleviate challenges in online operations. Moreover, the training also provides farmers with information on policy support and subsidies for carbon sink product sales, boosting their confidence in using online platforms and increasing their willingness to participate in online sales.

Social resource endowment: Whether or not farmers serve as village cadres significantly enhances their willingness to sell carbon sink products online, with a 1% significance level. Village cadres are more likely to access government policies and market information, which can provide them with potential policy support or incentives. This facilitates their ability to acquire information and expand sales channels when marketing carbon sink products online. Additionally, village cadres have a stronger social network, which, coupled with support from their peers and government policies, can greatly increase their willingness to participate. This leads to a higher acceptance of online sales of carbon sink products, aligning with the previous hypothesis. Therefore, farmers are more inclined to sell carbon sinks online, supporting the initial assumption. However, the non-agricultural employment rate of households has no significant effect on farmers' willingness to sell

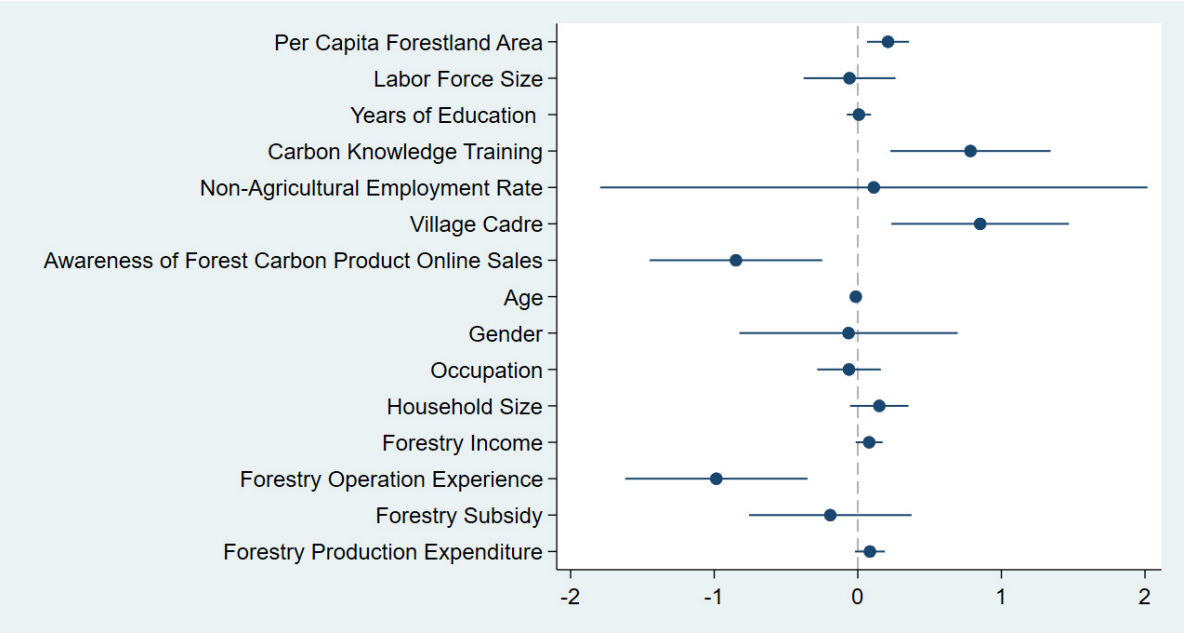

FIGURE 9
Forest plot of regression results.

carbon sink products online. This might be due to the balancing effect of advancements in internet and mobile communication technologies. Even households with a low proportion of non-agricultural employment can easily obtain information about the online sales of carbon sink products through smartphones, computers, and other devices, thus reducing the influence of non-agricultural employment rate on access to such information. Additionally, although farmers from households with a higher non-agricultural employment rate have broader social networks, these connections are primarily focused on non-agricultural fields, and may not be effectively utilized for the online sale of carbon sink products. The awareness of internet sales for forest carbon sink products has a significant negative impact on sales willingness at the 1% significance level. This is because the current online market for forest carbon sink products is still immature. After farmers become aware of the online sales channels, they may worry that the effort they invest will not yield stable returns, which lowers their enthusiasm. Moreover, although online sales theoretically offer broad coverage, they require farmers to invest more time and resources upfront to learn and adapt to the process. Consequently, after realizing the internet skills required for online sales, many farmers may feel overwhelmed, which diminishes their willingness to explore new sales channels.

