# Pesticide reduction: Technical preference and influencing factors of rice farmers in China

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**Research Article**

**Keywords:** pesticide reduction, technical preference, influencing factors, rice farmers, China

**Posted Date:** May 31st, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1552109/v1

# Pesticide reduction: Technical preference and influencing factors of rice farmers in China

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**Abstract:** Based on the successful experience of pesticide reduction in China. This study uses survey data from Hubei Province to measure farmers' preferences for pesticide reduction technologies considering their needs, and compare the heterogeneous factors influencing farmers' adoption decisions. The results show that larger-scale farmers prefer drone services and efficient machinery, while smaller-scale farmers prefer scientific standards and biopesticides for pesticide reduction. Second, farmers' adoption behavior of pesticide reduction technologies is mostly influenced by education, risk attitude, income, agricultural labor, scale, rice price, residue testing, brand, training, subsidy, and demonstration. Among them, education, risk attitude, scale, rice price, cost, and training significantly affect farmers' adoption level of multiple pesticide reduction technologies. Further, higher rice prices and participation in training could promote the use of pesticide reduction technologies on a larger area by farmers. Therefore, the real needs of farmers should be focused on the promotion of pesticide reduction technologies. And pesticide reduction programs in different regions should carry out precise intervention policies. These findings can provide practical policy guidance for effective pesticide reduction in developing countries.

**Key words**: pesticide reduction; technical preference; influencing factors; rice farmers; China

## 1. Introduction

Excessive and inefficient use of chemical pesticides is common in many developing countries, although the use of pesticides is still an important measure of pest management (Sun et al., 2020; Huang et al., 2021). For a long time, humans have used chemical pesticides in large quantities to stabilize and improve crop yields and solve basic survival problems. But the characteristics of chemical pesticides are high toxicity, easy residue, difficulty to degrading, as well as pest resistance, and other problems, not only seriously endanger human health, but also cause ecological damage and environmental pollution (Gould et al., 2018; Luo et al., 2021). Therefore, how work on chemical pesticide reduction is the common goal of countries around the world to achieve sustainable, low-carbon, and green development in agriculture in recent decades (Wossink, 2007; Lévesque et al., 2021). For example, Japan has developed a hierarchical Japanese Agriculture Standard, which has greatly encouraged farmers to use as few pesticides as possible. Australia is early to realize the development of organic farming and carbon sink farming. And agricultural subsidies are linked to agricultural environmental assessment in Europe.

In order to achieve pesticide reduction goals, scholars have made valuable arguments about how to incentivize agricultural producers to use fewer pesticides. On the one hand, scholars have focused on increasing the adoption of biopesticides, green control technologies, and integrated pest management (IPM) by farmers to replace the use of highly chemical pesticides. For example, Petrescu-Mag et al. (2019) investigated farmers' willingness to pay for biopesticides. Gao et al. (2017) explored the adoption of green control technologies in Chinese family farms. And Wyckhuys et al. (2021) also call for the worldwide insistence on promoting IPM in agriculture to achieve pesticide reductions. On the other hand, scholars have explored the factors that lead to the overuse and misuse of pesticides by farmers. Yang et al. (2019) found that unfriendly green agricultural markets and imperfect policies are the main driving factors of pesticide overuse for farmers. Sun et al. (2019) found that the lack of individual knowledge and ability of farmers and the imperfect agricultural extension services are important reasons for farmers' misuse of pesticides. The above research undoubtedly plays an important role in guiding the reduction of pesticides in agricultural production practices around the world.

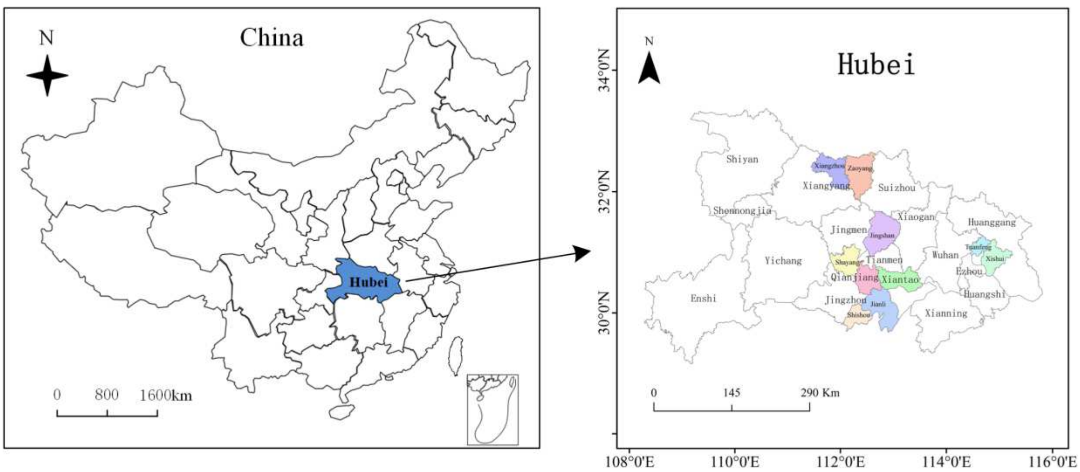
China, the world's largest producer and consumer of pesticides, but at the same time also made greater achievements in pesticide reduction after 2015. Data from China's National Bureau of Statistics show that the average annual use of pesticides for crop pest control in China from 2012 to 2014 was 311,000 tons, an increase of 9.2% from 2009 to 2011. The average utilization rate of pesticides is only 35%, which leads to very serious pollution of the soil and water environment. Therefore, the Chinese government recognizes the urgency of pesticide reduction. In 2015, the Ministry of Agriculture and Rural Affairs issued a notice to all provinces and regions to actively implement the "zero growth" pesticide use program. Promote diversified pesticide reduction technologies while respecting farmers' true wishes. Since 2015, the use of pesticides in China has been on a downward trend, and the effect of pesticide reduction is remarkable. Why has China been able to achieve pesticide reductions smoothly and effectively? What experiences can be used as a reference for other developing countries?

