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The Impact of Information Acquisition Channels and Risk Preferences on Farmers' Chemical Pesticide Reduction Behavior

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Abstract

Farmers, as the primary decision makers in agricultural production, are crucial to ensuring food safety and ecological security through chemical pesticide reduction, thereby contributing to agricultural sustainability. While existing research has acknowledged the influence of information factors on farmers' pesticide reduction behavior, there remains a lack of comprehensive consideration of multiple information acquisition channels. The differential impacts and underlying mechanisms among these channels require further exploration. This study focuses on cash crops with higher chemical pesticide usage, utilizing field survey data from 573 peach farmers across seven province-level regions (including provinces, autonomous regions, and municipalities) in China in 2023 to assess the impact of information acquisition channels on farmers' chemical pesticide reduction behavior. The results indicate the following: (1) Information acquisition channels significantly promote farmers' implementation of chemical pesticide reduction behavior. (2) Information acquisition channels encourage the adoption of agricultural and biological control technologies, but have no significant impact on physical control technologies. (3) Information acquisition channels have a more substantial impact on older farmers and those in the eastern-central regions compared to other demographic groups. (4) Information acquisition channels alter farmers' risk preferences, thereby facilitating chemical pesticide reduction behavior. Based on the above conclusions, government agencies should diversify information acquisition channels and enhance the dissemination of information related to chemical pesticide reduction. Furthermore, given the characteristics of different green control technologies, government agencies should select appropriate information acquisition channels to conduct targeted promotion and outreach to farmers.

Keywords: information acquisition channels; chemical pesticide reduction behavior; risk preferences; green control technology; peach farmer

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1. Introduction

Pesticides are an indispensable input in modern agriculture, serving a critical role in controlling crop diseases and pests, ensuring food security, and securing the stable supply of essential agricultural commodities. However, excessive or improper use of chemical pesticides can lead to food safety problems, contribute to non-point source pollution, and even endanger public health [1]. These consequences directly contradict the objectives of sustainable development. In China, the farming sector remains predominantly composed

of smallholder farmers, who have long relied on excessive use of chemical pesticides to achieve high yields [2]. According to statistics, in 2020, China's pesticide usage reached 248,200 tons, with pesticide application per unit area being 3.9 times the world average—far exceeding levels in developed countries like France and Japan [3].

The European Commission adopted the Sustainable Use of Pesticides Regulation in June 2022, aiming to reduce chemical pesticide use by 50% by 2030 [4]. However, concerns over crop yields, economic stability, and overall food security ultimately led to the proposal being shelved [5]. On 7 February 2024, the European Parliament adopted the European Commission's (EC) legislative proposal on plants developed using new genomic technologies (NGTs), easing restrictions in the field of agricultural biotechnology. This move seeks to establish a new equilibrium between innovation, sustainability, and safety regulation [6,7]. In China, in November 2022, the Ministry of Agriculture and Rural Affairs of the People's Republic of China issued the Action Plan for Chemical Pesticide Reduction by 2025, setting different reduction targets for grain crops and cash crops. Notably, for high-value cash crops such as fruits, vegetables, and tea, the plan aims to reduce chemical pesticide use intensity by 10% compared to the baseline during the 13th Five-Year Plan period, a target that is more ambitious than that set for grain crops. In August 2024, the Central Committee of the Communist Party of China and the State Council jointly released the Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development, which explicitly calls for the continuous promotion of reduction and efficiency enhancement of agricultural inputs, including pesticides. From a technical perspective, the policy document explicitly emphasizes shifting away from over-reliance on chemical pesticides for pest and disease control, and adhering to the principles of targeted intervention, simultaneous addressing of symptoms and root causes, and integrated management. International experience indicates that policy enforcement and technological innovation are key drivers for reducing chemical pesticide use, though they also face resistance from farmers and cost pressures. China, grounded in its smallholder farming context, is exploring sustainable development pathways under decentralized farming conditions through a combined strategy of "policy guidance + technology adaptation + livelihood security."

Regarding specific measures, many countries including Germany and the United States promote Integrated Pest Management (IPM), which employs a combination of strategies such as crop rotation, introduction of natural enemies, and cultivation of resistant varieties to reduce chemical pesticide usage [8]. Considering China's agricultural development context, the term "chemical pesticide reduction behavior" employed in this study refers to the behavior of adjusting agricultural production methods in accordance with crop growth laws, controlling and minimizing the total amount of chemical pesticides applied to achieve adequate disease, pest, and weed control effectiveness. Currently, the primary measures can be categorized into three types of green control technologies: agricultural control technologies, physical control technologies, and biological control technologies [9,10]. These represent the deepening, expansion, and localized implementation of the Integrated Pest Management (IPM) concept. These technologies can maintain crop yields while reducing farmers' reliance on chemical pesticides through factor substitution. This approach makes them a key focus in current initiatives for agricultural green development, particularly in achieving pesticide reduction and efficiency enhancement. However, green control technologies are characterized by high costs, complex operations, and uncertain outcomes, with longer time lags before observable effectiveness compared to chemical pesticide control. Consequently, many farmers are reluctant to adopt these technologies or even avoid them altogether, leading to low adoption rates [11]. As of 2023, the coverage rate of green control measures for major crop pests and diseases in China

stands at only 54.1% [12]. Given this situation, identifying the key factors influencing farmers' chemical pesticide reduction behavior has become critical for advancing agricultural sustainable development.

As direct participants in agricultural production, farmers' pest and disease control behavior determines the intensity of chemical pesticide use within a region. Scholars have conducted in-depth research on chemical pesticide reduction behavior from various dimensions. Important influencing factors include individual characteristics such as age, gender, social identity, risk preference, and education level [13,14]; household endowments including operational scale, family size, and income level [15,16]; and external factors such as government regulations and market conditions [17–19].

Some scholars have focused on the role of information [9,20]. In real-world agricultural production settings, information is often asymmetric, making it difficult for farmers to access complete information [21]. Moreover, disparities in knowledge, capabilities, capital, and social status result in varying abilities to process information [22]. Consequently, farmers are often constrained to make production decisions based on limited information. Information acquisition channels serve as crucial pathways through which farmers obtain information. These channels perform essential functions in the process of information acquisition [23]. As vehicles for information transmission, they provide diverse sources of information and knowledge that support production decisions, thereby helping to reduce the cost of information acquisition and enhance farmers' management decisions. Meanwhile, farmers use multiple information sources that may be complementary or substitutes to each other, and this also implies that any single source does not satisfy all information needs of the farmer [24].

