Journal of Integrative Agriculture
2012, 11(12): 2107-2115

Available online at www.sciencedirect.com
ScienceDirect

December 2012

RESEARCH ARTICLE

Farmer's Knowledge on GM Technology and Pesticide Use: Evidence from Papaya Production in China

HOU Lin-ke[1], HUANG Ji-kun[1], WANG Xiao-bing[1], HU Rui-fa[2] and XUE Chun-ling[3]

[1] *Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, P.R.China*
[2] *School of Management and Economics, Beijing Institute of Technology, Beijing 100081, P.R.China*
[3] *College of Economic and Management, South China Agricultural University, Guangzhou 510642, P.R.China*

Abstract

Genetically modified (GM) technology can significantly reduce pesticide use and increase yield in crop production. However, the benefit from reducing pesticide use varies substantially among farmers. The overall goal of this paper is to understand the relationship between farmers' knowledge of GM technology and pesticide use in genetically modified papaya (GMP) production. Based on a survey of 223 farms in three main papaya production provinces in 2010, the data show that almost all papaya planted in 2009 was genetically modified. However, only 28% of papaya farmers knew that they planted GMP, and 55% of them did not know GMP is resistant to papaya ringspot virus (PRSV). Further analyses using the general least squares (GLS) method show that farmers' knowledge of GMP significantly affects their pesticide use, and potential gain from GM technology is far below its full potential. The paper concludes with policy implications.

Key words: genetically modified papaya, knowledge, pesticide use

INTRODUCTION

There has been rapid growth of genetically modified (GM) crop areas since the late 1990s (James 2011). With an 87-fold increase from 1996 to 2010, the global accumulated GM crop area is now 1 billion ha, distributed across 29 countries (James 2011). The GM varieties carry favorable traits and include grains (e.g., maize and soybean), fruits and vegetables (e.g., melon, papaya, and tomato), and other common crops.

The rapid adoption of GM technology has boosted agricultural productivity. For example, Huang *et al*. (2002a) and Qaim and Zilberman (2003) show that Bt cotton reduced pesticide use and increased crop yield in China and India. These findings are also supported by evidence found in other countries (Thirtle *et al.* 2003; Hofs *et al.* 2006; Marvier 2007; Ali and Abdulai 2010).

Surprisingly, although Bt cotton reduced pesticide use on average, smallholders adopting Bt cotton continued to overuse pesticides. For example, Huang *et al*. (2002b) and Pemsl *et al*. (2005) found that despite significant reduction in pesticide use, Bt cotton farmers still used excessive amounts of pesticides. They also found that pesticide use varied substantially among farmers.

To explain why farmers overuse pesticide, existing studies have explored two potential mechanisms: risk preference and asymmetric information. First, risk aversion is often cited as one of the main reasons for farm-

---

Received 8 November, 2011 Accepted 9 March, 2012

Correspondence HUANG Ji-kun, Tel: +86-10-64889440, Fax: +86-10-64856533, E-mail: jkhuang.ccap@igsnrr.ac.cn

ers' excessive use of pesticide in the international literature (Carlson 1970; Feder 1979). The risk can result from psychological attitudes towards risk (risk preferences) and external factors. External factors help explain why the same farmer may make different decisions under different uncertain environments. As to the pesticides use case, external factors could include uncertainties on pest ecology, pest infestation, technology, and market. Huang *et al.* (2008) also suggested that smallholders were vulnerable to harvest risk from pest infestation, and hence inclined to overuse pesticide even after farmers adopted Bt cotton in China.

Secondly, imperfect information on technology is also an important factor that affects farmers' pesticide use as it contributes to uncertainty (Mas-Colell *et al*. 1995). Pingali and Carlson (1985) reported that more accurate assessment of subjective probabilities leads to lower pesticide use. Swinton and King (1994) found that herbicide use is often reduced under information-based management.

The overall goal of this paper is to understand the relationship between farmers' knowledge on GM technology and pesticide use on one important fruit among Chinese smallholders: genetically modified papaya (GMP). To achieve the overall goal, this study answers the following questions: What is the trend of GMP production in China? Do farmers know GMP technology? What are likely impacts of farmers' knowledge about GMP on their pesticide use?