With the success of pesticides reduction in China since 2015, this study uses data from a survey of rice farmers in Hubei Province, China to focus on answering two questions: which pesticides reduction technologies do farmers prefer? What factors influence farmers' pesticides reduction technology adoption decisions? Distinguishing from the previous literature, the main contributions of this paper are as follows: First, many previous studies have focused on the supply side of agricultural extension and have only isolated the adoption behavior of farmers for a single pesticide reduction technology, which ignores the real needs of farmers themselves. Because there are many pesticide reduction technologies to choose from in practice, and farmers' technology adoption preferences are heterogeneous(Bazoche et al., 2011; Lévesque et al., 2021). For example, it is not mandatory for all farmers to adopt biopesticides. Therefore, The Weighted Frequency Approach has been used to measure the priority order of farmers' technology adoption preferences for pesticide reduction. Second, Different pesticide reduction technologies will be applied to different groups of farmers, and thus there are potential differences in the factors influencing their adoption. We then use the Heckman model to compare the factors influencing the adoption of various pesticide reduction technologies to improve the applicability of the technologies. The answers to the above two questions are beneficial to the development of actionable regional pesticide reduction plans based on respect for the true wishes of farmers.

# 2. Materials and Methods

### *2.1 Survey Data*

Hubei Province is one of the most famous grain production bases in China, and its Jianghan Plain in the Yangtze River Basin produces a large amount of rice for domestic consumption. Since 2015, Hubei Province has also achieved success in pesticide reduction, attributed to the agricultural management issuing guidance programs to farmers on the implementation of pesticide reduction technologies for major food crops. The pesticide reduction technology has also been made a key component of agricultural extension. So, Hubei Province is a representative region for our study of pesticide reduction experiences in China. Members of the research team selected a total of ten cities (counties) from the major rice-growing regions in Hubei Province in July 2021, according to the principle of stratified random sampling in Xiantao, Qianjiang, Jingshan, Shayang, Zaoyang, Xiangzhou, Jianli, Shishou, Xishui, and Tuanfeng (Fig.1). Then, 10-20 villages are randomly selected from each city (county), and 10-15 rice growers are selected from each village for investigation. We finally succeeded in obtaining 1193 valid data that could be used for empirical analysis. It is worth noting that in order to make our samples more representative and practical reference, the selection of study sample areas refers to the official list of green control pilot counties[①] published by the Chinese Ministry of Agriculture and Rural Affairs. The survey questionnaire mainly included farmers' personal characteristics, family characteristics, and production management characteristics. Among them, the focus was on collecting detailed data on rice farmers' pesticides inputs and reduction technologies adoption. In order to guarantee the scientific data collection, we pre-trained all investigators to make the perception of questionnaire items consistent. In addition, we collected some photographic and audio materials from the survey site.




[①] For a detailed list, see the website (https://www.natesc.org.cn/).

**Figure 1** Distribution of study areas

*Notes*: Different colors represent the geographic locations where samples are obtained, and only up to the city (county) level are indicated here.

## *2.2 Model*

**(1)** The Weighted Frequency Approach (WFA) has been used to measure the priority order of rice farmers' technology adoption preferences for pesticide reduction. First, we need to define the categories of pesticide reduction technologies. Drawing on the official document "Zero Growth Action Plan for Pesticide Use by 2020" issued by China's Ministry of Agriculture and Rural Affairs. Pesticide reduction techniques are grouped into four categories: Control, Replacement, Precision, and Unification (CRPU). See Table 1 for a detailed description.

**Table 1** Categories of pesticide reduction technologies in China

| Category | Definition | Technology |
| --- | --- | --- |
| Control | That is, to achieve sustainable control of pesticides. Promote green control techniques to create environmental conditions conducive to crop growth, natural enemy protection, and pests suppression. | • Ecological control<br>• Physical trapping |
| Replacement | That is, biopesticides instead of chemical pesticides, efficient machinery instead of small inefficient machinery. The purpose is to expand the use of low toxicity pesticides and improve the efficiency of pesticide use. | • Biopesticides<br>• Efficient machinery |
| Precision | That is, to achieve the precise use of pesticides. The focus is on the accurate identification of pests and the use of suitable doses of pesticides at the right time. Avoid farmers misusing pesticides. | • Scientific standard |
| Unification | That is, to achieve unified pest control. Support specialized service organizations for pest control, to solve the difficulties of scattered smallholder farmers' pesticide use. | • Drone service |

*Notes*: Official policy text are available at http://www.zzys.moa.gov.cn/gzdt/201503/t20150318_6309945.htm. The "Technology" column in the table only lists some typical examples of pesticide reduction technologies in rice cultivation, but not all. Biological control specifically refers to the ecosystem consisting of rice, ducks, lobsters and frogs. Efficient machinery refers to large electric or oil pesticide spraying machinery.

Second, pesticide reduction technology preference ranking was collected from rice farmers. The questionnaire was designed with items to allow each farmer to rank the above six technologies in order of their need from 1-6 (1 = strong preference and 6 = no preference at all). Finally, the cumulative sample size of each pesticide reduction technology in order of 1-6 is used to measure the composite score of demand preference for each technology. The calculation formula is as follows:

$$Z_k = \sum_{n=1}^{N} w_n R_n \quad (1)$$

Where, $Z_k$ represents the composite score of demand preference for the $k$th technology. $R_n$ and $w_n$ are the cumulative frequencies and weights for the $n$th ranking of this technology, respectively. To avoid the errors associated with individual subjective assignments, we use equidistant assignments. That is, $w_n = (7-n)/6$. Then, the ascending order of $Z_k$ is used to determine the priority of farmers' pesticide reduction technology preferences.