Different sources of information shape farmers' decisions in distinct ways [25]. Traditional smallholder farmers have limited access to information, primarily obtaining it from books, newspapers, and neighboring farmers [26]. Scholars have found that organizational channels, such as agricultural cooperatives and government agencies, are positively correlated with farmers' adoption of green agricultural technologies [27]. Regarding new media channels, the popularization and use of smartphones and other devices can help farmers access more information [28]. Accessing information via the Internet facilitates decision-making among farmers regarding chemical pesticide reduction behavior [29,30]. Other studies have identified an inverted U-shaped relationship between farmers' internet usage duration and the adoption of green control technologies [11]. At the same time, pesticide dealers exert significant influence over farmers' pesticide application behavior [31]. Supporting this, Diemer et al. found that pesticide dealers serve as a crucial source of information for Ugandan farmers [32].

In addition, scholars have devoted considerable attention to evaluating the effectiveness of different information acquisition channels. Villamil et al. asked farmers in Illinois to evaluate and rank these channels, finding that agricultural organizations, agricultural newsletters as well as other farmers and neighbors serve as the primary channels of agricultural information [33]. Furthermore, studies have shown that farmers' access to information through the internet and participation in training programs can significantly increase the adoption of green production technologies. Among these, internet-based information channels have been found to be particularly effective [34,35]. Compared to traditional information channels, modern information channels can reduce farmers' reliance on chemical inputs such as fertilizers and pesticides [36]. In summary, each information acquisition channel has distinct advantages and limitations, and the effectiveness of information dissemination varies depending on the socio-economic context of the target region and the characteristics of the local farming population [37].

In summary, existing research provides important references for the relationship between information acquisition channels and chemical pesticide reduction behavior, but the role of different channels remains controversial. Second, most studies have focused on farmers' behavioral decision-making in adopting green agricultural technologies, with fewer studies concentrating on farmers' implementation of chemical pesticide reduction behavior. Furthermore, prior research on chemical pesticide reduction behavior has not explored the mechanisms by which information acquisition channels influence it. For farmers, their risk preferences are one of the key factors. Finally, past studies on information acquisition channels and farmers' behavior have not emphasized the types of crops they cultivate.

This study utilizes survey data collected from 573 peach farmers across seven major peach-producing provinces (autonomous regions, municipalities) in China: Guangxi, Sichuan, Guizhou, Zhejiang, Shanghai, Hubei, and Hebei. We measure chemical pesticide reduction behavior by the adoption of agricultural, physical, and biological control technologies. By employing both binary Probit and ordered Probit models, the study assesses the impact of information acquisition channels on farmers' chemical pesticide reduction behavior. The primary contributions of this study are as follows: First, we fully consider the diversity of information acquisition channels and emphasize the differences in the roles of various channels. Second, by incorporating risk preference into the analytical framework, it elucidates the underlying mechanisms through which information acquisition channels affect farmers' decisions on chemical pesticide reduction. Third, compared to grain crops, cash crops (especially perennial fruit trees) exhibit a higher dependence on chemical pesticides. Due to their extended production cycles, complex pest and disease situation, and stringent market demands for product appearance, they present greater potential and urgency for pesticide reduction. This study focuses on peach farmers, extending pesticide reduction research from field grain crops to more complex technical and decision-making contexts. This focus not only reveals unique pesticide reduction drivers specific to fruit tree cultivation systems but also provides theoretical insights and practical paradigms for the green transition of similar high-input cash crops globally.

2. Theoretical Analysis and Research Hypotheses

2.1. Information Acquisition Channels and Chemical Pesticide Reduction Behavior

The diffusion of innovations theory posits that the spread of an innovation is a dynamic social process shaped by multiple factors, including the attributes of the innovation itself, communication channels, the time dimension, the structure of the social system, and individual differences [38]. Information acquisition channels refer to the pathways through which farmers actively or passively obtain information that supports their production activities and daily life. Enhanced access to information on chemical pesticide reduction, particularly through diversified channels, facilitates more scientific and rational decision-making. In rural China, farmers acquire information not only via traditional channels such as newspapers and books, but also through organizational channels like village committees and cooperatives, as well as from agricultural input retailers and manufacturers. With the advancement of digital technologies and increasing internet accessibility, new media channels are playing an increasingly significant role in information dissemination. With its high penetration rate and interactivity, new media is profoundly reshaping the traditional information power structure in rural areas—transforming it from the former top-down, one-way communication model into a multi-directional, interactive network connecting farmers, experts, and markets. This shift not only significantly broadens farmers' access to information but also provides them with actionable knowledge and direct market access tools through intuitive formats like videos and live streaming. Overall, farmers with

access to a greater variety of information acquisition channels tend to have broader social networks and more favorable conditions for obtaining information, thereby improving the timeliness and accuracy of the information they receive [39].

According to bounded rationality theory, individuals do not pursue absolutely optimal solutions in the decision-making process; instead, they seek satisfactory solutions under the constraints of incomplete information and cognitive limitations. Rational farmers will systematically consider existing information resources and prudently evaluate behavioral consequences before implementing chemical pesticide reduction behavior [40]. Throughout this process, the collection, filtering, and interpretation of information can reshape subjective norms, such as social perceptions and value judgments, and subsequently influence behavioral decisions. Hence, this study further examines the relationship between information acquisition channels and farmers' chemical pesticide reduction behavior. First, information acquisition channels provide farmers with improved access to agricultural production knowledge and policy insights, enabling a systematic understanding of the safety risks associated with pesticide overuse and promoting the concept of agricultural green development. Second, these channels facilitate the acquisition of practical knowledge and operational skills related to green control technologies, thereby enhancing farmers' technical capacity and adoption motivation. Third, diversified information sources help reduce information search costs, bridge the information gap between small-scale farmers and modern agricultural systems, and optimize the allocation of agricultural resources, including chemical pesticides [26]. Fourth, information acquisition channels can reshape farmers' expectations regarding the market prospects of green agricultural products, alleviate information asymmetry in production and marketing, and improve anticipated market returns. Such economic incentives further encourage farmers to reduce chemical pesticide use. Therefore, it can be hypothesized that a wider variety of information acquisition channels increases the probability of farmers' chemical pesticide reduction behavior. Accordingly, the following research hypothesis is proposed:

H1. *Information acquisition channels have a significant positive effect on farmers' chemical pesticide reduction behavior.*

2.2. The Intermediary Role of Risk Preference

Beyond pursuing profit maximization, risk minimization is also a critical production decision-making objective for farmers [41]. Risk preference refers to an individual's willingness to accept and approach to managing risk, serving as a key antecedent factor in behavioral decision-making [42]. It is one aspect of human personality that can manifest differently across various domains [43]. Furthermore, risk preference exhibits situational dependence and dynamic plasticity, particularly when an individual's knowledge, resources, and external environment change. Information acquisition channels mitigate farmers' risk aversion by providing opportunities to learn new technologies and access markets, thereby promoting pesticide reduction behavior. This has systematically altered farmers' risk preferences in this specific domain.