The rest of this paper is organized as follows. Section 2 introduces the trend of papaya production and the development of GMP in China. Section 3 presents the sampling and data used in this study. Section 4 provides descriptive analysis on farm characteristics, farmers' knowledge on GMP and pesticide uses. Section 5 provides the empirical results based on GLS techniques of the impact of farmers' knowledge about GMP on their pesticide use by multivariate analysis. The last section concludes with policy implications.

PRODUCTION AND DEVELOPMENT OF GMP IN CHINA

GMP is a suitable case study because, like Bt cotton, there was widespread adoption among smallholders who continued to overuse pesticides. In 2006, China approved the commercialization of GMP, Huanong 1, and the crop area of GMP increased substantially thereafter. Based on our field survey to 223 papaya farms in Guandong, Guangxi and Hainan provinces, nearly all papaya farmers planted GMP by 2009, however, some farmers did not know that had planted GMP for several years, and some of other farmers did not know GMP reduced pesticide use. Meanwhile, we also observed that there were large differences in pesticide use among farmers although they planted the same GMP varieties.

Papaya is mainly produced in Southern part of China, including Hainan, Guangdong, Guangxi, Fujian and Yunnan provinces. It is a perennial plant, and normally grows for a couple of years. Before the middle 1990s, papaya was produced and consumed locally. There was nearly no expansion of papaya area in major provinces (Fig. 1). Papaya became a regular fruit for consumer overall China after the mid of 1990s. Demand for papaya has increased as income rose. Interestingly, the increased demand for papaya was not met by increased domestic production between the late 1990s and middle 2000s. Indeed, domestic production fell during this period (Fig. 1). The rising demand was largely met by increased import of papaya from international market (Fig. 2).

Interviews with producers and local agricultural officials revealed that a serious papaya disease was the main cause of falling papaya production in Chinese papaya production. A disease called papaya ringspot virus (PRSV) broke out after late 1980s. PRSV is a virulent plant pathogen, and its chief vector is the aphid. PRSV usually causes symptoms like yellow or mosaic leaves, distortion of leaves and deformed to inedible

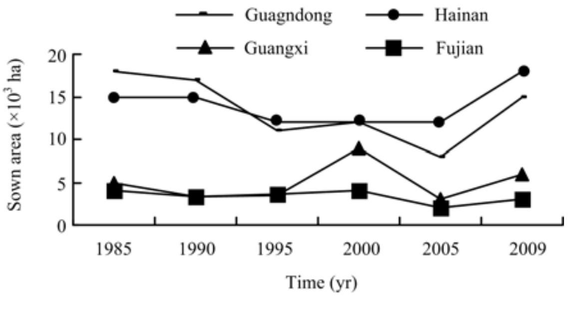

Fig. 1 Papaya sown area in Guangdong, Hainan, Guangxi and Fujian provinces in China (×10^3 ha), 1985-2009. Source: author's interview.

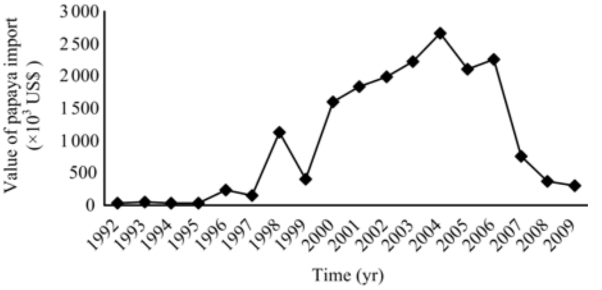

Fig. 2 Value of papaya import in China at 1992 constant price (×10^3 US$), 1992-2009. Source: Wind database, 1993-2010.

fruit. Moreover, severely infected plants die.

