frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 14 February 2024
DOI 10.3389/fsufs.2024.1333053

OPEN ACCESS

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RECEIVED 13 December 2023
ACCEPTED 26 January 2024
PUBLISHED 14 February 2024

CITATION
Shen D, Wang L and Cai L (2024) Aging agricultural labor force, outsourcing service of pest control and biopesticide application: a case study of 10 counties in Fujian Province. *Front. Sustain. Food Syst.* 8:1333053. doi: 10.3389/fsufs.2024.1333053

Aging agricultural labor force, outsourcing service of pest control and biopesticide application: a case study of 10 counties in Fujian Province

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Introduction: Under the background of increasingly severe aging of agricultural labor force and relatively slow land circulation, agricultural production outsourcing has become the main means of agricultural modernization. Despite the existence of a voluminous literature on outsourcing service of pest control, little is known about its effect on biopesticides use.

Methods: To fill this knowledge gap, this study uses rice planting data from 1,045 Chinese farm households to analyze the impact of different aging agricultural households and the pest control outsourcing service on the application of biopesticides by using the logit regression model.

Results and Discussion: The study results showed that: (1) Participation in pest control outsourcing services significantly promotes biopesticide application. But this positive effect varied across age groups. (2) Compared with aging households, non-aging farmers tend to use biopesticides. Given this, it is recommended that pay attention to the ecological effect of pest control outsourcing services, strengthen the assistance to the aging labor group in the green pesticide promotion policy, and guide the aged planting decision makers to participate in pest control outsourcing services, thereby effectively improving the sustainable development of green agriculture.

KEYWORDS

aging labor force, socialized pest control services, eco-agriculture, green agriculture, biopesticide

1 Introduction

Biopesticides are pesticide formulations that are directly made from living organisms or their metabolites and used to control harmful organisms. It can also involve synthesizing pesticide formulations with the same structure as natural compounds to achieve pest control.[1] Despite its high selectivity and eco-friendly nature, this product holds a relatively small

1 Official Website of Fujian Provincial Department of Agriculture and Rural Affairs. (2023). Available at: http://www.fj.gov.cn/hdjl/hdjlzsk/nyt/zz/202111/t20211105_5765603.htm(Accessed October 17, 2023).

percentage of the pesticide market share, accounting for less than 10% (Luo et al., 2020), and its promotion is faced with several practical dilemmas.

Firstly, separating farmland rights into three categories gives the land quasi-public attributes. The benefits of using biopesticides, such as ecological benefits and value, are mostly public. Therefore, the use of biopesticides should be guided and regulated by government incentives and constraints. Secondly, the expense of utilizing biopesticides is significant, and the time it takes to see a return on investment is lengthy. Some studies have found that there is a psychological bias between current utility and future utility in intertemporal decision making (Wu et al., 2023). Those using biopesticides often do not experience immediate economic benefits and need a high level of expertise in their application. The higher the farmers' time preference, that is, the more they prefer the "current utility" of pesticides, the lower their willingness to adopt biopesticides.

Some studies have discussed the factors affecting the adoption of new agricultural technologies such as biopesticides, but most of the research attention has focused on the personal characteristics of farmers (Luo et al., 2023) (such as education level, risk attitude), production characteristics (He et al., 2022), and public policies (Wang J. X. et al., 2023; such as publicity methods and subsidy policies). However, the research on new agricultural production modes is relatively insufficient.

Especially in the background of a large number of young rural and robust labor force flowing to the city, in most of the agricultural areas that lack location advantages and missed the opportunity of rural industrialization, agriculture is primarily dominated by older people (He, 2018).

Whether biopesticides can be widely and effectively adopted in the face of the aging agricultural labor force is still controversial. Many scholars have argued that the health, physical, and learning disabilities of an aging workforce will constrain the implementation of agroecological management (Peng et al., 2019; Qiu et al., 2019; Zhao et al., 2020). However, some scholars believe that the aging labor force will not have a significant negative impact on production in the short term because agricultural production tends to be standardized, the demand for labor intensity is decreasing, and there are substitutes for other factors of production (Guo and Zu, 2015; Nie and Yan, 2016).

