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Willingness of South Florida Fruit Growers to Adopt Genetically Modified Papaya: An *Ex-ante* Evaluation

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Papaya ringspot virus (PRSV) has been a major factor inhibiting the expansion of papaya production in South Florida. The University of Florida has developed transgenic papaya line X17-2, which is tolerant to PRSV, is suitable for commercial production, and has a potential yield improvement as high as 239%. In spite of the yield potential, some fruit growers may be skeptical about adopting this improved GM cultivar for a variety of reasons. Consequently, a probit model with data from a survey of likely producers was used to identify those factors that may influence the adoption of new GM papaya cultivars. Education level, farm size, and income derived from agriculture were among the factors likely to affect adoption of the technology. The findings suggest that a targeted education program will go far in increasing the rate of adoption of the technology.

Key words: genetic engineering techniques, papaya ring spot virus, PRSV, papaya line X17-2.

Introduction

The debate about agricultural technology adoption, which traditionally has centered on innovations in conventional crop practices, has shifted to the adoption of genetically modified (GM) crops. Much of the literature in this regard has focused on factors influencing the adoption of field/row crops. In contrast, little or no attention has been given to researching the factors influencing or likely to influence the adoption of GM orchard crops. Such investigation is warranted given the perennial nature as well as the extent of the sunk/upfront costs involved in orchard production as compared to field/row crops. Consequently, the aim of this study is 1) to contribute to filling such a gap in the literature and 2) to explore the factors likely to influence the adoption of GM papaya in South Florida.

The latter objective is motivated by the fact that within the continental United States, South Florida offers the best conditions for papaya cultivation, as the region's subtropical climate is suitable to grow the crop year-round. Unfortunately, as in many other papaya production areas of the world, the papaya ringspot virus (PRSV) has been a major factor inhibiting the expansion of papaya production in South Florida. PRSV is a devastating disease with negative economic consequences for growers. To overcome this constraint, the University of Florida used genetic engineering techniques to develop transgenic papaya line X17-2, which is tolerant to PRSV and is suitable for commercial production in Florida, as well as Puerto Rico and the Caribbean region. This new papaya line has been the base for the development of four papaya cultivars, which are expected to be released initially to South Florida growers by 2018. The expected yield improvement is assumed to be more than 200%, as the potential yield of GM papaya is 95 tons/ha (Migliaccio, Schaffer, Crane, & Davies, 2010), whereas the average yield of conventional non-GM papaya production is assumed to be 25.22 tons/ha (Crane & Mossler, 2009). Consequently, there is a need to identify those factors that may influence the adoption of new GM PRSV-tolerant papaya cultivars in an *ex-ante* situation so that a targeted education program can be effected. To our knowledge, no previous research has focused on these factors in the US papaya market.

Background

Papaya ringspot virus (PRSV) is a major limiting disease in commercial papaya production worldwide (Gonsalves, 1998). Aphids are the vector agents responsible for transmitting the disease, and once it is introduced to a locality, it becomes established in weeds and perennial plants. Management strategies such as use of insecticides, removal and destruction of diseased plants, and quarantine regulations have had very limited success in controlling the PRSV disease. The development of papaya cultivars tolerant to PRSV using conventional breeding techniques has been difficult given that tolerance to PRSV is believed to be multigenic[1] (Fitch, 2010).

1. *Multigenic or polygenic resistance to a plant disease involves several genes. This type of resistance is harder to define; exactly which genes are involved may be unknown (Munkvold, 1996).*