Prior to GMP, there was no effective approach against the virus. Initially, although farmers applied substantial pesticide to control PRSV, they reaped nearly nothing at harvest time. Later, farmers would cut down infected papaya plants and bury them deeply in soil. In Guangdong and Hainan, some farmers had to give up papaya production even though the price of papaya was rising. In Fujian province, there was no any expansion of papaya area in the 1990s and actually fell in the early 2000s. In sum, the production and land area of papaya fell during the 1990s.

Guangxi Province experienced a rising area of papaya in the late 1990s, but its area also fell significantly in the early 2000s (Fig. 1). Local officials told us that the expansion of papaya area in Guangxi in the late 1990s was mainly due to several state farms that initiated large papaya plantation through the reclamation of new land in response to rising market demand for and increasing price of papaya. However, after a couple of years of papaya production, the outbreak of PRSV also occurred in the reclaimed land. As what should be expected, papaya area also decreased significantly in the early 2000s in Guangxi.

In fact, the outbreak of PRSV also occurred worldwide before the 1990s. Severe PRSV had been plagued over Brazil, Hawaii and Thailand from the 1960s to 1990s (Stokstad 2008; Napasintuwong and Traxler 2009). In Hawaii, the production of papaya was reduced largely from 1992 to 1997 because of the outbreak of PRSV. To address PRSV problem, scientists successfully transformed viral coat proteins (CPs) into papaya with resistant to PRSV in Hawaii in 1998 (Gonsalves *et al.* 2007). Introduction of GMP has helped Hawaii to restore its papaya production since the early 2000s.

Scientists in China also initiated a GMP research program in the 1990s. In 1998, the trans-genetic material for papaya was found by College of Natural Resources and Environment, South China Agricultural University. In 2004, a biotech papaya variety viral replicase gene and resistant to papaya ringspot virus (PRSV) — Huanong 1, was developed by South China Agricultural University. After years of field trials, this GMP was approved for commercialization in Guangdong Province by China's National Biosafety Committee in 2006.

With commercialization of Huanong 1 and the adoption of other GMP abroad, papaya production has recovered and increased steadily after 2006 (Fig. 1). In 2009, almost all the four provinces reached or surpassed their production level before PRSV attack. Accompanied with an increase in the domestic production of papaya after 2006, imports have declined significantly. The value of papaya import fell to about 500 thousand US$ in 2009, which was only one sixth of the imports in 2006 (Fig. 2).

SAMPLING APPROACH AND DATA

The data used in this study were collected in January, 2010, by Center for Chinese Agricultural Policy, Chinese Academy of Sciences. The sample collection proceeded in a stratified random way. First, three provinces, Guangdong, Guangxi and Hainan, were selected, as these three provinces account for more than 90% of papaya production in China. Second, a total of 15 villages were randomly selected from Guangdong (9 villages), Guangxi (3 villages) and Hainan (3 villages) to reflect potential differences in production technologies, scale of farming, and papaya usage for vegetable, fruit or processing materials. Finally, we randomly selected papaya farms (households) from the selected villages. Papaya in Guangdong and Guangxi in our study villages were mainly produced by the small-scale farms, therefore we selected more farms from these two provinces for survey. At end, there were 138 households and 72 households that were surveyed and had complete and valid information from Guangdong and Guangxi, respectively. In Hainan, because nearly all papaya farms were large-scale and the number of papaya farms was small, we interviewed all papaya farms (13) that had produced and sold papaya in the 3 villages selected. In total, we have 223 valid papaya farms used in this study.

The survey covered detailed information on the papaya plantation, household characteristics, and farmers' knowledge on GMP. In order to document the evolution of GMP's adoption, we collected detailed information on the history of varieties on the largest plot of papaya from each papaya farm household in the past 5 yr; production, inputs, particular pesticide use, and yield by plot in 2009. For farmers' knowledge on GMP technology, we designed a knowledge test with the following three questions. They are: "Do you believe you planted GMP in your field?"; "Is GMP resistant to PRSV?"; and "Does GMP reduce pesticide use?".