It is worth noting that agricultural production outsourcing services is developing rapidly in China, which has become one of the important ways to improve agricultural productivity, to promote the transformation of agricultural production mode and to ensure food safety (Cai and Wang, 2021). On the one hand, outsourcing services in production can replace household labor, make up for labor shortage caused by the transfer of non-agricultural sectors, and ensure the smooth progress of agricultural production (Shen et al., 2015). On the other hand, outsourcing services can realize the scale operation of specific production links (Sun et al., 2019a). By the end of 2022, the number of specialized control organizations had reached 93,200 in China, and the coverage rate of technical unified control of the three major staple grains had reached 43.6%. Pest control services undertaken by specialized organizations reduce the labor force's physical constraints and provide high-quality pest control information that can reduce the risk of pest epidemics.

Theoretically, the involvement of pest control outsourcing organization brings hitchhiking agricultural services and pest control information, and the coordinating function of such organization operation and the economy of flat channel sales all contribute to reducing the cost of biopesticide application. At the same time, in 2014, the Ministry of Agriculture Plantation Management Division announced the "crop pest specialization and green prevention and control fusion pilot program" followed by the provinces combined with their actual situation to develop municipal crop pests and green prevention and control fusion of work programs, demonstration bases, to play the "1 + 1 > 2" model. However, the existing empirical studies on outsourcing pest control services and promoting biopesticides are relatively insufficient.

Therefore, it is necessary to comprehensively explore the logical relationship between the aging agricultural labor force, pest control outsourcing services, and the application of biopesticides. The answer to these questions will help to extend the theory of the aging labor force and green production behavior. Additionally, we can explore the potential for using specialized outsourcing services for agricultural control, which will provide practical value in promoting green agriculture.

2 Theoretical analysis and research hypothesis

2.1 Impact of the aging labor force on biopesticide application

The mode of agricultural production in China is dominated by small-scale family operations, under this basic national condition, the material cost and time cost required for ecological farming are high. The aging labor force is prone to the exclusion of new technologies of agricultural machinery and techniques due to constraints in physical and cognitive abilities, and the degree of their application is also low (Chen et al., 2011; Cai and Zhang, 2015; Wei and Song, 2022). Compared with conventional pesticides, biopesticides are less resistant and environmentally friendly. However, some biopesticide products are highly technical and complicated to apply. Farmers adopting biopesticides may need to invest extra time and energy in specialized training, which requires farmers to have a certain degree of learning ability (Yan et al., 2021). And farmers' perceptions of traditional chemical pesticides and biopesticides also affect their application behavior (Fu and Song, 2010; Sun, 2022; Wang and Gao, 2022). The aging labor force is at a disadvantage in terms of physical strength, learning ability, cognitive level, and innovation consciousness, which is not conducive to the application of biopesticides by farmers. Based on the above analysis, this paper puts forward the first hypothesis.

> *Hypothesis 1 (H1):* The aging of labor force will hinder the application of biopesticides by farmers.

2.2 Impact of pest control outsourcing organizations on biopesticide application

Biopesticides have the advantages of high efficiency, low toxicity, and low residue, but at the same time, biopesticides are slow in effect and high in cost. Individual farmers have limited channels for pesticide purchasing and information access, so choosing biopesticides will increase farmers' medicinal costs, information search costs, and production and operation risks (He et al., 2022).

As a platform for pest control operations, pest control outsourcing organizations have an essential role in promoting biopesticides. Many

pest control organizations have cooperative, agricultural materials seller, and other diversified enterprise attributes; the pest control outsourcing model has changed the traditional way of selling agricultural materials. Biopesticides can now reach farmers without passing through multiple levels of distribution; specialized pest control organizations with diversified business entities can directly apply biopesticides. Flattening this sales channel can reduce the cost of biopesticides, making them more economical. Lower economic and time costs can improve farmers' biopesticide application execution.

Furthermore, many regions have provided financial subsidies to demonstration sites for integrating green crop pest control and professional pest control outsourcing, which may further enhance the probability of biopesticide application by farmers. Pest control outsourcing organizations have relative advantages regarding technology, workforce, pesticide information, and policy support. Therefore, this paper puts forward the second hypothesis.