First, these channels provide opportunities to learn new technologies. Their core function lies in transforming unknown production risks into known, controllable, and trustworthy pathways, thereby reducing uncertainty. The behavior of reducing chemical pesticides places high demands on practitioners, requiring not only accurate identification of pests and diseases but also an understanding of the applicable scenarios for green control technologies. Improper application of these technologies may lead to the opposite of the intended control effect. On one hand, information acquisition channels leverage visualization methods (such as short videos and demonstration field observations) to achieve cognitive

restructuring, transforming abstract technologies into concrete operational procedures. This directly alleviates farmers' fear of technical complexity. On the other hand, interactive training and expert support networks build farmers' self-efficacy, shifting their mindset from the anxiety of "not being able to learn" to the confidence in "being able to master it." This significantly enhances their willingness to tolerate operational risks.

Second, these channels provide opportunities to access markets. Exposure to and processing of market information help enhance farmers' ability to obtain information. According to existing research, farmers with stronger information acquisition abilities are more likely to prefer risk [44]. Meanwhile, in traditional agricultural decision-making, farmers' greatest concern regarding green technologies lies in the inability to secure stable returns after incurring investment costs. Information acquisition channels can provide farmers with clear pricing data, sales channels, and demand insights, thereby reducing profit compression and misjudgments of market trends caused by delayed market information. This, in turn, lowers their aversion to market risks. This psychological shift from loss aversion to gain pursuit is precisely the core of altering risk preferences.

In decision-making regarding chemical pesticide reduction behavior, farmers with high risk preferences typically possess greater psychological resilience and hold a more positive attitude toward risk [45]. They can leverage the advantages of resource endowments, self-organizing ability, and learning ability to respond to challenges. In contrast, farmers with low risk preferences often lack the ability to manage risk and often perceive risk as uncontrollable [42]. This risk-averse tendency significantly inhibits their willingness to implement chemical pesticide reduction behavior. Based on this reasoning, we propose the following research hypothesis:

H2. *Information acquisition channels have a significant positive effect on chemical pesticide reduction behavior by altering farmers' risk preferences.*

Based on the above research hypothesis, the theoretical model is shown in Figure 1.

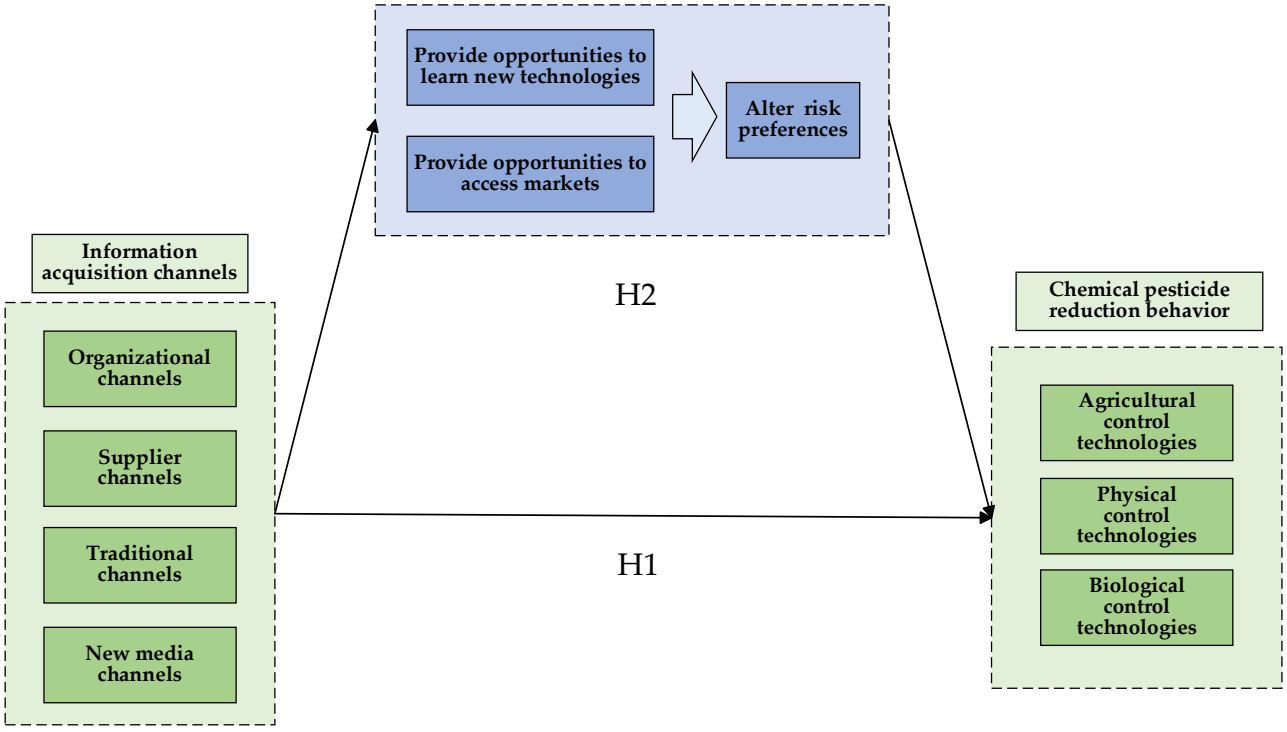


Figure 1. Theoretical model.

3. Materials and Methods

3.1. Data Collection and Analysis

The research data were collected through an on-site survey of peach farmers conducted in 2023 by the research team of the National Peach Industry Technology System in China. The survey covered seven representative province-level regions, including Guangxi Zhuang Autonomous Region, Sichuan Province, Guizhou Province, Zhejiang Province, Shanghai Municipality, Hubei Province, and Hebei Province. These areas span the three major geographical regions of China: the eastern region (Zhejiang and Shanghai), the central region (Hubei and Hebei), and the western region (Guangxi, Sichuan, and Guizhou). This broad coverage ensures representation of diverse industrial scales and regional characteristics.

The sampling methodology employed a multi-stage stratified random sampling approach. First, we selected 1–3 major peach-producing counties (districts) in each province in consultation with industry experts. Second, we randomly selected 1–3 townships from each sampled county (district). Third, 1–3 administrative villages were randomly selected from each township, and 10–15 farming households were randomly chosen from each sampled village for face-to-face interviews. The survey questionnaire covered individual and family characteristics, basic information on peach production, chemical pesticide reduction behavior, and primary information acquisition channels. To ensure questionnaire quality, systematic training on the survey content was provided to the researchers before the fieldwork began. A total of 621 questionnaires were collected. After excluding those with missing key information or internal inconsistencies, 573 valid questionnaires were retained, with an efficiency of 92.27%.