CHARACTERISTICS AND KNOWLEDGE OF FARMERS ON GMP AND PESTICIDE USES

Characteristics of farms and pesticide uses

Our survey revealed that, except for one household, all farmers surveyed planted GMP in 2009. This conclusion is based on the lab test of the papaya samples from farm's field. During the field survey, fresh leaves, fruit or seeds were collected from each farm field and stored in a plastic pack as samples by enumerators. These samples then were directly sent to Institute of Tropical Bioscience and Biotechnology, Chinese Academy for Tropical Agricultural Sciences (CATAS), for papaya' GM traits test. In total, 211 papaya samples (168 samples from Guangdong; 24 samples from Guangxi and 19 samples from Hainan, respectively) were tested. The number of samples tested was less than that of samples surveyed because when we implemented the survey in January, 2010, some farmers, especially those in Guangxi had cut their papaya trees, and thus we were not able to collect papaya samples to laboratory test. Of 211 papaya samples, 210 samples were GMP and only one sample was negative to GMP by using CaMV35S promoter and NOS terminator tests.

Table 1 presents the statistical description of variables used in this study. The results show there were variations of the quantity of pesticide and price across provinces. The average quantity of pesticide used in Hainan (23.2 kg ha^{-1}) was 4-5 kg ha^{-1} more than that used in Guangdong or Guangxi. Consistent with quantity of pesticide use, pesticide price in Hainan was lowest among three provinces.

Data shows that papaya is mainly produced by smallholders (Table 1, row 3). The average size of farms was only 1 ha while they were only 0.4 and 0.7 ha in 2009 in Guangdong and Guangxi, respectively. The large-scale farms with average size of 7.4 ha appeared in Hainan because, in our samples, there were a few papaya farms that were operated by external investors from Taiwan of China (and other places) who rented land from local villages or households and consolidated cropland for their papaya production in recent years. For the characteristics of household's head, there is no statistically significant difference in the aspects of age and the years of education attainment across provinces (the results of *t*-tests are not reported here). On average, household head was 48 yr old with nearly 8 yr of formal education (Table 1, column 1, rows 4-5).

Table 1 Descriptive statistics of papaya farms in China, 2009[1)]

	Average	Guangdong	Guangxi	Hainan
Pesticide use (kg ha^{-1})	18.3	17.8	18.4	23.2
Pesticide price (RMB yuan kg^{-1})	94.0	98.4	87.9	80.0
Household Characteristics				
Papaya area (ha)	1.0	0.7	0.4	7.4
Age of household head (yr)	48.3	49.5	46.2	47.1
Education of household head (yr)	7.7	7.2	8.3	8.5
Farm characteristics				
Papaya for vegetable (%)	22	35	0	8
Papaya for fruit (%)	69	62	78	92
Papaya for processing materials (%)	9	4	22	0
Percentage of intercropping or inter-planting area (%)	26	26	27	23
Samples	223	138	72	13

[1)] Source: authors' own survey. The same as below.

Our samples covered papaya usage as fruit, vegetable or processing materials (Table 1, rows 6-8). It was observed that around 70% of papaya was fruit papaya. Vegetable papaya was mainly produced in Guangdong, while around a quarter of papaya was used as processing materials in Guangxi.

In the management of papaya production, intercropping or inter-planting was also used in all of the three provinces. Our data showed that around one quarter (26%) of farmers planted papaya intercropped with other crops (e.g., peanuts or beans, Table 1, penultimate row). Farmers believed that intercropping or inter-planting of other crops with papaya could help to reduce the severity of PRSV breakouts.

Table 2 summarizes the relationship between pesticide use and pesticide price as well as other factors. There is an obviously negative correlation between price and the quantity of pesticide use, such that the higher the price, the less the quantity of pesticide used. There seems no consistent or obvious relationship between pesticide use and age of household head or education. Differences of pesticide use across product usage were evidenced. For the processing product, farmers used an average of 20 kg ha^{-1} in papaya production in 2009, which was higher than those used for fruit (18.9 kg ha^{-1}) and vegetable (15.6 kg ha^{-1}). As mentioned earlier, intercropping or inter-planting of papaya with other crops helps to alleviate the negative impact of PRSV. Farmers decreased pesticide use on plots with more than 50% of intercropping or inter-planting by around 4 kg ha^{-1} (with the non-intercropping and non-interplanting taken as a reference).