3.2 Regression results and analysis of control variables

Personal characteristics variables: Age, gender, and occupation do not have a significant impact on farmers' willingness to sell forest carbon sink products online. The regression coefficient for age is −0.0137, which is small and statistically insignificant, indicating that changes in age have a minimal effect on farmers' willingness to engage in online sales of forest carbon sink products. Although younger farmers are generally more inclined to embrace new approaches, older farmers may offset their limited adaptability to innovative sales channels through their accumulated experience and broader social networks. The gender variable shows a weak negative coefficient of −0.0642, which is statistically insignificant, indicating that there is no meaningful difference between male and female farmers in their willingness to sell forest carbon sink products via online platforms. The diminishing influence of traditional gender roles in rural areas may explain why gender no longer significantly affects internet usage or willingness to sell online. Similarly, the regression result for occupation (−0.0613) is not statistically significant, indicating no clear difference in online sales willingness among farmers with different jobs. This could be because decisions regarding forest carbon sink products sales online involve a range of considerations—such as personal capacity, access to technology, and risk perception—rather than being determined solely by occupational background.

Household Characteristics: The size of a household does not significantly influence a farmer's willingness to sell forest carbon sink products online. While larger households often face greater financial demands, such decisions are typically shaped by a broader mix of considerations that go beyond household size alone. On the one hand, households with a larger proportion of elderly members may lack the skills or familiarity with internet-based operations, which could reduce their overall enthusiasm for online sales. On the other hand, if most family members are engaged in traditional forestry production and have limited time or capacity to explore digital sales channels, even strong economic needs may not translate into a higher willingness to participate in online markets. Moreover, household income from forestry exhibits a significantly positive effect on farmers' willingness to sell

TABLE 3 Robustness test results of factors influencing farmers' willingness to engage in online sales of forest carbon sink products.

Variables	Ols	Probit
Per capita forestland area	0.1201***	0.1309***
	(2.9106)	(2.9942)
Labor force size	−0.0566	−0.0569
	(−0.5266)	(−0.5924)
Years of education	0.0149	0.0094
	(0.5257)	(0.3642)
Carbon knowledge training	0.4616***	0.4915***
	(2.6108)	(2.9425)
Non-agricultural employment rate	0.1786	0.1427
	(0.2875)	(0.2535)
Village cadre	0.5167***	0.4906***
	(2.6963)	(2.7195)
Awareness of forest carbon product online sales	−0.5421***	−0.5550***
	(−2.8868)	(−3.0701)
Age	−0.0080	−0.0065
	(−0.8913)	(−0.8140)
Gender	−0.0682	−0.0782
	(−0.2690)	(−0.3378)
Occupation	−0.0425	−0.0341
	(−0.5784)	(−0.5127)
Household size	0.1067	0.1005*
	(1.5983)	(1.6902)
Forestry income	0.0370*	0.0491*
	(1.8828)	(1.7910)
Forestry operation experience	−0.5234***	−0.5813***
	(−2.6568)	(−3.0839)
Forestry subsidy	−0.1365	−0.0892
	(−0.7551)	(−0.5222)
Forestry production expenditure	0.0493*	0.0525
	(1.6804)	(1.6045)
Sample size	246	246

*$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$ indicate statistical significance at the 10, 5, and 1% levels, respectively.

forest carbon sink products online, at the 10% significance level. This indicates that with every increase of 10,000 yuan in household forestry income, the willingness of farmers to engage in online sales of forest carbon sink products increases to a certain extent. This is because households with higher forestry income are economically better off and are thus able to bear the upfront costs and risks associated with internet sales. Even if the initial returns are suboptimal, these households possess the financial resilience to sustain participation. Additionally, these households have the means to access the latest trends and policies in carbon sink sales and are more likely to invest in acquiring internet-related skills, which in turn boosts their willingness to participate in online sales of forest carbon sink products.