3.2. Variable Settings

3.2.1. Dependent Variables

The dependent variable in this study is chemical pesticide reduction behavior, which is measured through the adoption of three categories of green control technologies: agricultural control technologies (e.g., orchard grass planting), physical control technologies (e.g., colored sticky traps, insecticidal lamps) and biological control technologies (e.g., biopesticides, natural enemies of insects). The adoption of each green control technology is represented by a binary variable (1 = adopted, 0 = not adopted). The decision to adopt one or more of these technologies is defined as implementing chemical pesticide reduction behavior, whereas non-adoption indicates no implementation. The three binary indicators are then summed to create an index ranging from 0 to 3, reflecting the degree of implementation. It should be noted that the core of this index lies in measuring the diversity of farmers' adoption behaviors of green control technologies, rather than assuming complete additivity or equivalence among different technologies. From the perspective of overall management of the agricultural ecosystem, adopting multiple green control technologies typically produces synergistic and complementary effects, helping to control pests and diseases more stably, sustainably, and thereby more effectively replacing chemical pesticides [46].

3.2.2. Independent Variables

The independent variable in this study is information acquisition channels. Drawing on existing literature and considering the characteristics of the survey sample [27,34], these channels are classified into four categories: organizational channels, supplier channels, traditional channels, and new media channels. Organizational channels include cooperative organizations, village committees, and government agricultural technology extension agencies. Supplier channels comprise agricultural input manufacturers and agricultural input retailers. Traditional channels consist of print media such as newspapers and books,

as well as village broadcasts. New media channels include social media (e.g., WeChat, QQ), digital television, and short-video platforms (e.g., TikTok). Responses from respondents to the question "Which of the above channels do you frequently use to obtain agricultural technical information?" served as the basis for assigning values to the information acquisition channel variable, where a value of 1 is assigned if a channel was used to obtain agricultural technical information, and 0 otherwise. Next, the number of specific channels included in each category, namely organizational channels, supplier channels, traditional channels, and new media channels, is aggregated separately to serve as the value of the respective category information acquisition channels variable, with value ranges of 0–3, 0–2, 0–2, and 0–3, respectively. Finally, the values of these four variables are summed to calculate the total value of the information acquisition channels variable, with values assigned on a scale of 0 to 10.

3.2.3. Mechanism Variables

The mechanism variable in this study is risk preference. Farmers' risk preferences are measured by their attitudes toward the adoption of green control technologies, based on the following response options: would only consider adoption after most others have used it successfully and all risks are eliminated, or would still not adopt = 1; would consider adoption as long as some other users have succeeded, even if certain risks remain = 2; would be willing to try the technology if the potential benefits are high, even if the risks are significant = 3. A higher value indicates a greater degree of risk preference.

3.2.4. Control Variables

Farmers' decision-making behavior is influenced by a multitude of factors. It is generally recognized that both individual and family characteristics shape their behavioral choices. This study selects the following individual characteristics: gender, age, education level, peach planting experience, political profile, and whether the farmer serves as a village cadre. Family characteristics include peach planting scale, labor endowment, peach sales revenue, whether agricultural insurance is purchased, and whether the agricultural products are certified under the "San pin yi biao" system (representing standardized, pollution-free, green, organic, and geographically identified agricultural products). In the regression analysis, both peach planting scale and peach sales revenue are log-transformed. The specific assignment and descriptive statistics of each variable are shown in Table 1.

Table 1. Variable assignment and descriptive statistics.

Variable Category	Variable Name		Variable Assignment	Mean	Standard Deviation
Dependent variables	Chemical pesticide reduction behavior	Implementation degree	The total adoption of green control technologies: 0–3	0.894	0.895
		Agricultural control technology	Yes = 1; no = 0	0.136	0.343
		Physical control technology	Yes = 1; no = 0	0.265	0.442
		Biological control technology	Yes = 1; no = 0	0.492	0.500

Table 1. *Cont.*

Variable Category	Variable Name		Variable Assignment	Mean	Standard Deviation
Independent variables	Information acquisition channels	Organizational channels	Do you obtain agricultural technical information from cooperative organizations: yes = 1; no = 0	0.321	0.467
			Do you obtain agricultural technical information from village committees: yes = 1; no = 0	0.539	0.499
			Do you obtain agricultural technical information from government agricultural technology extension agencies: yes = 1; no = 0	0.646	0.479
		Supplier channels	Do you obtain agricultural technical information from agricultural input manufacturers: yes = 1; no = 0	0.353	0.478
			Do you obtain agricultural technical information from agricultural input retailers: yes = 1; no = 0	0.522	0.500
		Traditional channels	Do you obtain agricultural technical information from newspapers or books: yes = 1; no = 0	0.192	0.394
			Do you obtain agricultural technical information from village broadcasts: yes = 1; no = 0	0.150	0.357
		New media channels	Do you obtain agricultural technical information through social media: yes = 1; no = 0	0.839	0.367
			Do you obtain agricultural technical information through digital television: yes = 1; no = 0	0.403	0.491
			Do you obtain agricultural technical information through short-video platforms: yes = 1; no = 0	0.068	0.252
Mechanism variables	Risk preference		Would only consider adoption after most others have used it successfully and all risks are eliminated, or would still not adopt = 1; Would consider adoption as long as some other users have succeeded, even if certain risks remain = 2; Would be willing to try the technology if the potential benefits are high, even if the risks are significant = 3	2.000	0.883

Table 1. *Cont.*

Variable Category	Variable Name		Variable Assignment	Mean	Standard Deviation
Control variables	Individual characteristics	Gender	Male = 1; female = 0	0.805	0.397
		Age	Actual age of interviewee (year)	54.630	9.301
		Education level	Primary school and below = 1; junior high school = 2; high school = 3; junior college = 4; university and above = 5	2.208	0.905
		Peach planting experience	Years of peach planting (year)	19.743	12.314
		Political profile	Party members = 1; non-members = 0	0.365	0.482
		Village cadre	Whether to serve as a village cadre: yes = 1; no = 0	0.192	0.394
	Family characteristics	Peach planting scale	Peach planting scale (mu)	31.312	66.727
		Labor endowment	Number of laborers engaged in agricultural production (person)	2.263	1.863
		Peach sales revenue	Total income of peach planting in households of farmers (10000 yuan)	16.480	36.232
		Agricultural insurance	Whether to purchase agricultural insurance: yes = 1; no = 0	0.258	0.438
		"San pin yi biao"	Yes = 1; no = 0	0.396	0.490

3.3. Model Settings

3.3.1. Binary Probit Model

The dependent variable in this study is whether farmers implement chemical pesticide reduction behavior, which is represented as a binary (0–1) variable. Following established scholarly practices [47], a binary Probit model is employed to estimate the influence of information acquisition channels on chemical pesticide reduction behavior. The model is specified as follows:

$$D_i = \alpha_0 + \alpha_1 X_i + \alpha_2 Control_i + \sigma_i \quad (1)$$

In Equation (1), D_i represents whether farmer i implements chemical pesticide reduction behavior, X_i represents the information acquisition channels, $Control_i$ represents the control variables, α_0 is the constant term, α_1, α_2 are parameters to be estimated, and σ_i represents the random disturbance term.