(2) The Heckman model will be used to estimate the factors affecting the adoption of pesticide reduction technologies among rice farmers. This model can not only argue the factors influencing farmers' adoption (or not) of pesticide reduction technology, but also analyze the factors influencing the level (proportion) of technology adoption. And Heckman model can deal with the potential self-selection and endogeneity problems (Heckman and Richard, 1985). First of all, We construct a model of the factors influencing pesticide reduction technology adoption among rice farmers based on previous scholarly research (Fig. 2).

These factors mainly contain personal factors, family factors, production management factors, market factors, and policy factors (Grovermann et al., 2017; Pan et al., 2021; Zhao et al., 2021). As for personal factors, we selected four important indicators: age, gender, education, and risk attitude. These factors are considered to influence the production habits and cognitive level of farmers, which further affects their pesticide use decisions (Khan and Damalas, 2015; Huang et al., 2021). As for family factors, income, agricultural labor, and children were chosen. Among them, income and children members of the family influenced farmers' consumer demand for high-quality agricultural products (Benoît et al., 2020). Agricultural labor is also the key to influencing the efficiency of pesticide use (Guo et al., 2020). And the scale and cooperative organization were chosen as production management factor variables because of the presence of scale effects (Qin and Lv, 2020). In addition, market factors are directly related to the production benefits of farmers and are the source of farmers' decisions. For example, residue testing could reveal whether an agricultural product exceeds pesticide standards, and branding can effectively convey information about product quality (Yang et al. 2019). Similarly, agricultural extension policies have a non-negligible role in guiding and regulating the adoption of pesticide reduction techniques by China farmers (Sun et al., 2020).

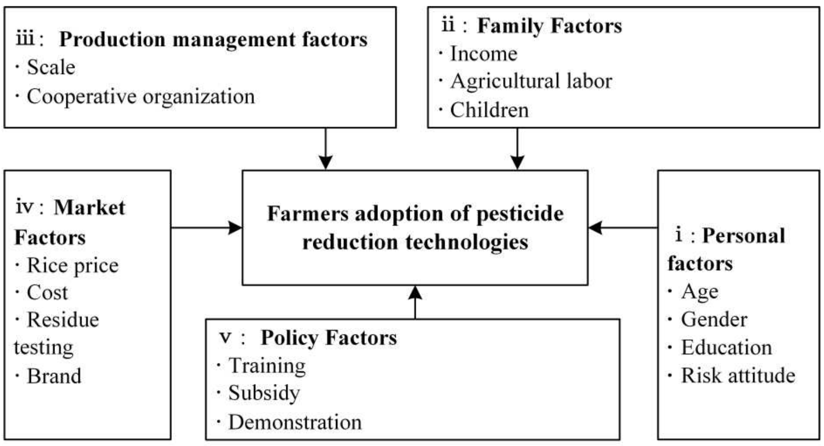



**Figure 2** Model of factors influencing farmers adoption of pesticide reduction technologies

*Notes*: The figure refers only to the listing of the main influencing variables.

Then, We need to construct a two-stage Heckman model using the above variables. The first stage was to use a Logit model to estimate the factors that whether rice farmers adopt pesticide reduction technologies.

$$\text{Logit}\ (A_i^1) = \log\ \left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 Personal_i + \beta_2\, Family_i + \beta_3 Produce_i + \beta_4 Market_i + \beta_5 Policy_i + \mu_i \quad (2)$$

Where, $A_i^1$ and $p$ denote the behavior and probability of adoption of pesticide reduction technologies by farmers $i$th, respectively. $\beta_i$ is the impact coefficient of each factor to be estimated. $\beta_0$ is the intercept term and $\mu_i$ is the random error of the model. In further estimating the factors influencing the degree of adoption of pesticide reduction technologies, the problem of self-selection bias of the sample needs to be addressed. We need to obtain the inverse Mills ratio in the first stage estimation, obtained by dividing the density function of the normal distribution with the cumulative distribution function.

$$\varphi = \emptyset(\hat{\sigma}X_i)/\partial(\hat{\sigma}X_i) \tag{3}$$

Then, the second stage equation has been constructed substituting $\varphi$ as the independent variable and using OLS to estimate the factors influencing the level of farmers' adoption of pesticide reduction technologies.

$$A_i^2 = \alpha_0 + \alpha_1 Personal_i + \alpha_2 Family_i + \alpha_3 Produce_i + \alpha_4 Market_i + \alpha_5 Policy_i + \alpha_6\varphi + \varepsilon_i \tag{4}$$

Where, $A_i^2$ is the level of farmer's adoption of pesticide reduction technologies. That is, $A_i^2 = m/6$, and $m$ refers to the number of pesticide reduction technologies adopted by the $i$th rice farmer. Similarly, $\alpha_i$ is the impact coefficient of each factor to be estimated. $\alpha_0$ is the intercept term and $\varepsilon_i$ is the random error. The definitions and statistical descriptions of all variables in the model are shown in Table 2.