> *Hypothesis 2 (H2):* Participation in the pest control outsourcing service promotes farmers' biopesticide application.

2.3 Interactive effects of pest control outsourcing organizations and the aging labor force on biopesticide application

In summary, pest control outsourcing organizations have comparative advantages in technology, workforce, and pesticide information. Participation in pest control outsourcing services can improve the economy of farmers' application of biopesticides, which is conducive to the promotion of biopesticides.

In contrast, the aging labor force may inhibit the positive impact of pest control outsourcing on biopesticide applications. Compared with the younger group, the aging labor force is in a weaker position in terms of physical strength, learning ability, information acquisition, and innovation consciousness, and they are less receptive to new things, which is not conducive to promoting biopesticide application behavior (Wang F. et al., 2023).

Explicitly speaking: ① Pest control work is multi-stage, open spatially, and has temporal requirements, any error or delay in agricultural time may impact crop yield. Moreover, the effect of pest control is lagging, which makes the outsourcing service of pest control have problems such as high cost of labor supervision, prone to moral hazard, and difficulty in holding accountable after the event (Sun et al., 2019b; Li and Zhou, 2020). In production practice, to reduce the uncertainty and risk of pest control outsourcing, aging households with labor constraints are more likely to choose the semi-contracting mode of "outsource labor but not pesticide"(Wang et al., 2022), which is not conducive to promoting biopesticides.

② The aging labor force has a weaker ability to obtain information on non-farm employment and the employment channels are limited. They will devote more energy to agricultural production and are more sensitive to changes in the cost-income ratio of agricultural production. Their decision-making process focuses on whether new technologies or services can bring higher and more stable economic returns. Biopesticides, on the other hand, have high input costs and a long payback period, and the benefits from adopting biopesticides are more clearly reflected in the ecological aspect, with no apparent economic benefits in the short term. Hence, older households often prefer traditional chemical pesticides due to their conservative nature. Based on the above analysis, this paper puts forward the third hypothesis.

> *Hypothesis 3 (H3):* The aging labor force will reduce the positive impact of pest control outsourcing on farmers' biopesticide applications.

3 Research methods

3.1 Data sources and sample description

The data in this paper comes from the rice cultivation and control situation in Fujian Province surveyed during 2018–2020, using stratified sampling based on the rice production data information. Two factors were considered in the selection of survey area: One is to select the high-yield and planting areas of rice in Fujian Province according to the statistical yearbook; Second, according to the "Opinions on the Implementation of Rice Production Functional Areas," it is stipulated that the permanent basic farmland management shall be implemented within the scope of rice production functional areas, and no unit or individual shall occupy or change the purpose without authorization. The delineation of rice functional area is related to the national "grain bag." Finally, we identify 10 counties, such as ShaoWu, YouXi, ChangTing, NanAn, and ZhangPu, as the sampling area (Table 1).

In this paper, two towns were randomly selected from each county, and two villages were selected from each town to interview rice growers and specialized pest control organizations serving the local area to ensure the representativeness of rice planting in the survey area. During the 3 years, about 10–13 households were selected from each village, 1,200 questionnaires were distributed, and 1,045 valid questionnaires were recovered, with a validity rate of approximately 87.1%.

From 2018 to 2020, the surveys on rice pest control in the above 40 villages were completed. The overall sample characteristics are as follows:

(1) From the perspective of farmers' characteristics, most of the respondents are middle-aged people, with an average age of 54 years, an average education of 6 years and an average farming experience of

TABLE 1 Survey area of rice pest control in Fujian Province.