Forestry production characteristics variables: Participation in forestry management activities has a significant negative impact on the willingness to engage in online sales at the 1% significance level. This indicates that farmers who are actively involved in forestry management are less willing to try online sales. The reason for this is that these farmers have invested considerable time and effort into traditional sales methods and are highly dependent on the stability they offer. As a result, they are concerned that the uncertainties of online sales could disrupt their existing, stable income sources. On the other hand, farmers involved in forestry management might focus their main efforts on the specific tasks of production and operation, leaving them with limited skills and knowledge for online sales. As a result, they show less interest in engaging with internet sales channels. The regression coefficient for forestry subsidies is −0.1914 and is not significant, suggesting that subsidies have not had a noticeable effect on farmers' willingness to pursue online sales. This could be because the subsidy amounts are relatively small and do not significantly influence their sales decisions, or because farmers may not fully recognize the connection between subsidies and internet sales. Consequently, subsidies have not served as a key factor in their decision to engage in online sales, failing to make the expected impact on their willingness. Forestry production expenditures did not significantly affect farmers' willingness to engage in online sales of forest carbon products. This is because farmers with higher forestry production expenditures tend to focus more on direct forestry outputs. The internet sales model for carbon sink products has a relatively minor impact on short-term forestry profits, with lower returns. As a result, the combined effects lead to no significant impact of higher forestry production expenditures on farmers' willingness to engage in online sales.

3.3 Robustness check

To further verify the robustness and reliability of the model, this study replaces the Logistic model with OLS and Probit models for robustness testing. The results are presented in Table 3. As shown, the estimated coefficients and significance levels of the explanatory variables are largely consistent with the previous regression results, indicating that the overall regression outcomes of the model exhibit a certain degree of robustness.

4 Discussion

The regression findings of this study largely align with existing empirical research. In particular, the significant positive impact of per capita household forest land area on farmers' willingness to engage in online forest carbon sink sales supports White et al. (2018) argument that resource endowment plays a critical role in participation decisions, underscoring that the scale of forestry resources owned forms a fundamental basis for farmers' consideration of entering the carbon sink market. At the same time,

the significant positive influence of carbon knowledge training on farmers' willingness to engage in online sales corroborates Cammarata et al. (2024) argument that the transfer of specialized knowledge boosts participant motivation, underscoring the vital role of targeted information in facilitating behavioral change. Furthermore, the positive effect associated with village cadre status supports Lin and Yang (2023) conclusion that social networks and policy support systems are key drivers in fostering active participation in carbon sink trading, revealing the distinctive importance of rural social structures and trust in promoting innovative transaction models. Nevertheless, this study uncovers some distinctive findings that merit further investigation, offering a more refined understanding of farmer behavior within specific contexts. Notably, the size of the labor force and the number of years of education, which are often considered important indicators of human capital, do not have a significant impact on farmers' willingness to engage in online forest carbon sink sales. This differs from the findings of Yang et al. (2024) and prompts a reconsideration of the nature of Internet transactions. Unlike traditional forestry activities that rely heavily on physical labor, the online sales of carbon sink products are inherently less dependent on the number of household laborers. Therefore, the quantity of the labor force is not easily translated into a comparative advantage for participating in online transactions. Similarly, in the context of digitalization, years of education do not necessarily equate to higher Internet proficiency or operational ability. In fact, more specialized and targeted training in carbon sinks and online operations may lead to more immediate results. This suggests the need to distinguish between the influence of general educational background and specific skills training on farmers' digital behaviors.

More importantly, farmers who understand the interconnected sales of forest carbon sinks are often reluctant to participate, which contradicts the conclusion of Håbesland et al. (2016). Farmers' ability to access information and their understanding of Internet sales channels should have increased their willingness to participate. However, the opposite effect occurs in reality. The likely reason lies in the fact that, in a market environment with an imperfect system, when farmers are introduced to new Internet sales channels, they often focus on potential risks, such as issues with carbon sink trading platforms, operational costs, and uncertainties in returns. This might lead them to be too cautious to try. This underscores that information accessibility is insufficient to encourage active participation in online sales. To genuinely motivate farmers, it is essential to simultaneously establish risk protection mechanisms, reduce operational barriers, and refine market regulations.

5 Conclusion and policy implications

5.1 Conclusion

After controlling for the potential influence of personal characteristics, family characteristics, and forestry production characteristics on farmers' willingness to sell carbon sink products online, the study finds the following: From the perspective of natural resource endowment, the per capita forest land area has a significant positive impact on farmers' willingness to engage in online sales of carbon sink products. From the perspective of human resource endowment, the number of laborers and years of education do not significantly affect the willingness to sell carbon sink products online, while carbon knowledge training has a significant positive effect on willingness to engage in online sales. From the perspective of social resource endowment, being a village cadre has a significant positive impact on the willingness to sell carbon sink products online, while knowledge of forest carbon sink internet sales has a significant negative impact, and the family's non-agricultural employment rate does not have a significant effect. Additionally, variables such as family forestry income and forestry operations significantly influence the willingness to engage in online sales to varying degrees, while other variables did not pass the significance test.