**Table 2** Definition and description of variables

| Variables | Definition and assignment | Average | S.D. |
|---|---|---|---|
| Dependent variables | | | |
| Adoption behavior | Whether the rice farmer adopts any pesticide reduction technology in CRPU: Yes=1, no=0 | 0.816 | 0.102 |
| Adoption level | The level of farmer's adoption of pesticide reduction technologies | 0.122 | 0.059 |
| Independent variables | | | |

| | | | |
|---|---|---|---|
| Age | Age of the interviewee (year) | 58.695 | 10.320 |
| Gender | Gender of the interviewee: Male=1, female=0 | 0.718 | 0.107 |
| Education | Number of years of education of the interviewee (year) | 7.325 | 3.008 |
| Risk attitude | Risk preference of interviewees: Risk averse=1, neutral=2, risk like=3 | 1.625 | 0.354 |
| Income | Total income of family members in 2020 (million yuan) | 10.045 | 8.733 |
| Agricultural labor | Number of laborers engaged in agricultural production in the household | 1.748 | 0.592 |
| Children | Are there any children under 6 years old in the household: Yes=1, no=0 | 0.312 | 0.127 |
| Scale | Scale of rice cultivation (ha) | 1.807 | 0.563 |
| Organization | Whether to participate in professional farmer cooperative organizations of rice: Yes=1, no=0 | 0.219 | 0.094 |
| Rice price | Average price of rice marketed for sale in 2020 (yuan/kg) | 2.171 | 0.282 |
| Cost | Average cost of rice pest control in 2020 (million yuan/ha) | 0.128 | 0.023 |
| Residue testing | Whether the rice sold is tested for pesticide residues: Yes=1, no=0 | 0.074 | 0.009 |
| Brand | Whether the produced rice has a brand: Yes=1, no=0 | 0.061 | 0.028 |
| Training | Whether to participate in technical training on pesticide reduction: Yes=1, no=0 | 0.433 | 0.150 |
| Subsidy | Whether to receive subsidies for adopting pesticide reduction technologies: Yes=1, no=0 | 0.150 | 0.082 |
| Demonstration | Is there a demonstration base of pesticide reduction technology in the vicinity: Yes=1, no=0 | 0.378 | 0.109 |
| Region | Sample farmers belong to the study area: Jingzhou=1, others=0 | 0.101 | 0.435 |

*Notes*: The data in the table are counted from 1193 survey questionnaires. 1 ha = 15 mu in China. Due to the differences of economic and cultural levels in different regions, we control the regional variables in the form of virtual variables. Here we only take Jingzhou as an example.

# 3. Results and Discussion

## *3.1 Pesticide Reduction in China*

Since 2012, the Chinese government has attached great importance to ecological and environmental issues and formulated a "greening" development strategy, introducing a series of laws, strategies, and policies. And in 2015, the Ministry of Agriculture and Rural Affairs implemented the "Zero Growth Action Plan for Pesticide Use by 2020" in order to reduce the number of pesticides. From Fig. 3(a), it can be seen that the growth of pesticide use in China's agricultural production was significantly controlled after 2015. In addition, the data in Fig. 3(b) show that the growth rates of total pesticide use in China in 2015, 2016, 2017, 2018, and 2019 were -1.13%, -2.41%, -4.89%, -9.12%, and -6.72%, actually exceeding "zero growth" and achieving "negative growth", the effect of pesticide reduction is very significant. And some forecast data show that the rate of pesticide reduction in China will continue to be maintained in the coming decades. As the world's largest producer and consumer of pesticides, China's successful experience in controlling the growth of pesticide use rapidly and effectively has some practical reference value.

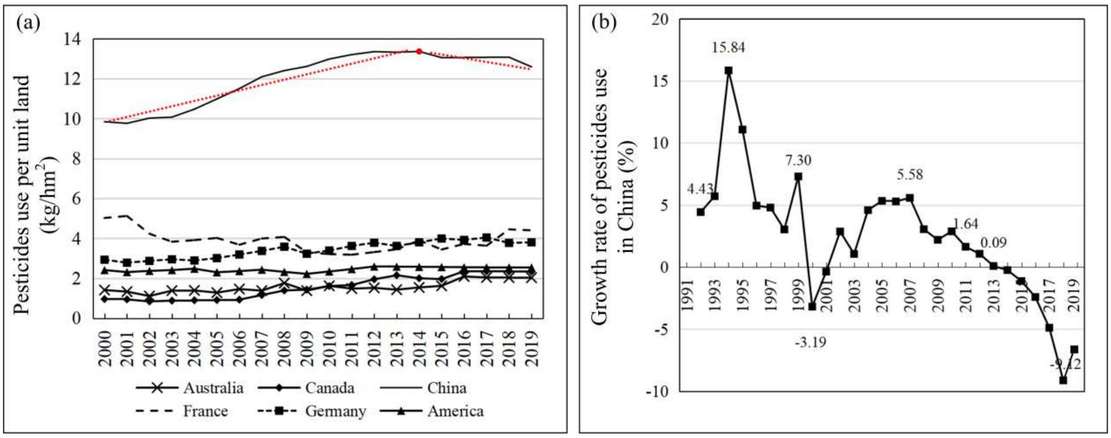



**Figure 3** Pesticide use in China and other developed countries

*Notes*: The data in (a) are from FAO (https://www.fao.org/); the red dot on the black line of pesticide use in China is the highest point, and the red dashed line is the trend line of change. The data in (b) are from CNBU (http://www.stats.gov.cn/); the growth rate is the growth amount in the next year divided by the pesticide use in the previous year.