City	County	Town	
Nanping	Shaowu	Hongdun	Nakou
	Jianyang	Jiangkou	Chongluo
Sanming	Youxi	Yangzhong	Xiwei
	Jianning	Lixin	Xikou
Longyan	Shanghan	Zhongdu	Lufeng
	Zhangting	Guanqian	Tongfang
Zhangzhou	Zhangpu	Chihu	Shiliu
	Longhai	Dongsi	Jiuhu
Quanzhou	Yongchun	Dapu	Penghu
	Nanan	Matou	Yingdu

31 years. 52.4% of the farmers are engaged in non-agricultural work. (2) From the perspective of family characteristics, the average agricultural labor force accounts for 56% of the family population, 23.5% of the family members participate in the agricultural cooperative. (3) The production and management characteristics of farmers are as follows: the average planting area is 1.98 mu (One mu equals 1/15 ha.), 72.7% of the families grow rice for the purpose of sales, and the average income from rice planting accounts for 37.9% of the family income. (4) In 1,045 survey samples, 254 households participated in the outsourcing service of rice pest control, accounting for 24.3% of the total.

The main variables were selected and defined as follows:

(1) Key variables. The dependent variable in the text "Farmers' biopesticide application behavior," application behavior = 1, no application = 0, to count the biopesticide application by farmers.

The leading independent variables include "Degree of labor force aging" and "Pest control outsourcing services." The Law on the Protection of the Rights and Interests of the Elderly in China defines citizens over 60 as the elderly. According to this definition, we obtained the number of family agricultural labor force and the number of agricultural labor force over 60 years old in the questionnaire survey, and then divided the number of agricultural labor force over 60 years old by the number of family agricultural labor force to get "Degree of labor force aging." This calculation method was also used in the study of Du et al. (2021). "Pest control outsourcing services," participation in pest control outsourcing services = 1, no participation = 0.

(2) Other control variables, including farmers' characteristics (Education level, Farming experience, Part-time Farming), family production and management characteristics (Proportion of planting income, Agricultural labor force, Planting scale, Member of a cooperative, Degree of rice commercialization), regional variables and year. Among them, "Part-time Farming" refers to whether farmers have non-agricultural employment behavior, yes = 1, no = 0. The "Proportion of planting income" refers to the proportion of rice planting income in household income. "Agricultural labor force" is the number of labor input per unit area. "Planting scale" refers to the area of rice planting. "Member of a cooperative" refers to whether farmers join an agricultural cooperative, not cooperative member = 0, cooperative member = 1. "Degree of rice commercialization" means the proportion of rice used for sale in total rice production. The description and statistics of variables are shown in Table 2.

3.2 Model setting

Since biopesticide application behavior is a discrete choice problem, the bivariate logit model was used to investigate the factors affecting the application behavior of biopesticides in farmers. Let Y* be an unobservable latent variable while Y and X are observable, so we have formula (1).

$$Y = \begin{cases} 1, & \left(Y^* > 0\right) \\ 0, & \left(Y^* \le 0\right) \end{cases} \tag{1}$$

Precisely as in formula (2).

$$Y = \alpha + \beta X_1 + \gamma X_2 + \theta X_i + \mu \tag{2}$$

In the formula, the explanatory variable Y indicates whether the farmers apply biopesticides or not, with a value of 1 assigned to applying biopesticides and 0 assigned to not applying. The critical explanatory variable X1 indicates the degree of aging agricultural labor force, with the degree of aging agricultural labor force = the number of agricultural laborers aged 60 years old and above ÷ the total number of agricultural laborers of the family, and the value varies in the interval of [0–1]; X2 indicates whether to participate in the outsourcing service of pest control; Xi indicates a series of control variables such as characteristics of farm households, household production, region, etc. "μ" is the random perturbation term, and "i" is the number of variables.

It should be noted that the model is nonlinear, and the parameter estimation cannot directly compare the effect of an independent variable on the dependent variable while other conditions remain unchanged. Therefore, the effect of participation in pest control outsourcing services on the application of biopesticides is explained through the marginal utility, estimation direction, and significance of the independent variables.

4 Empirical analysis of regression results

The data collected for this study was processed and analyzed using "STATA,16." Before the analysis, we eliminate the outliers and missing values in the sample and take the logarithmic treatment of the planting area to address the significant sample variance caused by the varying planting areas of farmers.