3.3.2. Ordered Probit Model

The dependent variable, the implementation degree of farmers' chemical pesticide reduction behavior, is an ordered categorical variable. In accordance with established research methodologies [48], this study employs an ordered Probit model for empirical analysis. The model is specified as follows:

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 Control_i + \delta_i \quad (2)$$

In Equation (2), Y_i represents the implementation degree of chemical pesticide reduction behavior by farmer i, X_i represents the information acquisition channels, $Control_i$ represents the control variables, β_0 is the constant term, β_1, β_2 are parameters to be estimated, and δ_i represents the random disturbance term.

3.3.3. Mechanism Analysis Model

To examine the pathways through which information acquisition channels influence farmers' chemical pesticide reduction behavior, this study draws on existing research

and employs a two-step modeling approach [49]. The first-step model is the same as Equation (2). The second-step model is specified as follows:

$$M_i = a_0 + a_1 X_i + a_2 \text{Control}_i + \varepsilon_i \quad (3)$$

In Equation (3), M_i represents the risk preference of farmer i, X_i represents the information acquisition channels, Control_i represents the control variables, a_0 is the constant term, a_1, a_2 are parameters to be estimated, and ε_i represents the random disturbance term.

4. Results

4.1. Baseline Regression

Since multicollinearity may exist among variables, a multicollinearity test was conducted prior to regression. The results showed that the variance inflation factors (VIFs) of each variable were much less than 10, indicating that there was no severe multicollinearity among the variables. To examine the impact of information acquisition channels on farmers' chemical pesticide reduction behavior, this study employs both binary Probit and ordered Probit models for estimation. As shown in Columns (1) and (2) of Table 2, information acquisition channels have a statistically significant positive effect at the 1% level on both the implementation decision and degree of chemical pesticide reduction behavior. This suggests that farmers with access to more information acquisition channels are more likely to implement chemical pesticide reduction behavior and implement it to a greater degree, thus supporting H1.

Regarding different types of information acquisition channels, Columns (3) and (4) in Table 2 demonstrate that organizational channels exert a significant positive influence on both the implementation decision and degree at the 1% level. In contrast, supplier channels exhibit a significant negative effect on both outcomes at the 1% level. Two possible explanations are proposed for this negative relationship. First, in information-constrained rural environments, the complexity of pest and disease control and the diversity of control measures often render local experiential knowledge inadequate. Agricultural input retailers are frequently perceived as primary information sources in plant protection. Driven by profit maximization, these retailers may occasionally encourage increased chemical pesticide use. Under asymmetric information, farmers often passively follow their recommendations, which undermines motivation to reduce chemical pesticide use through green control technologies. Second, chemical pesticide sales remain a core profit source for agricultural input manufacturers. Widespread adoption of green control technologies would directly reduce chemical pesticide sales. Manufacturers tend to present a one-sided portrayal of green technologies, emphasizing higher costs compared to conventional chemical pesticides while downplaying environmental benefits. Moreover, field demonstrations organized by manufacturers often highlight the rapid effectiveness of chemical pesticides, making farmers more inclined to choose chemical pesticides as a solution for pest and disease control. Traditional channels show a significant positive effect on the implementation decision at the 1% level and on the implementation degree at the 10% level. Similarly, new media channels have significant positive effects on the implementation decision at the 5% level and on the implementation degree at the 10% level. These findings indicate that, with the exception of supplier channels, organizational, traditional, and new media channels all effectively disseminate information and promote chemical pesticide reduction among farmers.

Regarding the control variables, education level, peach planting scale, and certification under the "San pin yi biao" program significantly promote chemical pesticide reduction

behavior. Farmers with higher levels of education tend to possess greater knowledge and a broader understanding, making them more inclined to adopt greener behavior in pest and disease control. Furthermore, a larger planting scale is accompanied by lower unit costs, thus realizing economies of scale. Moreover, agricultural products certified under the "San pin yi biao" program require compliance with residue limits and quality safety standards, and the resulting price premium can offset the higher costs of green technologies, creating an economic incentive for farmers to reduce chemical pesticide use.

Table 2. Baseline regression.

Variables	(1)	(2)	(3)	(4)
	Implementation Decision	**Implementation Degree**	**Implementation Decision**	**Implementation Degree**
Information acquisition channels	0.134 ***	0.083 ***		
	(0.033)	(0.026)		
Organizational channels			0.292 ***	0.254 ***
			(0.067)	(0.055)
Supplier channels			−0.348 ***	−0.274 ***
			(0.084)	(0.066)
Traditional channels			0.308 ***	0.146 *
			(0.113)	(0.087)
New media channels			0.174 **	0.132 *
			(0.083)	(0.068)
Gender	−0.007	0.046	0.047	0.069
	(0.152)	(0.125)	(0.156)	(0.126)
Age	−0.016 **	−0.013 **	−0.018 **	−0.015 **
	(0.007)	(0.006)	(0.008)	(0.006)
Education level	0.138 *	0.169 ***	0.100	0.139 **
	(0.079)	(0.062)	(0.081)	(0.063)
Peach planting experience	−0.013 **	−0.009 *	−0.017 ***	−0.011 **
	(0.006)	(0.005)	(0.006)	(0.005)
Political profile	0.145	0.179	0.182	0.210 *
	(0.138)	(0.114)	(0.142)	(0.116)
Village cadre	0.257	0.212	0.340 *	0.241 *
	(0.172)	(0.134)	(0.178)	(0.135)
Peach planting scale	0.155 *	0.178 **	0.155 *	0.181 **
	(0.089)	(0.073)	(0.091)	(0.074)
Labor endowment	0.016	0.039	0.010	0.026
	(0.045)	(0.028)	(0.052)	(0.028)
Peach sales revenue	0.024	0.053	0.004	0.037
	(0.074)	(0.062)	(0.076)	(0.062)
Agricultural insurance	0.110	0.242 *	0.045	0.145
	(0.162)	(0.128)	(0.175)	(0.136)
"San pin yi biao"	0.600 ***	0.399 ***	0.748 ***	0.512 ***
	(0.143)	(0.114)	(0.149)	(0.116)
Observations	573	573	573	573
LR chi2	131.9	181.6	175.6	221.8
Pseudo R^2	0.171	0.131	0.228	0.160

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In contrast, age and peach planting experience significantly inhibit chemical pesticide reduction behavior. Older farmers tend to be less receptive to new ideas and technologies and may have lower learning ability. Farmers with longer experience in peach planting tend to rely more heavily on conventional chemical pesticide control, which may discourage their implementation of chemical pesticide reduction behavior.