### *3.2 Results of technology preference prioritization*

We obtained the pesticide reduction technology adoption preference priority order of rice farmers using the WFA. The results can be seen in Fig.4. First, the sample statistics from the 1-6th order of the single technology demand preference in Fig.4(a) show that the scientific standard is placed in an important position, with the largest sample size in the first and second positions. In the actual survey, farmers have elaborated their willingness to follow pesticide labels for the scientific use of pesticides in order to meet the national policy of pesticide reduction. Second, the composite scores of the pesticide reduction technologies in Fig.4(b) are in descending order: Scientific standard > Biopesticides > Efficient machinery > Ecological control > Physical trapping > Drone service. That is, following scientific application standards is still the most preferred method of pesticide reduction by rice farmers. Third, we grouped statistics on pesticide reduction technology preferences of rice farmers of different scales and found differences. Large-scale farmers prefer to select drone service and efficient machinery to achieve pesticide reduction. While Small-scale farmers prefer to select scientific standard and biopesticides.

The above results are valuable for guiding the reduction of pesticides in practice. On the one hand, it is fundamental and important to follow scientific standards for pesticide application, especially for small-scale farmers. Many scholars have pointed out that overuse, misuse, and ineffective use of pesticides due to non-compliance with scientific standards of pesticide labels on the timing, dosage, variety, and function of pesticides are common in developing countries (Sun et al., 2019; Huang et al., 2021; Bagheri et al., 2021). Due to the limitations of farmers' own literacy, cognitive level, and pesticide knowledge skills, farmers do not fully rely on their own production experience to effectively control pests (Petrescu-Mag et al., 2019). Farmers' own experience is even called a "bad habit" for pesticides application (Wang et al., 2018). On the other hand, differentiated pesticide reduction technology extension activities should be carried out to meet the real needs of farmers of different scales. Large-scale farmers have a large demand for drone services and efficient machinery out of the need to save labor costs and improve production efficiency (Qin and Lv, 2020). In contrast, small-scale farmers need to bear larger transaction and negotiation costs in using large machinery (Gao et al., 2021).

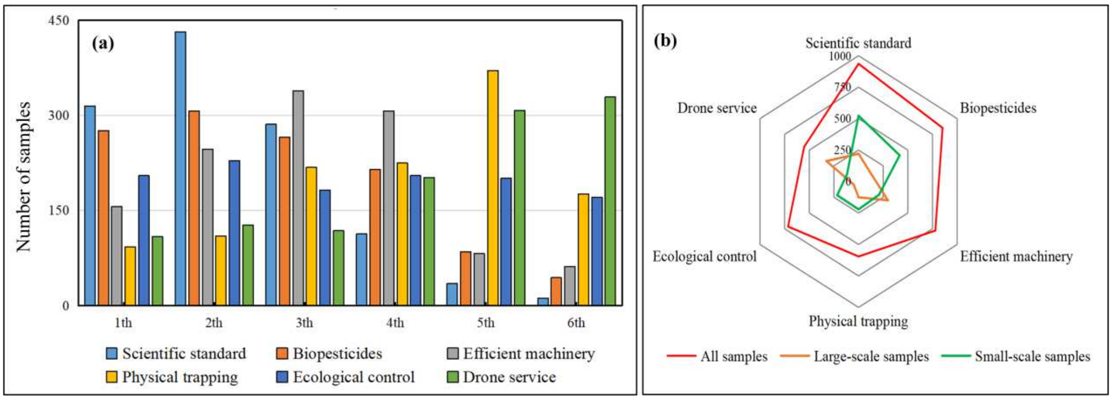



**Figure 4** Pesticide reduction technology preference scores of samples

*Notes*: Figure (a) is the distribution of preference scores for pesticide reduction technologies. (b) is the composite score of each technology calculated by WFA. And the full sample is divided into two subsamples, large-scale and small-scale, according to the 1 ha threshold for recounting.

### *3.3 Estimation results of factors influencing the adoption of pesticide reduction technology*

The variables defined above were put into Eq.(2) in order to explore the factors affecting farmers' choice of pesticide reduction technologies. First, we tested the variables in the model for covariance by the variance inflation factor values to rule out possible serious covariance problems among the variables. Next, the coefficients of the model were estimated in Stata software using Logit robust estimation to avoid heteroskedasticity problems due to model omission of important variables or sample outliers. The factors influencing the adoption behavior of the six pesticide reduction technologies among the sample farmers were regressed in turn (Table 3), and the estimated results of the model coefficients were more reliable as indicated by the overall test Wald values of the regression results of each model.

(1) Farmer characteristics variables affecting adoption of pesticide reduction technologies. There is a significant negative effect of interviewee age on the adoption of biopesticides and scientific standards. This is because the older the farmer is the more profoundly influenced by the

traditional crude chemical pesticide use habits (Bagheri et al., 2021). The effect of gender on scientific standards is significantly negative. It indicates that women are more concerned about the normative use of pesticides attributed of their concerns about the quality of food (Khan and Damalas, 2015). The effect of education on the adoption of multiple pesticide reduction technologies is significantly positive. This validates the emphasis of Yang et al.(2014) on the importance of education in guiding the regulation of pesticide use by farmers. Risk attitude had a positive effect on ecological control and on physical trapping, but a negative effect on scientific standard. Ecological and physical control are typical emerging green control technologies, which require "adventurers" to make brave attempts (Gao et al., 2017). In contrast, risk-averse farmers are more likely to use chemical pesticides beyond standards (Salazar and Rand, 2020). Similarly, farmers in high-income households are more likely to reduce pesticides. The results also show that families with children are more likely to use biopesticides and follow scientific standards. Because they have a greater demand for high-quality agricultural products. This is to protect their own and their families health from pesticide poisoning (Benoît et al., 2020). In addition, the scale has a significant positive impact on the adoption of efficient machinery and drone service. This suggests that such socialized services are more likely to be favored by large-scale farmers. And large and efficient pesticide spraying machinery is mostly occupied by cooperative organizations in practice. This shows that pesticide reduction is more likely to be achieved by promoting efficient machinery and drone services to cooperatives and large-scale farmers (Huang et al., 2021).