The empirical part first explores the effects of the aging agricultural labor force and pest control outsourcing on biopesticide applications. The estimation results are shown in the baseline equation (1) in Table 3. Then, we use subgroup regression to examine the impact of pest control outsourcing on biopesticide application under different labor force aging level, and the estimation results are shown in equations (2) and (3) in Table 4. Finally, to ensure the robustness and reliability of the empirical results in this paper, subgroup regression and winsorization of control variable were used to test robustness. The estimation results are shown in Tables 5, 6.

4.1 Baseline regression equation results

Before conducting the regression, we checked for multicollinearity among the variables by diagnosing their covariance. The variance inflation factor (VIF) of the continuous variables in the model ranged from 1.03 to 2.56, indicating that there was no significant multicollinearity present. The results in Table 3 show that the value of p of the Hosmer-Lemeshow test is 0.232, greater than 0.05, indicating that the model is well-fitted. The estimation results of equation (1) in Table 3 show that the aging agricultural labor force has a negative effect on biopesticide application with a coefficient of −0.486 and the value of p is 0.068, which passed the 10% significance test. It indicates that households with older agricultural labors are less likely to use biopesticides. Hypothesis 1 is verified.

TABLE 2 Description and descriptive analysis of the variables.

Variable name	Variable description	Mean	Standard deviation
Dependent variable			
Farmers' biopesticide application behavior	Whether biopesticides applied, yes = 1, no = 0	0.760	0.426
Independent variables			
Degree of labor force aging	Proportion of labor force aged 60 and above in household agricultural labor force	0.261	0.333
Pest control outsourcing services	Whether participate in pest control outsourcing service, participation = 1, no participation = 0	0.240	0.429
Control variables			
Education level	Years of education (unit: year)	6.225	3.357
Farming experience	Decision maker's years of farming (unit: year)	31.200	11.568
Part-time Farming	Whether there is part-time farming	0.520	0.500
Proportion of planting income	Proportion of rice planting income in household income	0.379	0.363
Agricultural labor force	Number of labor input per unit area	2.660	1.337
Planting scale	Rice planting area (unit: Mu)	1.983	1.405
Member of a cooperative	Not cooperative member = 0, cooperative member = 1	0.240	0.424
Degree of rice commercialization	The proportion of rice used for sale in total rice production	0.519	0.385
Regional variables	South Fujian = 1, North Fujian = 2, West Fujian = 3	1.930	0.713
Year	2018 = 1, 2019 = 2, 2020 = 3	1.730	0.828

One mu equals 1/15 ha.

The estimation results of equation (1) in Table 3 show that pest control outsourcing services positively affect biopesticide application with a coefficient of 0.74, the value of p is 0.002 and significance at 1% level. It indicates that participating in pest control outsourcing services will increase the probability of farmers' biopesticide application. Hypothesis 2 is verified.

The estimation results of the control variables in Table 3 show that farmers' biopesticide application is significantly positively affected by their farming experience (coefficient = 0.021, value of $p = 0.009$), planting scale (coefficient = 0.359, value of $p = 0.001$), and participation in agricultural cooperatives (coefficient = 0.700, value of $p = 0.005$). The reason is that farmers with more farming experience and larger planting areas usually have better access to agrotechnology training, closer contact with professional agricultural extension workers, and more relevant information. This makes them more likely to adopt biopesticides.

As one of the main subjects of modern agricultural scale operation, agricultural cooperatives play the role of purchasing and marketing, science and technology demonstration, technology promotion, etc. Farmers who join agricultural cooperatives can benefit from access to critical information and reduced costs for biopesticide application. Furthermore, the collective action of the cooperative's members in adopting the biopesticide technology can circumvent the technological uncertainties that a single individual may encounter (Tang and Luo, 2022). Therefore, participation in cooperatives will significantly increase farmers' probability of biopesticide application.

The proportion of planting income (coefficient = −0.903, value of $p = 0.002$) and the number of agricultural labor force (coefficient = −0.458, value of $p = 0.000$) significantly negatively affect the application of biopesticides. The possible explanation is that households with a higher proportion of planting income pay more attention to whether adopting new technologies can bring economic benefits as soon as possible. However, the effects of biopesticide application are more evident in the ecological aspect, and the short-term economic rewards are not obvious. Hence, households with a higher proportion of planting income are more likely to choose traditional chemical pesticides than biopesticides.