4.2. Robustness Test

To verify the robustness of the aforementioned findings, this study replaces the empirical models used in the analysis. Specifically, binary Logit and ordered Logit models are employed instead of binary Probit and ordered Probit models to re-estimate the relationships. The robustness check results, presented in Table 3, remain consistent with the baseline regression.

Table 3. Robustness test results 1.

Variables	(1)	(2)	(3)	(4)
	Implementation Decision	**Implementation Degree**	**Implementation Decision**	**Implementation Degree**
Information acquisition channels	0.237 ***	0.130 ***		
	(0.059)	(0.045)		
Organizational channels			0.498 ***	0.409 ***
			(0.115)	(0.096)
Supplier channels			−0.601 ***	−0.494 ***
			(0.145)	(0.113)
Traditional channels			0.554 ***	0.276 *
			(0.200)	(0.151)
New media channels			0.321 **	0.217 *
			(0.143)	(0.118)
Control variables	YES	YES	YES	YES
Observations	573	573	573	573
LR chi2	133.7	179.8	179.2	221.1
Pseudo R^2	0.173	0.130	0.232	0.160

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Considering that farmers aged 70 and above may differ from younger farmers in terms of physical and cognitive capacities, we excluded these older individuals and re-estimated the models. The results presented in Table 4 demonstrate that information acquisition channels maintain a statistically significant positive influence on farmers' chemical pesticide reduction behaviors. This finding provides further evidence supporting the robustness of our baseline regression.

Table 4. Robustness test results 2.

Variables	(1)	(2)	(3)	(4)
	Implementation Decision	**Implementation Degree**	**Implementation Decision**	**Implementation Degree**
Information acquisition channels	0.138 ***	0.085 ***		
	(0.034)	(0.027)		
Organizational channels			0.274 ***	0.241 ***
			(0.068)	(0.056)
Supplier channels			−0.316 ***	−0.251 ***
			(0.084)	(0.067)
Traditional channels			0.276 **	0.126
			(0.115)	(0.089)
New media channels			0.213 **	0.155 **
			(0.085)	(0.069)
Control variables	YES	YES	YES	YES
Observations	544	544	544	544
LR chi2	110.3	158.1	147.3	192.8
Pseudo R^2	0.152	0.120	0.203	0.146

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$.

When analyzing the impact of information acquisition channels on farmers' chemical pesticide reduction behavior, it is necessary to consider the potential endogeneity issues arising from reverse causality and omitted variables. This study selects "the average number of information acquisition channels among other farmers in the same village (excluding the farmer himself)" as the instrumental variable for information acquisition channels. The IV-Probit model was used to examine the implementation decision, while the 2SLS model was used to assess the implementation degree, with the results presented in Table 5.

Table 5. Robustness test results 3.

Variables	IV-Probit		2SLS	
	Phase I Information Acquisition Channels	Phase II Implementation Decision	Phase I Information Acquisition Channels	Phase II Implementation Degree
Information acquisition channels		0.471 ***		0.216 **
		(0.082)		(0.093)
Instrumental variable	0.578 ***		0.578 ***	
	(0.095)		(0.096)	
Control variables	YES	YES	YES	YES
Observations	573	573	573	573
F-value	36.13		36.13	
Wald test of exogeneity	9.84 ***			
Durbin-Wu-Hausman			4.60 **	

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$.

The first-stage F-value of both models exceeded the critical value of 10, and the instrumental variable passed the significance test at the 1% level. Additionally, the second-stage Wald test and the Durbin-Wu-Hausman test were statistically significant at the 1% and 5% levels, respectively, indicating the validity of the instrumental variable. The second-stage regression results show that the sign and significance level of the coefficient for information acquisition channels are basically consistent with the baseline regression. These results suggest that, after addressing endogeneity through the instrumental variable approach, information acquisition channels still exert a statistically significant positive impact on both farmers' implementation decision and the degree of implementation, further validating H1.

4.3. Further Analysis

To further compare the heterogeneous effects of information acquisition channels on the adoption of agricultural, physical, and biological control technologies, and, considering that farmers' choices among these three green control technologies are not independent but correlated, this study employs a multivariate Probit model, drawing on relevant literature [50,51]. The estimation results are presented in Tables 6 and 7.

Overall, information acquisition channels significantly promotes the adoption of agricultural and biological control technologies, but not physical control technologies. When examined by channel type, the institutional credibility of organizational channels substantially mitigates information asymmetry for farmers, thereby significantly promoting adoption of all three technologies. In contrast, supplier channels significantly inhibit the adoption of physical control technologies. As previously discussed, suppliers such as agricultural input retailers and manufacturers tend to recommend that farmers use chemical pesticides for pest and disease control. Traditional channels significantly promote the adoption of biological control technologies, possibly because compared to physical control technologies, biological control technologies especially biopesticides have been more widely promoted and adopted among farmers, and traditional media

may still play a role in disseminating relevant information. Finally, new media channels, characterized by convenience and timeliness, facilitate the adoption of physical control technologies by helping farmers promptly address issues related to input procurement and equipment operation.

Table 6. Impact of information acquisition channels on the adoption of different green control technologies.

Variables	(1)	(2)	(3)
	Agricultural Control Technology	**Physical Control Technology**	**Biological Control Technology**
Information acquisition channels	0.075 *	−0.019	0.154 ***
	(0.041)	(0.033)	(0.032)
Control variables	YES	YES	YES
Observations		573	
Wald chi2		256.2	

Standard errors in parentheses; *** $p < 0.01$, * $p < 0.1$.

Table 7. Impact of multiple information acquisition channels on the adoption of different green control technologies.

Variables	(1)	(2)	(3)
	Agricultural Control Technology	**Physical Control Technology**	**Biological Control Technology**
Organizational channels	0.205 **	0.214 ***	0.206 ***
	(0.087)	(0.072)	(0.064)
Supplier channels	−0.085	−0.459 ***	−0.078
	(0.105)	(0.087)	(0.077)
Traditional channels	−0.041	−0.118	0.374 ***
	(0.148)	(0.116)	(0.107)
New media channels	0.124	0.153 *	0.116
	(0.110)	(0.091)	(0.080)
Control variables	YES	YES	YES
Observations		573	
Wald chi2		291.8	

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4. Heterogeneity Analysis

4.4.1. Age Differences

With economic and social development, China's agricultural labor force is increasingly aging and exhibits intergenerational divergence. Older and younger generations of farmers differ in knowledge, skills, values, and production habits, leading inevitably to differences in production decision-making. Based on the age classification standards of the World Health Organization (WHO), this study divides farmers into a younger group and an older group using 60 years as the threshold. Regression results are presented in Table 8.