(2) Market variables affecting farmers' adoption of pesticide reduction technologies. Rice prices have a significant positive impact on rice farmers' adoption of ecological control and scientific standards. Rice produced with fewer pesticides is given the attribute characteristic of

"green", which could achieve higher market prices and consumer favors (Yang et al. 2019). Of course, some high-value rice production also sets strict production standards for the use of chemical pesticides (Sun et al., 2020). Pest management costs have a significant negative impact on rice farmers' adoption of ecological control and efficient machinery. This is because ecological control and the introduction of efficient machinery require farmers to bear high costs, such as the purchase of specialized equipment, raw materials, and fuel (Gao et al., 2021). Residue testing has a significant positive impact on rice farmers' adoption of biopesticides and scientific standards. Pesticide residue testing is the main means of identifying the quality and safety of agricultural products. Importantly, the use of highly toxic chemical pesticides is the main cause of pesticide residues (Gould et al., 2018). And the use of pesticides in accordance with scientific standards, or the use of biopesticides, can undoubtedly reduce pesticide residues. In addition, agricultural product brands benefit rice farmers in adopting ecological control, biopesticides, and scientific standards. The construction of agricultural product brands needs to follow certain production standards, especially the prohibition of the use of highly toxic chemical pesticides. This can not only increase the premium of the agricultural product brand, but also maintain its long-term reputation of the brand (Li and Guo, 2019).

(3) Policy variables affecting farmer's adoption of pesticide reduction technologies. Technical training has a significant positive impact on the adoption of pesticide reduction technologies for rice farmers, in addition to efficient machinery and drone services. By conducting technical training and guidance, agricultural extension personnel can effectively solve the difficulties encountered by farmers in the actual application of pesticide reduction technology and maximize the guarantee of technical effects (Wuepper et al., 2021). In addition, technical training

is also conducive to the improvement of farmers' pesticide awareness levels and the accumulation of pest and disease knowledge and skills (Sun et al., 2019). Subsidies have a significant positive impact on the rice farmers' adoption of physical trapping, efficient machinery, and drone services. This is due to the Chinese government's strong support and promotion of efficient machinery and drone services in recent years. Policy subsidies can effectively reduce the acquisition cost of pesticide reduction technologies and weaken the probability of risk loss from the uncertainty of technology use on economic returns (Li et al., 2018). The technology demonstration has a significant positive impact on the rice farmers' adoption of biological control, physical trapping, biopesticides, and drone services. Because technology demonstration for farmers can directly observe the use of the technology and its economic benefits, provide reference advice to neighboring farmers, and eliminate the "worries" in farmers' minds (Pan et al., 2021).

Finally, it should be emphasized that regional variables also have a significant impact on the rice farmers' adoption of ecological control, efficient machinery, and drone services. This shows that many of China's pesticide reduction technology promotion methods have typical regional characteristics. That is to say, the focus of technology promotion in different regions is different. Combined with the reality of our survey, most hills similar to Huanggang City in Hubei Province, China, are not suitable for the promotion of large machinery and drone service technology. In contrast, areas with many rivers compared to plains are suitable for promoting ecological control, such as the rice and lobster co-farming model in Qianjiang City, Hubei Province.

**Table 3** Estimation of factors influencing farmers' adoption of pesticide reduction technology

| Variables | M1: Ecological control | M2: Physical trapping | M3: Biopesticides | M4: Efficient machinery | M5: Scientific standard | M6: Drone service |
|---|---|---|---|---|---|---|
| | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) |
| Age | -0.290 (0.275) | 0.023 (0.165) | -0.454 (0.266)* | 0.725 (0.518) | -0.314 (0.119)** | 0.581 (0.413) |
| Gender | -0.015 (0.019) | 0.052 (0.040) | -0.294 (0.584) | -0.613 (0.509) | -0.135 (0.043)** | 0.107 (0.036) |
| Education | 0.140 (0.050)** | 0.071 (0.048) | 0.030 (0.015)** | -0.002 (0.012) | 0.312 (0.083)*** | 0.131 (0.074)* |
| Risk attitude | 0.037 (0.012)*** | 0.197 (0.026)*** | -0.047 (0.043) | -0.106 (0.133) | -0.168 (0.086)* | -0.290 (0.359) |
| Income | 0.029 (0.016)* | 0.017 (0.014) | 0.358 (0.173)** | 0.121 (0.056)** | 0.048 (0.037) | 0.045 (0.022)** |
| Agricultural labor | 0.591 (0.415) | 0.554 (0.157)*** | 0.037 (0.028) | -0.030 (0.014)** | 0.034 (0.673) | -0.849 (0.325)** |
| Children | -0.002 (0.002) | 0.002 (0.003) | 0.088 (0.008)*** | -0.002 (0.005) | 0.019 (0.009)** | 0.004 (0.006) |
| Scale | 0.339 (0.248) | -0.302 (0.173)* | -0.121 (0.211) | 0.169 (0.046)*** | 0.166 (0.465) | 0.333 (0.028)*** |
| Organization | 0.540 (0.524) | 0.659 (0.513) | 1.581 (0.622) | 2.040 (0.481)*** | 0.360 (0.277) | 0.374 (0.169) |
| Rice price | 0.242 (0.051)*** | -0.163 (0.338) | 0.277 (0.258) | -0.156 (0.271) | 1.015 (0.509)* | -0.970 (1.092) |
| Cost | -0.141 (0.076)* | -0.730 (1.135) | 0.005 (0.016) | -0.127 (0.071)* | -0.036 (0.563) | 0.043 (0.526) |
| Residue testing | 3.360 (0.376) | -5.467 (7.865) | 2.685 (0.877)*** | 4.211 (4.441) | 4.885 (2.414)** | 1.480 (1.504) |
| Brand | 0.195 (0.109)* | -0.196 (0.136) | 0.130 (0.054)** | -0.108 (0.093) | 0.228 (0.078)** | 4.157 (7.006) |
| Training | 0.115 (0.049)** | 0.175 (0.027)*** | 0.389 (0.115)*** | 0.262 (0.354) | 0.148 (0.035)*** | -0.029 (0.257) |
| Subsidy | 0.396 (0.247) | 0.411 (0.150)** | 0.420 (0.181) | 0.309 (0.144)** | -0.047 (0.378) | 0.071 (0.016)*** |
| Demonstration | 0.283 (0.156)* | 0.629 (0.357)* | 0.408 (0.227)** | 0.153 (0.226) | 0.558 (0.795) | 0.956 (0.390)** |
| Region | 0.275 (0.136)** | -1.964 (2.602) | 0.691 (0.595) | -3.211 (1.471)** | -0.643 (1.098) | -0.408 (0.190)* |
| Pseudo $R^2$ | 0.085 | 0.082 | 0.057 | 0.165 | 0.176 | 0.129 |
| Wald Chi2 | 28.062*** | 27.093*** | 60.562** | 26.370*** | 23.054*** | 17.985** |