Generally speaking, households with sufficient agricultural labor are more likely to choose self-prevention and control (Cai and Wang, 2021); using biopesticides will increase the cost of pesticide and information search and may even pose operational risks, which limit farmers' biopesticide application.

4.2 Impact of pest control outsourcing on biopesticide application under different labor force aging level subgroups

To analyze the impact of pest control outsourcing on biopesticide application under different labor force aging level, this paper groups the sample farmers according to the degree of the aging labor force and conducts group regression.

The internationally recognized aging standard is that in a certain population, when the proportion of people aged 65 and above reaches 7%, or the population aged 60 and above reaches 10%, it is called an aging population. Related studies, such as Tang et al. (2021), refer to this standard for the treatment program's aging subgroups. The age threshold recognized by Chinese law for the aging population is

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TABLE 3 The regression results of biopesticide application based on Logit model.

Variable name	Baseline equation (1)		
	Coef.	SE	*p* value
Main explanatory variables			
Pest control outsourcing services	0.740***	0.241	0.002
Degree of labor force aging	−0.486*	0.266	0.068
Control variables			
Education level	−0.046	0.028	0.100
Farming experience	0.021***	0.008	0.009
Part-time Farming	0.116	0.190	0.542
Agricultural labor force	−0.458***	0.063	0.000
Planting scale	0.359***	0.108	0.001
Member of a cooperative	0.700***	0.248	0.005
Degree of rice commercialization	0.340	0.329	0.302
Proportion of planting income	−0.903***	0.287	0.002
Region			
North Fujian	−1.111***	0.259	0.000
West Fujian	−0.374	0.256	0.145
Year			
2019	0.284	0.229	0.214
2020	0.282	0.227	0.213
Constant	1.872***	0.461	0.000
Observed value	1,045		
Hosmer-Lemeshow test	Chi-square	*p* value	
	10.490	0.232	

*, ** and ***, denote significant at the 10, 5 and 1% statistical levels.

60 years old. So, in this paper, we take the family agricultural labor force aged 60 years old and above as the observation object. Firstly, we divide the number of agricultural labor force over 60 years old by the number of family agricultural labor force to get the degree of labor force aging. And then, to define the "non-aging group" and the "aging group," we refer to internationally recognized standards and related studies. The "non-aging group" is defined as having an aging degree of less than or equal to 10%, while the "aging group" has an aging degree of more than 10%. The "non-aging group" has 549 samples, while the "aging group" has 496 samples.

Equations (2) and (3) in Table 4 report the results of the subgroup regressions, which show that in the non-aging group, pest control outsourcing significantly and positively affects biopesticide application at the 1% statistical level, with a coefficient of 1.007 and the value of p is 0.005. Moreover, the marginal effect is 0.137, which indicates that participating in pest control outsourcing services increases the probability of biopesticide application by farmers by 13.7% compared to non-participation while controlling for other variables. While in the aging group, pest control outsourcing has a non-significant positive effect on biopesticide application, with a coefficient of 0.210 and the value of p is 0.556, suggesting that the aging labor force inhibits the positive effect of pest control outsourcing on biopesticide application, which validates Hypothesis 3.

4.3 Robustness tests

4.3.1 Robustness test based on winsorization of control variables

In the case of large samples, some continuous control variables may have extreme values. To verify the robustness of the above conclusions, this paper carries out double-tailed treatment on the 1% quartile on some continuous control variables, including education level, farming experience, proportion of planting income, agricultural labor force and degree of rice commercialization.

The regression results are shown in Table 5. It can be seen that the regression results of key variables are consistent with those mentioned above after double-tailed treatment of control variables. The aging agricultural labor force has a negative effect on biopesticide application with a coefficient of −0.493 and the value of p is 0.066, which passed

TABLE 4 The result of subgroup regression.