Columns (1) and (2) show that for the younger group, the effect of information acquisition channels is not statistically significant. When examined by channel type, organizational channels show a significant positive effect at the 1% level, while supplier channels show a significant negative effect, also at the 1% level. A possible explanation is that younger farmers tend to rely on fixed information sources, so the number of channels does not positively influence the degree of their chemical pesticide reduction behavior. Nevertheless, the authoritative nature of organizational channels remains effective in promoting pro-environmental decisions.

Table 8. Regression results for farmers of different age groups.

Variables	(1)	(2)	(3)	(4)
	Implementation Degree			
	The Younger Group		The Older Group	
Information acquisition channels	0.025		0.251 ***	
	(0.030)		(0.055)	
Organizational channels		0.195 ***		0.399 ***
		(0.065)		(0.117)
Supplier channels		−0.281 ***		−0.288 **
		(0.077)		(0.135)
Traditional channels		0.121		0.262
		(0.103)		(0.176)
New media channels		0.010		0.519 ***
		(0.080)		(0.138)
Control variables	YES	YES	YES	YES
Observations	391	391	182	182
LR chi2	100.8	124.0	73.59	94.45
Pseudo R^2	0.104	0.128	0.191	0.245

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$.

Columns (3) and (4) indicate that for the older group, information acquisition channels have a significant positive effect at the 1% level. This suggests that, compared to younger farmers, older farmers exhibit a higher degree of implementation of chemical pesticide reduction behavior when they have access to more information channels. When examined by channel type, both organizational channels and new media channels show significant positive effects at the 1% level, whereas supplier channels show a significant negative effect at the 5% level. A possible explanation is that older farmers have greater trust in official information from organizational channels and are more willing to implement recommended production behavior after receiving technical guidance. Meanwhile, new media channels offer timely informational support, which can reduce perceived uncertainties associated with new technologies and help compensate for age-related limitations in learning ability.

4.4.2. Region Differences

Based on the geographical locations of the surveyed provinces, this study divides the sample into western and eastern-central regions. Guangxi Zhuang Autonomous Region, Sichuan Province, and Guizhou Province are classified as the western region, while Zhejiang Province, Shanghai Municipality, Hubei Province, and Hebei Province are categorized as the eastern-central region. The regression results are presented in Table 9.

Columns (1) and (2) show that in the western region, the impact of information acquisition channels on chemical pesticide reduction behavior is not statistically significant. Two possible reasons are proposed. First, some information channels rely on face-to-face communication, but the mountainous and hilly terrain in the western region hinders transportation and reduces the frequency of interaction, thereby limiting the amount of information accessible to farmers. Second, due to farmers' generally low educational levels, more information acquisition channels may actually raise the difficulty of discerning reliable information, thereby failing to enhance the implementation degree of chemical pesticide reduction behavior. When examined by channel type, the effects of organizational channels and supplier channels are consistent with the baseline regression. However, traditional channels exhibit a significant negative impact. A potential explanation is that farmers in the western region demonstrate lower receptiveness to new ideas and

approaches than those in the eastern-central region. This tendency is further reinforced by the fact that traditional channels in these areas primarily disseminate information on chemical pesticide application. Meanwhile, the impact of new media channels on chemical pesticide reduction behavior is not statistically significant. This may be attributed to the underdeveloped telecommunications infrastructure in western regions due to challenging topography, resulting in limited network coverage. Coupled with farmers' generally low educational attainment, the effectiveness of new media channels remains limited.

Table 9. Regression results for farmers in different regions.

Variables	(1)	(2)	(3)	(4)
	Implementation Degree			
	Western Region		Eastern-central Region	
Information acquisition channels	−0.046		0.300 ***	
	(0.035)		(0.051)	
Organizational channels		0.243 **		0.339 ***
		(0.100)		(0.079)
Supplier channels		−0.311 ***		−0.207 *
		(0.110)		(0.118)
Traditional channels		−0.240 *		0.525 ***
		(0.131)		(0.136)
New media channels		0.114		0.227 *
		(0.098)		(0.116)
Control variables	YES	YES	YES	YES
Observations	231	231	342	342
LR chi2	30.36	44.29	189.8	217.3
Pseudo R^2	0.0617	0.0900	0.235	0.269

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Columns (3) and (4) indicate that in the eastern-central region, information acquisition channels have a significant positive effect on chemical pesticide reduction behavior. The results across different types of channels are largely consistent with the baseline regression: organizational, traditional, and new media channels show significant positive effects, whereas supplier channels continue to inhibit chemical pesticide reduction behavior. This suggests that, compared to mountainous and hilly areas, plain regions possess more developed infrastructure and more suitable conditions for technology application.

4.5. Mechanism Analysis

With reference to the testing procedures proposed by existing scholars, this study focuses on the causal relationship between the core independent variable and the mediating variable, while the impact of the mediating variable on the dependent variable should be direct and evident. The mechanism analysis results on the role of risk preference in the relationship between information acquisition channels and farmers' chemical pesticide reduction behavior are presented in columns (1) and (2) of Table 10. The coefficient for the effect of information acquisition channels on risk preference is 0.057, which is statistically significant at the 5% level. This indicates that information acquisition channels can positively influence farmers' chemical pesticide reduction behavior by altering their risk preferences. This result supports H2.

Table 10. Test results of mediating effects.

Variables	(1)	(2)
	Implementation Degree	Risk Preference
Information acquisition channels	0.083 ***	0.057 **
	(0.026)	(0.028)
Control variables	YES	YES
Observations	573	573
LR chi2	181.6	49.88
Pseudo R^2	0.131	0.0407

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$.

5. Discussion

First, the more information acquisition channels farmers have access to, the higher the likelihood and the greater the degree of implementing chemical pesticide reduction behavior. When examined by channel type, organizational, traditional, and new media channels all show significant positive effects on chemical pesticide reduction behavior, which aligns with previous findings [27]. Scholars hold divergent views regarding the role of supplier channels. Some studies suggest that obtaining information from agricultural input retailers can facilitate chemical pesticide reduction [52], while others argue that, driven by commercial incentives, these retailers may recommend higher doses or more types of agrochemicals even when accurately diagnosing pests and diseases [53]. This study confirms the information dissemination function of supplier channels to farmers, aligning with existing research [32]. However, it reveals a negative correlation between supplier channels and farmers' chemical pesticide reduction behavior, indicating that the issue of excessive recommendations persists in China's peach industry. Addressing the excessive profit-seeking tendency is necessary for supplier channels to play a positive role in chemical pesticide reduction.