*Notes*: Standard errors of coefficients are in parentheses. The constant term results not presented. *, ** and *** indicate significance at the statistical levels of 10%, 5% and 1%, respectively.

### *3.4 Estimation results of the factors influencing farmer's adoption level of pesticide reduction technologies*

To explore how the above variables further influence the level of pesticide reduction technology adoption among rice farmers, Heckman regressions on the sample were used (Table 4). Since the presence or absence of subsidies only addresses whether the adoption behavior occurs, it was removed in the second stage of the regression, thus satisfying the basic requirements of the Heckman regression. The significance of the inverse Mills ratio obtained from the regression indicates that the problem of sample selectivity bias exists and that the Heckman two-stage regression method is reasonably applied.

**Table 4** Estimation results of the Heckman model and its robustness test

| Variables | First stage: Adoption behavior | Second stage: Adoption level | Tobit 1: Adoption level | Tobit 2: Area ratio |
|---|---|---|---|---|
| | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) | Coefficient (S.E.) |
| Age | 0.004 (0.003) | 0.153 (0.172) | 0.007 (0.005) | 0.002 (0.003) |
| Gender | 0.142 (0.151) | 0.114 (0.061) | 0.002 (0.005) | 0.003 (0.003) |
| Education | 0.228 (0.094)** | 0.045 (0.022)** | 0.630 (0.247)** | 0.098 (0.042)** |
| Risk attitude | 0.183 (0.106)* | 0.609 (0.326)* | 0.051 (0.028)** | 0.007 (0.002)*** |
| Income | 0.096 (0.039)** | 0.003 (0.022) | 0.002 (0.001)* | 0.001 (0.001) |
| Agricultural labor | 0.019 (0.010)* | 1.056 (0.813) | 0.510 (0.613) | 0.086 (0.051)* |
| Children | 0.013 (0.015) | 0.004 (0.006) | -0.004 (0.003) | -0.004 (0.003) |
| Scale | 0.237 (0.126)* | 0.248 (0.055)*** | 0.227 (0.096)** | -0.067 (0.040)* |
| Organization | 0.757 (0.719) | 0.215 (0.742) | 0.004 (0.003) | 0.001 (0.001) |
| Rice price | 0.291 (0.122)** | 0.144 (0.081)* | 0.011 (0.007)* | 0.022 (0.009)** |
| Cost | -0.194 (0.626) | -0.136 (0.062)** | -0.004 (0.002)* | -0.003 (0.002)* |
| Residue testing | 3.692 (2.111)* | 4.153 (3.092) | 0.002 (0.002) | -0.002 (0.002) |
| Brand | 1.349 (0.635)** | -1.993 (1.147) | 0.182 (0.111)* | 0.018 (0.132) |
| Training | 0.187 (0.055)*** | 0.205 (0.088)** | 0.041 (0.011)*** | 0.097 (0.041)** |

| | | | | |
|---|---|---|---|---|
| Subsidy | 0.121 (0.051)** | _ | -0.004 (0.002)** | 0.001 (0.001) |
| Demonstration | 0.606 (0.343)* | 0.617 (0.522) | 0.016 (0.182) | 0.012 (0.015) |
| Region | -0.396 (1.085)* | -0.487 (0.872) | -0.009 (0.004)** | 0.005 (0.004) |
| $\varphi$ | _ | 0.802 (0.371)** | _ | _ |
| Pseudo $R^2$ | 0.194 | 0.168 | 0.021 | 0.018 |
| Wald Chi2 | 20.784*** | 18.740*** | _ | _ |
| LR Chi2 | _ | _ | 32.25*** | 65.72*** |

*Notes*: The estimated adoption behavior in the first stage is the adoption of any of the CRPU technologies by rice farmers. Standard errors of coefficients are in parentheses. The constant term results not presented. *, ** and *** indicate significance at the statistical levels of 10%, 5% and 1%, respectively. The Tobit model on the right-hand side is mainly used to test the robustness of the empirical results.

First, we can obtain the factors influencing the adoption behavior of pesticide reduction technologies by rice farmers estimated from the first stage. These mainly include education, risk attitude, income, agricultural labor, scale, rice price, residue testing, brand, training, subsidy, and demonstration. Statistics on the significance of the coefficients show that they have influenced the adoption of pesticide reduction techniques by rice farmers. And these results are consistent with Table 3. So we won't repeat the reason here.