Variable name	Labor force aging group							
	(2) Non-aging group (≤10%)				(3) Aging group (>10%)			
	Coef.	SE	*p* value	Dy/dx	Coef.	SE	*p* value	Dy/dx
Main explanatory variables								
Pest control outsourcing services	1.007***	0.355	0.005	0.137	0.210	0.357	0.556	0.035
Control variables								
Education level	−0.043	0.045	0.338	−0.006	−0.035	0.038	0.353	−0.006
Farming experience	0.015	0.014	0.272	0.002	0.030***	0.011	0.005	0.005
Part-time Farming	−0.762**	0.317	0.016	−0.104	0.546**	0.261	0.036	0.090
Agricultural labor force	−0.465***	0.113	0.000	−0.063	−0.442***	0.080	0.000	−0.073
Planting scale	0.142	0.144	0.324	0.019	0.623***	0.169	0.000	0.103
Member of a cooperative	0.795**	0.373	0.033	0.109	0.610*	0.345	0.077	0.101
Degree of rice commercialization	0.260	0.491	0.596	0.036	0.316	0.479	0.509	0.053
Proportion of planting income	−1.814***	0.413	0.000	−0.247	−0.120	0.473	0.800	−0.020
Region								
North Fujian	−1.051**	0.430	0.015	−0.125	−1.146***	0.349	0.001	−0.192
West Fujian	−1.039**	0.411	0.011	−0.123	0.143	0.368	0.697	0.019
Year								
2019	0.867**	0.369	0.019	0.108	−0.080	0.346	0.818	−0.014
2020	0.281	0.328	0.392	0.040	0.482	0.337	0.152	0.077
Constant	3.536***	0.744	0.000		0.296	0.628	0.638	
Observed value	549				496			
Hosmer-Lemeshow test	Chi-Square		P-Value		Chi-Square		P-Value	
	6.903		0.547		12.810		0.119	

*, ** and ***, denote significant at the 10, 5 and 1% statistical levels. Dy/dx are average marginal effects.

the 10% significance test. And pest control outsourcing services positively affect biopesticide application with a coefficient of 0.727, the value of p is 0.002 and significance at 1% level. Hypothesis 1 and Hypothesis 2 are again verified.

4.3.2 Robustness test based on subgroup regression

To test the robustness of the estimation results, this paper regroups the samples according to the degree of aging labor force. We divide the samples into three groups: the degree of aging labor force in the range of [0–0.3] is Group I, the degree of aging in the range of [0.3–0.6] is Group II, and the degree of aging in the range of [0.6–1] is Group III. We then conduct subgroup regressions once more.

The regression results of equations (5), (6), and (7) in Table 6 show that pest control outsourcing has a significant positive effect on biopesticide application at the 5% statistical level in Group I, where the degree of aging is low. However, the coefficients fail the significance test in Groups II and III, which suggests that the positive effect of pest control outsourcing on biopesticide application diminishes with the increase in the labor force's aging. Hypothesis 3 is again verified.

5 Conclusion and policy implications

Based on the micro-research data of 1,045 rice farmers in 10 counties and cities in Fujian Province from 2018 to 2020, this paper constructs a binary Logit model and uses subgroup regression to empirically analyze the relationship between the aging agricultural labor force, pest control outsourcing services and the behavior of farmers' biopesticide application. The main conclusions are as follows:

First, participation in the pest control outsourcing service positively affects farmers' biopesticide application and is significant at

TABLE 5 The regression result of double-tailed treatment on the 1% quartile.

Variable name	Equation (4)		
	Coef.	SE	*p* value
Main explanatory variables			
Pest control outsourcing services	0.727***	0.240	0.002
Degree of labor force aging	−0.493*	0.268	0.066
Control variables			
Farmers' Characteristics Variables	Controlled		
Household Characteristics Variables	Controlled		
Region	Controlled		
Year	Controlled		
Constant	1.949***	0.464	0.000
Observed value	1,045		
Hosmer-Lemeshow test	Chi-Square	*p*-Value	
	6.564	0.584	

*, ** and ***, denote significant at the 10, 5 and 1% statistical levels.

TABLE 6 Robustness test results based on subgroup regression.