Farmers' knowledge on GMP and pesticide uses

Our survey evaluated farmers' knowledge on GMP and its relationship with pesticide use. To do so, Table 3 reports the results of tests on farmers' knowledge about GMP. Interestingly, despite the rapid expansion of GMP in study areas, a majority of farmers (72%) did not know that they actually planted GM crop. Less than half of the farmers (45%) knew GMP is resistant to PRSV and only 52% of them knew that less pesticide was needed in the planting of GMP. These results are not surprising as we were told by farmers that no staff had visited them in recent years, which is also consistent with the nationwide weakening of the agricultural extension system (Hu *et al*. 2007). Furthermore, interviews with seedling dealers and traders revealed that they seldom told farmers the varieties purchased by farmers were GMPs due to marketing concern. This is not surprising because papaya is not listed in the directory of "Regulation of Genetically Modified Organism Safety" even the GM papaya has been officially commercialized in China since July, 2006.

To better understand farmers' knowledge on GM

Table 2 Papaya farmer's characteristics and pesticide use in 2009

	Sample	Pesticide use	
		Mean (kg ha^{-1})	Standard deviation
Total	223	18.3	16.2
By pesticide price (RMB yuan kg^{-1})			
≤44	79	24.9	17.9
44-90	74	21.1	15.8
>90	70	7.9	7.10
By age of household head			
≤40	54	18.9	14.9
40-50	85	18.1	16.4
>50	84	18.1	16.9
By education of household head			
Elementary school or below	81	17.6	17.2
Middle school	105	18.4	15.4
High school or above	37	19.5	16.5
By product usage			
Papaya for vegetable	49	15.6	14.4
Papaya for fruit	153	18.9	16.2
Papaya for processing materials	21	20.0	19.8
By intercropping/inter-planting area (%)			
0	103	19.7	17.4
1-50	96	17.5	15.6
>50	24	15.5	13.2

Table 3 Papaya farmer's knowledge on GMP

Questions	Answer (%)	
	Yes	No
Do you believe you planted GMP?	28	72
Is GMP resistant to PRSV?	45	55
Does GMP use less pesticide?	52	48

technology and pesticide use, Table 4 reports pesticide use by different groups of farmers with different knowledge on GMP reported in Table 3. First, farmers are classified into two groups: those who knew they planted GMP, and those who did not know they actually already planted GMP in their field. Second, within each of the two groups, farmers were further classified into two subgroups: those who knew that GMP is resistant to PRSV or GMP can use less pesticide, and those who did not know that GMP is resistant to PRSV and GMP can use less pesticide.

As Table 4 shows, the farmers who knew they planted GMP, on average, used less pesticide (14.9 kg ha^{-1}) than those who did not know (19.6 kg ha^{-1}, rows 2 and 3). The joint effect of knowledge on whether planted GMP and benefits of GMP's resistant to PRSV or pesticide use is even larger. For example, on the condition of knowing they planted GMP, the group who knew GMP is resistant to PRSV or GMP can use less pesticide only used 13.3 kg ha^{-1} (column 3), which was much less than that used by the other three groups of farmers. These also motivate us to empirically measure the direction and magnitude of the impacts of farmers' knowledge about GMP on pesticide use in the next section.

MODEL SPECIFICATION AND EMPIRICAL RESULTS

Model specification

To measure the impact of farmers' knowledge on the application of pesticide, we specify the following model:

$$Y_i = a_1 + mK_i + cP_i + dX + e_i \quad (1)$$

Where Y_i represents the pesticide use per hectare (kg ha^{-1}) by the *ith* household in papaya production. K is dummy variable equaling to 1 if they knew that they planted GMP, 0 otherwise. The coefficient m measures how much the farmers who knew that they planted GMP used less chemical pesticide than those who did not know that they planted GMP. The variable P_i denotes the average price of pesticide, which was calculated by total expense on pesticide divided by aggregated quantities of pesticide bought in the market for *i*th household, and thus the coefficient of c is the marginal effect of pesticide price. The vector, X, includes household and farm characteristics, as well as village dummy. The variables representing household characteristics include age and education attainment of household head (both of them are measured in years). Variables on plot features include two dummies on papaya variety (one dummy variable that equals to 1 if the papaya was used for fruit, and 0 otherwise; the other dummy variable that equals to 1 if the papaya was used for processing, and 0 otherwise) and percent age of intercropping and inter-planting area. Village dummies are included to control for unobserved heterogeneity across villages. The parameters, d, denotes a set of coefficients for the control variables; e_i is error terms.

Based on eq. (1), we extend it to further explore the impacts of interaction of knowledge and information on pesticide use with more detailed information on knowledge and information in the following form:

$$Y_i = a_1 + b_1K_{1i} + b_2K_{2i} + b_3K_{3i} + cP_i + dX + e_i \quad (2)$$

Compared with eq. (1), here we introduce three dummy variables K_1, K_2 and K_3. K_1 equals to 1 if farmers knew that GMP was resistant to PRSV when they planted GMP, 0 otherwise. K_2 equals to 1 if farmers did not know that GMP was resistant to PRSV, but they did know they planted GMP, 0 otherwise. K_3 equals

Table 4 Pesticide use by papaya farmer's knowledge on GMP in 2009

	Sample	Pesticide use (kg ha^{-1})		
		Average	Knew resistant to PRSV or GMP uses less pesticide	Did not know resistant to PRSV and GMP uses less pesticide
All farmers	223	18.3	17.3	20.0
Farmers knew they planted GMP	62	14.9	13.3	23.0
Farmers did not know they planted GMP	161	19.6	19.7	19.6

to 1 if farmers knew that GMP was resistant to PRSV but did not know they planted GMP in their own field, 0 otherwise. Holding other variables constant, the sign and magnitude of coefficients b_1, b_2 and b_3 measure whether and to what extent farmers' knowledge on GMP have impact on their pesticide use. Other controlling variables used in eq. (2) are the same as those in eq. (1).

Impacts of knowledge and other factors on pesticide use

The two equations are estimated by GLS and the results are reported in Table 5. The results in columns 1 and 2 refer to eqs. (1) and (2), respectively. The results show that our models generally perform well in explaining pesticide use. The adjusted R^2 equals 0.27 in eq. (1) and 0.28 in eq. (2), which is considerably good for cross-sectional data used in this study. Major variables, including the proxies of knowledge and information and pesticide price, are statistically significant with the expected signs (Table 5, rows 1-6).

The column 1 in Table 5 shows that, after controlling for the effects of other factors, farmers reduced their pesticide use by 4.16 kg ha^{-1} if they knew their papaya was a GM variety. This is about 25% of the average pesticide amount used by farmers. This result is also consistent with the descriptive statistics presented in Table 4. In the second model (Table 5, column 2), holding other factors constant, farmers who knew that GMP is resistant to PRSV, reduced the pesticide use by 5.17 kg ha^{-1}, on the condition that they knew they planted GMP. The reference is farmers who neither knew they planted GMP nor the GMP resistance to PRSV.

While the regressions do not find significant effects of household characteristics on pesticide use, pesticide prices and papaya farm practices matter. For example, the results also show that farmers responded to pesticide price when they applied pesticide. The estimated parameter was statistically significant at the 1% level (Table 5, row 5). While there was no statistically difference in pesticide input between farmers who planted fruit papaya and farmers who planted vegetable papaya, farmers who planted papaya for processing materials used about 12 kg ha^{-1} (Table 5, row 12) more pesticide. This result is expected as both fruit and vegetable papaya are for direct consumption, and there could be concern about pesticide residuals on edible papaya.