Second, we can obtain the factors influencing the adoption level of pesticide reduction technologies by rice farmers from the second stage. The positive impact of education on the level of adoption is tested by significance. This shows that more education can promote farmers to actively adopt more pesticide reduction technologies. Risk attitudes can also significantly promote the adoption of more pesticide reduction technologies, as the adoption of many emerging technologies is considered a risky thing by farmers (Bagheri et al., 2021). The larger-scale the farmer, the more types of pesticide reduction techniques they use. The economic effects of different reduction techniques need to be verified one by one in practice, so that farmers may be willing to accept a certain technology on a large scale. Otherwise, they will face a greater risk of loss (Han et al., 2021). Rising rice prices are helping farmers adopt more pesticide reduction techniques. This is the fundamental goal of production that should be carried out by farmers in order to obtain market profits. Of course, the results also show that the cost of pest management has increased significantly after the adoption of more pesticide reduction techniques. This is inevitable because of the improvement of many raw materials and production processes (Gao et al., 2021). Of course, technical training is still necessary, if you want to make different pesticide reduction technologies quickly promoted. Different technical operation points need guidance and help from agricultural technology extension personnel (Huang et al., 2021). This finding could provide recommendations to guide the diffusion of diversified pesticide reduction techniques.

### *3.5 Robustness estimation*

In order to verify the stability of the above empirical results, we combined the two-step decision-making problems of pesticide reduction technology adoption behavior and the adoption level of farmers into one step. It is also necessary to set the adoption level of 0 for samples that have not adopted pesticide reduction techniques. The Tobit model, also known as the restricted dependent variable model, is suitable for handling sample selection and data consolidation problems and can be used as a robustness test in this paper. We used two approaches to obtain robust estimates, the results of which are shown in Table 4.

On the one hand, we only replace the method and estimate the influencing factors of farmers' adoption level of pesticide reduction technologies. And find that the significant influencing factors in the regression results are basically consistent with the results obtained by Heckman. This proves the reliability and stability of the empirical results. On the other hand, we replace the dependent variable for re-estimation based on the Tobit model. That is the ratio of the area applied by pesticide reduction technology to the total area cultivated. The results show that education, risk attitudes, agricultural labor, scale, rice prices, cost, and training are important factors affecting the ratio of area adopted by farmers in pesticide reduction techniques. Among them, education and risk attitudes are important factors at the individual level. The promotion of pesticide reduction work requires highly educated and risk-taking people as pioneers (Salazar and Rand, 2020). Moreover, rice prices and training are important external environmental factors. It is also necessary to drive rice farmers to widely apply pesticide reduction technology through the dual power of the market and the government (Yang et al., 2019; Pan et al., 2021).

# 4. Conclusion and policy implications

Based on the successful experience of pesticide reduction among rice farmers in Hubei Province, China, we used survey data to measure farmers' preferences for pesticide reduction technologies and their influencing factors. This study provides a more comprehensive focus on the real needs of farmers, and these findings can provide practical policy guidance for effective pesticide reduction in developing countries. The main findings of the paper are as follows:

First, the general pesticides reduction technology adoption preferences of rice farmers are in descending order of scientific standard, biopesticides, efficient machinery, ecological control, physical trapping, and drone service. However, they also exhibit scale heterogeneity, showing that larger-scale farmers prefer drone services and efficient machinery, while smaller-scale farmers prefer scientific standards and biopesticides. Second, the adoption behavior of different pesticide reduction technologies has different influencing factors, but are mostly influenced by variables such as education, risk attitude, income, agricultural labor, scale, rice price, residue testing, brand, training, subsidy, and demonstration. Among them, education, risk attitude, scale, rice price, cost, and training are the variables that significantly affect farmers' adoption level of multiple pesticide reduction technologies. Further, personal factors similar to education and risk attitude, and external factors similar to rice price and training combine to affect the ratio of area adopted by farmers for pesticide reduction technologies.

The following policy insights can be derived from the above findings: First, it is recommended to develop a pesticide reduction technology extension program that can meet the real needs of farmers. We should pay attention to information about the needs of farmers with different characteristics themselves and carry out personalized and precise technical extension services. Specifically, for large-scale farmers to promote efficient machinery and drone services, and for small-scale farmers to promote scientific application techniques and biopesticides. Second, market and policy factors also need to be optimized, in addition to farmer-specific factors, to achieve widespread adoption of pesticide reduction technologies. It is recommended to build a green agricultural supply system to achieve high prices for quality agricultural products, and to induce farmers to take the initiative to reduce pesticide application. At the same time, strengthen pesticide reduction technology training, subsidies, demonstration, and other promotional activities to make the technology more easily understood and accepted by farmers. Therefore, it is still necessary to carry out targeted technical extension interventions in the context of designing pesticide reduction technology programs with local characteristics.

## Funding

This work was supported by The National Natural Science Foundation of China (grant number: 72073048, 71803145). The National Social Science Foundation of China (grant number: 17BFX119).

## Conflict of Interest Declaration

The authors declare that they have no competing interest.

## Author contribution

**Di Liu:** Investigation, Data curation, Formal analysis, Visualization, Writing - & editing. **Yanzhong Huang:** Conceptualization, Methodology, Validation, Investigation, Writing - review & editing. **Xiaofeng Luo:** Funding acquisition, Project administration, Writing - original draft.

## Data availability

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

## Declarations

**Ethical approval:** Ethical approval was taken from the Huazhong Agricultural University, ethical approval committee.

**Consent to participate:** Not applicable.

**Consent to publish:** Not applicable.

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