Variable name	Labor force aging group					
	(5) Group I		(6) Group II		(7) Group III	
	Coef.	SE	Coef.	SE	Coef.	SE
Main explanatory variables						
Pest control outsourcing services	0.683**	0.309	0.609	0.475	−0.095	1.144
Control variables						
Farmers' Characteristics Variables	Controlled		Controlled		Controlled	
Household Characteristics Variables	Controlled		Controlled		Controlled	
Region	Controlled		Controlled		Controlled	
Year	Controlled		Controlled		Controlled	
Constant	2.580***	0.620	0.534	0.938	0.671	1.803
Hosmer-Lemeshow test	Chi-square	*p* value	Chi-square	*p* value	Chi-square	*p* value
	6.047	0.642	6.955	0.541	6.294	0.614

*, ** and ***, denote significant at the 10, 5 and 1% statistical levels.

the 1% level. In contrast, the aging agricultural labor force significantly negatively affects farmers' biopesticide application.

Second, there are significant differences in the impact of pest control outsourcing services on biopesticide application in the face of households with different levels of aging. The empirical results show that participation in pest control outsourcing services leads to increased use of biopesticides by the non-aging group compared to the aging group.

Third, the results of individual and household characteristics of farmers showed that farmers with more farming experience, larger planting areas, and membership in cooperatives were more likely to apply biopesticides. In contrast, the probability of biopesticide application was lower for those with more family farm labor and a higher share of farm income.

Finally, there are some limitations to this study. The degree of organization of pest control outsourcing may vary from crop to crop. The investigation object of this paper is rice farmers, which can only reflect the causal relationship between the pest control outsourcing services and the application of biopesticides in the context of the aging labor force of food crops. Perhaps the pest control behavior of cash crops is different, which is the direction of the next research.

Promoting biopesticides is of great significance to the development of green agriculture. Based on the conclusions drawn, the following recommendations are suggested:

Firstly, we should pay attention to the positive impact of pest control outsourcing on the application of biopesticides and treating pest control outsourcing organizations as an essential platform for the

promotion of biopesticides, increasing the promotion and publicity of pest control outsourcing services, and actively guiding the participation of aging agricultural decision makers in pest control outsourcing services.

At the same time, it is necessary to promote the standardization of pest control outsourcing services continuously. The existing pest control outsourcing organizations need to be registered and certified by the government departments of agricultural machinery and technology. It is suggested that members of these organizations should be trained on biopesticides, and the control organizations should be digitally registered with drug use information, which will not only improve the applicators' understanding of biopesticide application to the greatest extent, but also accelerate the integration of green production technology and pest control outsourcing organization platform. It will also make it easier for the public sector to monitor the scientific use of pesticides applied in the field.

Secondly, one of the prominent challenges facing agricultural production is the aging labor force. In the process of biopesticide promotion, it is vital to develop new ways to teach agriculture techniques and provide training for elderly workers. We should also increase awareness of biopesticides and educate older farmers about the dangers of traditional chemical pesticides and the benefits of using biopesticides. To spread the message, we can use village committees, large growers, and agricultural cooperatives as intermediaries to share information about national green prevention policies and raise awareness about protecting the environment.

Thirdly, the relevant government departments should increase the financial subsidies for biopesticides and pest control outsourcing, and this will help reduce the economic burden on farmers who choose to use these methods. Additionally, policies should be introduced to encourage companies to invest in research and development of biopesticides, which will ultimately lead to lower production costs and sales prices. As a result, farmers will be more likely to accept and utilize biopesticides in their farming practices.

Data availability statement

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

Author contributions

DS: Data curation, Formal analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. LW: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. LC: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. LW is sponsored by the National Natural Science Foundation of China (grant number: 71873035), and Science and Technology Special Innovation Fund of Fujian Agriculture and Forestry University: Study on the impact and effect of the adoption of control outsourcing services—based on the research of rice and water stem production. LC is sponsored by the talent introduction Project of Ningde Normal University (grant number: 2022Y20), and Fujian University Intelligence Unit for Target Poverty Alleviation and Poverty Relapse Prevention (grant number: KF10). The funders had no role in the study design, data collection and analysis, the decision to publish, or the preparation of the manuscript.

Conflict of interest

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

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