The role of extending information and knowledge needs to be highlighted for policy makers when they

Table 5 GLS estimation of the impact of farmers' knowledge about GMP on pesticide use

	Pesticide use (kg ha^{-1})	
	Model 1	Model 2
Farmers knew that they planted GMP	-4.16 (1.89)*	
Knew GMP resistant to PRSV or GMP uses less pesticide (*K1*)		-5.17 (1.95)*
Did not know GMP resistant to PRSV or GMP uses less pesticide (*K2*)		3.38 (0.86)
Farmers did not know that they planted GMP		
Knew GMP resistant to PRSV or GMP use less pesticide (*K3*)		0.70 (0.28)
Pesticide price (RMB yuan kg^{-1})	-0.07 (6.95)***	-0.07 (6.79)***
Household characteristics		
Age of household head (yr)	-0.04 (0.29)	-0.02 (0.18)
Education of household head (yr)	-0.38 (0.89)	-0.38 (0.88)
Farm characteristics		
Papaya for fruit	3.57 (1.12)	3.67 (1.14)
Papaya for processing materials	12.89 (2.05)**	11.95 (1.92)*
Percentage of intercropping or inter-planting (%)	-0.08 (1.99)*	-0.08 (2.10)*
Village dummies	No report	No report
Constant	29.22 (3.34)***	27.76 (3.07)***
Model diagnosis:		
1. Test of collinearity		
The largest VIFs	3.31	3.36
2. Test of homoskedasticity (Breusch-Pagan test)		
Chi-squared	25.6	24.13
No. of observations	223	223
Adjusted R^2	0.27	0.28

z-statistics in parentheses, ***, ** and * represent statistically significant at 1, 5 and 10%, respectively. The largest variance inflation factors (VIFs) of the independent variables in the two models are 3.31 and 3.36, implying no collinearity between variables. The chi-squared values of Breusch-Pagan test are 25.6 and 24.1, respectively, suggesting that the null hypothesis of homoskedasticity cannot be rejected. We, therefore, use GLS to correct for heteroskedasticity.

introduced new technologies to small-scale farmers. Huang *et al.* (2003) asserted that China should rely on new technologies to reduce environmental stress and health damage caused by the overuse of chemical pesticides and herbicides. However, even after new technologies have been introduced, our results indicate that delivering appropriate information and knowledge to farmers on novel technologies can help farmers in fully reaping the benefit promised by the technologies.

CONCLUSION

The goal of this study to evaluate the impact of knowledge and information on the use of pesticide by using papaya as a case study. Our study is based on survey data from 223 farms in Guangdong, Guandxi and Hainan provinces. Descriptive statistics show that smallholders on average use a large amount of pesticide (18.3 kg ha^{-1}) against PRSV. It is noted that even though lab test of papaya sample showed that almost all of farmers planted GMP, more than 70% of them did not know that they plant GMP. This suggests that farmers should be provided better information on varieties either through the seed selling system or technology extension system.

Our results are consistent with the existing studies (Mas-Colell *et al*. 1995; Munshi 2004; Huang *et al*. 2010) that farmers' information and knowledge are correlated with their pesticide use. Descriptive analyses show that farmers with better information and knowledge tend to use less pesticide. Econometric analysis confirmed descriptive statistics that farmers who knew they planted GMP use 22% less pesticide than their counterparts who did not know they planted GMP. Furthermore, famers who knew that GMP is resistant to PRSV use much less pesticide compared to their counterparts, conditional on their knowing that they planted GMP.

These results suggest that a technology extension service which disseminates information and knowledge can help farmers further reduce their pesticide input even after they adopt GMP. The reduction of pesticide use in production is to a larger extent dependent on the knowledge of biotechnology rather than only adopting it in the production. This, in turn, suggests that further extension either of biotechnology or of conventional technology should provide training services to smallholders to improve their knowledge on technology.

Finally, we found that land under cultivation of papaya was almost devoted to GM crop in 2009 in the sampled areas. This indicates that the recovery of papaya area after 2007 was at least partly boosted by spread of GM variety. Even though GMP has been widely adopted in China, smallholders still had poor information and knowledge on it. Thus, how to effectively extend GM technology to farmers is a pressing problem that should be addressed in the future.