While this study aligns with existing research, it does have some limitations. It mainly considers farmers' natural, human, and social resource endowments but leaves out softer factors that could strongly influence their willingness to sell online, such as access to internet infrastructure, trust in digital trading platforms, and past experience with online shopping or transactions. These variables reflect farmers' digital literacy, risk perception, and behavioral patterns, all of which may play a critical role in shaping their willingness to engage in sales. The absence of such key variables could introduce omitted variable bias, potentially compromising the accuracy of coefficient estimates and weakening the model's explanatory power. Future research can further enhance the robustness of the model and the generalizability of the results by expanding the scope of the questionnaire and incorporating more comprehensive cognitive and behavioral variables.

5.2 Policy implications

First, leverage natural resource endowments and offer targeted support to large-scale farmers. Establish a hierarchical subsidy system. For farmers whose per capita forest land area exceeds the regional average, provide higher carbon sink sales subsidies and professional technical guidance. This will encourage farmers to expand their trading scale through Internet platforms and maximize the value of carbon sink resources. At the same time, to address the problem of fragmented land among small-scale farmers, the government should promote the transfer and integration of scattered forest land or encourage cooperative operations. Consolidate dispersed forest land resources through mechanisms such as the establishment of forestry cooperatives and carbon sink operation consortia. This will reduce the cost for individual farmers to participate in online sales, enabling them to benefit from economies of scale.

Second, enhance human capital by establishing a dual-track system that combines capacity building and risk mitigation. In terms of capacity building, efforts should be made to expand the coverage of carbon sink knowledge training. Incorporate a risk mitigation component into existing carbon knowledge programs to help farmers

understand the potential risks involved in Internet-based carbon sink sales and the corresponding coping strategies. In addition, targeted training should focus on strengthening farmers' Internet operation skills, such as platform navigation and data entry, to help transform their technical competencies into action-oriented confidence. In terms of risk mitigation, a carbon sink price insurance system should be established. Providing minimum income guarantees for farmers through government or platform-based mechanisms can significantly reduce their concerns about market fluctuations.

Third, leverage the exemplary role of village cadres and enhance the mobilization of social capital. First of all, launch pilot programs led by village cadres to facilitate the linkage mechanism between village cadres and farmers. Village cadres should lead by example in participating in the online sales of forest carbon sinks and inspire surrounding farmers to join through their practical actions and successful experiences. This can trigger a chain reaction, allowing policy information, technical support, and shared benefits to spread organically within the local community. In addition, village cadres participating in Internet-based carbon sink trading can be granted additional policy incentives, such as bonus points in performance evaluations or priority access to government project applications. These measures are aimed at enhancing their exemplary role, encouraging them to be more proactive in engaging in online sales efforts, and thereby motivating more farmers to participate.

Fourth, improve market infrastructure to lower risks and operational thresholds. First of all, enhance the development of the carbon trading platform and introduce functional modules such as "Policy Information" and "Risk Assessment." By providing farmers with policy insights, real sales examples, and interactive Q&A formats, help mitigate farmers' cognitive biases. Meanwhile, it is also necessary to design a user-friendly one-click trading tool. This will simplify the process, reduce operational costs for farmers, and make it easier for them to participate in online carbon sink sales. In addition, efforts should be made to strengthen rural Internet infrastructure, with a focus on expanding network coverage in remote areas and providing subsidies for Internet fees to low-income farmers to lower their Internet expenses. Furthermore, financial institutions can be encouraged to provide tailored loan products, allowing farmers to use their expected carbon income as collateral. This will alleviate the financial burden of the upfront investment required for the sale of Internet carbon sinks.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided written informed consent to participate in this study.

Author contributions

XR: Data curation, Investigation, Writing – original draft, Writing – review and editing, Formal Analysis, Methodology. YT: Data curation, Software, Visualization, Writing – original draft. YZ: Data curation, Investigation, Writing – review and editing. QC: Funding acquisition, Supervision, Validation, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2025.1611770/full#supplementary-material

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