Furthermore, this study examines the relationship between information channels and three distinct green control technologies, considering their differing attributes. The results indicate that information acquisition channels promote the adoption of agricultural and biological control technologies, but have no significant effect on physical control technologies. This discrepancy may be attributable to the following reasons. The adoption barriers for agricultural and biological control technologies primarily stem from their high technical complexity and uncertain long-term returns. Conversely, the core barrier to physical control technologies lies in their high upfront costs. The adoption of such technologies heavily relies on farmers' own capital or external subsidies. In this context, the primary function of information acquisition channels is to convey technical application methods and related cost information to farmers, thereby helping overcome cognitive barriers. However, when faced with tight budget constraints and a lack of subsidies, information acquisition channels cannot fundamentally alleviate farmers' financial pressure. In the channel-specific analysis, organizational channels have a significant positive impact on all three types of green control technologies. Traditional channels and new media channels facilitate the adoption of biological control technologies and physical control technologies, respectively, while supplier channels inhibit the adoption of physical control technologies.

Heterogeneity analyses based on the age differences among farmers and region differences illustrate that older farmers and those located in the eastern-central regions are more significantly influenced by the number of such channels. The positive impact on the elderly population corroborates existing research [34]. However, unlike previous studies [36], this research reveals that information acquisition channels exert a more pronounced

influence on farmers in eastern-central regions. This discrepancy may stem from variations in geographical divisions and crop types. Furthermore, compared to inputs such as seeds, chemical fertilizers, and pesticides, green pest control technologies present certain technical barriers. These findings underscore the importance of tailoring information delivery methods to the specific needs and capabilities of different age groups as well as regional differences.

The mechanism analysis indicates that risk preference serves as a key mechanism through which information acquisition channels influence chemical pesticide reduction behavior. Simultaneously, unlike previous studies that primarily focused on perceived risk [54], this research places greater emphasis on the mutability and multifaceted nature of farmers' risk preferences in the context of technology adoption. While information may not fundamentally alter farmers' innate personalities, it can partially and contextually alter their risk preferences within specific domains. Enhanced knowledge and a stronger sense of control over chemical pesticide reduction practices correlate positively with a higher willingness to take risks.

This study has several limitations that warrant future improvement. First, the use of a single ordinal item with only three categories to measure risk preferences is relatively one-dimensional, as it primarily reflects farmers' risk preferences in adopting green control technologies. Future research could further categorize risk preferences into multiple dimensions, such as financial risk, production risk, and social risk, to enhance the validity of risk preference measurement. Second, since the data were sourced from farmers' self-reports and lacked external validation, there may be a risk of social desirability bias. Third, aggregating the three types of green control technologies as a measure of the extent of chemical pesticide reduction may overlook the heterogeneity among these technologies, including differences in cost and effectiveness. Future studies could conduct more detailed analyses tailored to the specific characteristics of different green control technologies. Fourth, the findings, based on a study of peach farmers in seven provinces in China, may have limited generalizability to other crops or regions, and factors such as regional culture, social equity, and technology accessibility were not considered. Future research will encompass diverse crops and geographical areas and incorporate the aforementioned factors to verify the robustness of the conclusions.

6. Conclusions and Policy Recommendations

Based on 2023 field survey data from 573 peach farmers across seven province-level regions in China, our study assesses the impact of information acquisition channels on farmers' chemical pesticide reduction behavior. It finds that information acquisition channels significantly promote farmers' chemical pesticide reduction behavior. Specifically, these channels effectively encourage the adoption of agricultural and biological control technologies (with no notable impact on physical control technologies) and exert a stronger influence on older farmers and farmers in eastern–central regions. Mechanistically, these channels alter farmers' risk preferences, thereby driving pesticide reduction behavior.

On the basis of the above conclusions, the following policy recommendations can be drawn.

First, diversify information acquisition channels to enhance farmers' motivation for chemical pesticide reduction. On one hand, agricultural technology extension agencies, cooperative organizations and agricultural input retailers should be transformed into physical nodes for technical services. Through field demonstrations, personalized pesticide application plans, and the establishment of a village-level technical broker system, farmers' doubts about technical feasibility can be resolved. On the other hand, it is essential to fully leverage the strengths of new media channels in precision dissemination and effi-

cient interaction. By creating high-quality instructional demonstration videos, practical operation animations, and illustrated guides to farming knowledge, complex green control technologies can be transformed into intuitive and accessible visual content. Additionally, establishing real-time feedback mechanisms through live Q&A sessions and online community forums can further enhance engagement and effectiveness.

Second, enhance the dissemination of chemical pesticide reduction information to alter farmers' risk preferences. Beyond clarifying the urgency of reduction and ecological benefits of green technologies, it is vital to address concerns about technical efficacy and economic returns. Agricultural extension departments should develop standardized materials, such as technical specifications, cost–benefit analyses, and regional success cases, to help alleviate farmers' apprehensions regarding technological uncertainties and long payback periods. In parallel, targeted subsidies should be implemented to ease cost pressures and incentivize the adoption of green control technologies.

Third, select the appropriate information acquisition channels based on the characteristics of different green control technologies. Promotion strategies should be designed with consideration for the complexity of green control technologies and differences in farmers' learning abilities, and tailored to local conditions. Social networks can be leveraged to strengthen communication, while agricultural input retailers and manufacturers should be better regulated and guided to serve as key nodes in the supply and extension chain. Moreover, regional disparities between eastern, central, and western China must be taken into account. In less developed and remote areas, collective action can be promoted through cooperatives and village-level service stations. In more developed regions with better infrastructure, new media channels such as social media and short-video platforms can be utilized for precise and effective dissemination of green control technologies.

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Institutional Review Board Statement: According to Article 32 of the Administrative Measures for Ethical Review of Life Science and Medical Research Involving Humans in China, studies utilizing human data or biospecimens—which do not cause harm to individuals, involve sensitive personal information or commercial interests, or employ anonymized data—may be exempt from ethical review (https://www.gov.cn/zhengce/zhengceku/2023-02/28/content_5743658.htm, accessed on 20 October 2025). Our study did not require further ethics committee approval, as it involved no animal or human clinical trials and posed no ethical risks. In accordance with Article 1035 of the Civil Code of the People's Republic of China (https://www.moj.gov.cn/pub/sfbgw/zwgkztzl/2025nianzhuanti/2025mfdxcy/2025mfdxcy_mfdql/202505/t20250507_518708.html, accessed on 20 October 2025), the collection and use of personal information in this study were conducted with verbal consent from the participants. All information will be kept strictly confidential, and participation is entirely voluntary.

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