Acknowledgements

This work was supported by the the National Key Program on Genetically Modified New Varieties, China (2011ZX08015-002) and the International Development Research Center (106100-001).

References

Ali A, Abdulai A. 2010. The adoption of genetically modified cotton and poverty reduction in pakistan. *Journal of Agricultural Economics*, **61**, 175-192.

Carlson G A. 1970. Decision-theoretic approach to crop disease prediction and control. *American Journal of Agricultural Economics*, **52**, 216-226.

Feder G. 1979. Pesticides, information, and pest management under uncertainty. *American Journal of Agricultural Economics*, **61**, 97-103.

Gonsalves C, Lee D R, Gonsalves D. 2007. The adoption of genetically modified papaya in Hawaii and its implications for developing countries. *Journal of Development Studies*, **43**, 177-191.

Hofs J, Fok M, Vaissayre M. 2006. Impact of bt cotton adoption on pesticide use by smallholders: A 2-year survey in makhatini flats (South Africa). *Crop Protection*, **25**, 984-988.

Hu R, Shi K, Cui Y, Huang J. 2007. Change in China's agricultural research investment and its international comparison. *China Soft Science*, **2**, 53-58. (in Chinese)

Huang J, Hu R, Pray C, Qiao F, Rozelle S. 2003. Biotechnology as an alternative to chemical pesticides: a case study of bt cotton in China. *Agricultural Economics*, **29**, 55-67.

Huang J, Hu R, Rozelle S, Qiao F, Pray C E. 2002a. Transgenic varieties and productivity of smallholder cotton farmer in China. *The Australian Journal of Agricultural and Resource Economics*, **46**, 1-21.

Huang J, Mi J, Lin H, Wang Z, Chen R, Hu R, Scott R, Carl P. 2010. A decade of bt cotton in chinese fields: assessing the direct effects and indirect externalities of Bt cotton adoption in China. *Science China* (Life Science), **53**, 981-991.

Huang J, Qi L, Chen R. 2008. Knowledge on technology, risk preference and farmers' pesticide use. *Management World*, **5**, 71-76. (in Chinese)

Huang J, Rozelle S, Pray C, Wang Q. 2002b. Plant biotechnology in China. *Science*, **295**, 674-677.

James C. 2011. *Global Status of Commercialized Biotech/GM Crops:2011*. The International Service for the Acquisition of Agri-Biotech Applications, USA.

Marvier M, McCreedy C, Regetz J, Kareiva P. 2007. A meta-analysis of effects of Bt cotton and maize on nontarget invertebrates. *Science*, **316**, 1475-1477.

Mas-Colell A, Whinston M D, Green J R. 1995. *Microeconomic Theory*. Oxford University Press, New York. pp. 205-216.

Munshi K. 2004. Social learning in a heterogeneous population: technology diffusion in the indian green revolution. *Journal of Development Economics*, **73**, 185-213.

Napasintuwong O, Traxler G. 2009. Ex-ante impact assessment of GM papaya adoption in thailand. *AgBioForum*, **12**, 209-217.

Pemsl D, Waibel H, Gutierrez A P. 2005. Why do some bt-cotton farmers in china continue to use high levels of pesticides? *International Journal of Agricultural Sustainability*, **3**, 44-56.

Pingali P, Carlson G A. 1985. Human capital, adjustments in subjective probabilities, and the demand for pest controls. *American Journal of Agricultural Economics*, **67**, 853-861.

Qaim M, Zilberman D. 2003. Yeilds effect of genetically modified crop in developing countries. *Science*, **299**, 900-902.

Stokstad E. 2008. GM papaya takes on ringspot virus and wins. *Science*, **320**, 472.

Swinton S M, Robert P K. 1994. The value of pest information in a dynamic setting: the case of weed control. *American Journal of Agricultural Economics*, **76**, 36-46.

Thirtle C, Beyers L, Ismael Y, Piesse J. 2003. Can gm-technologies help the poor? The impact of Bt cotton in makhathini flats, KwaZulu-Natal. *World Development*, **31**, 717-732.

(Managing editor WENG Ling-yun)