In 1992, PRSV was discovered in the Puna region in Hawaii. By 1997, Hawaii's papaya production had dropped by one-half despite efforts to prevent the spread of the PRSV disease. To avert future damage to the Hawaiian papaya industry, scientists at Cornell University and the University of Hawaii collaborated to develop a papaya cultivar tolerant to PRSV. As a result of this effort, transgenic papaya line 55-1 was obtained using genetic engineering techniques to develop the Hawaiian papaya cultivars "SunUp" and "Rainbow," both of which possess several desirable production and market characteristics. Within the first year of release, the adoption rate of these GM cultivars was about 98% (Gonsalves, Lee, & Gonsalves, 2007). The high adoption rates following the release of these successful GM papaya cultivars was attributed to several factors, including positive communication campaigns, farmer engagement during the research and development and field trials, distribution of approximately 1,134 kg of free seeds to registered growers, and the fact that the technology addressed an immediate problem affecting farmers' livelihoods (Gonsalves et al., 2004). Despite the success the GM papaya cultivars had in saving the Hawaiian papaya industry, the downside is that licensing requirements and certain horticultural characteristics such as cold intolerance restrict these cultivars to production in Hawaii.

Within the continental United States, papaya can be grown year-round in South Florida (specifically Miami-Dade, Broward, and Palm Beach Counties), where the region's subtropical climate is suitable for the crop. After peaking at more than 500 acres in the early 1970s, papaya acreage has remained low due to a combination of factors, including low-cost papaya imports, and production constraints due to PRSV (C. Balerdi, personal communication, 2012). These factors have restricted domestic production largely to the green market segment. Green papayas are widely used in Asian cuisine, especially Vietnamese and Thai cuisine. Thus, the high yield potential of the new GM papaya cultivars may prove sufficient to boost papaya production in South Florida.

During 2008, 2009, and 2016, the US Food and Drug Administration (FDA), the Animal and Plant Health Inspection Service of the US Department of Agriculture (USDA APHIS), and the US Environmental Protection Agency (EPA), respectively, deregulated the University of Florida X17-2 transformed line (USDA APHIS, 2009). During this time-frame, field evaluations were conducted to evaluate four transgenic papaya lines (all with the X17-2 background) of the Solo and Maradol papayas suitable for commercial production in South Florida. It is expected that these new papaya cultivars could be released to the public by late 2018. The availability of new transgenic PRSV-tolerant papaya cultivars adaptable to South Florida conditions will help to diversify agricultural production in South Florida at a time when growers are actively looking for alternatives to increase farm income. We examine this issue in this article.

Conceptual Framework

Previous research on the adoption of agricultural technological innovations has concluded that farm size, land ownership, profitability/economics, risk perception, grower demographics, and production experience are among the factors having a significant effect on the decision by growers to adopt new technologies (Feder, Just, & Zilberman, 1985; Fernandez-Cornejo et al., 2007).

Factors related to grower demographics and production experience play significant roles in the adoption of new technologies. For example, younger growers are more likely to adopt innovations because they have a longer time horizon to gain experience and increase their revenues (Alexander & Van Mellor, 2005; Rogers, 1995). It has also been documented that the probability of adoption by growers increases with the number of years of formal education and previous production experience (Breustedt, Muller-Scheesel, & Latacz-Lohmann, 2008; Fernandez-Cornejo & McBride, 2002). Previous production experience of the grower with a particular crop is especially important if the GM crop possesses a trait that increases yields and reduces production costs when compared to the conventional crop.

Farm characteristics such as farm size play an important role in technology adoption decisions due to the uncertainty and risks involved. Larger growers are more likely to be early adopters due to risk factors (Feder & O'Mara, 1981; Fernandez-Cornejo et al., 2007; Just, Zilberman, & Rausser, 1980).

Past studies have examined the relationship between off-farm income and GM crop adoption decisions (Fernandez-Cornejo, Hendricks, & Mishra, 2005; Keelan, Thorne, Flanagan, Newman, & Mullins, 2009). It has been hypothesized that GM crops offer time savings and flexibility in crop management; however, empirical results are mixed. For example, Fernandez-Cornejo et al. (2005) found that off-farm income was a positive and significant factor for GM crop adoption decisions, whereas Keelan et al. (2009) did not find a significant relationship between these variables. It would be more realistic to explore GM crop adoption decisions when the major source of income comes from agriculture, which is the approach followed in the present study. Given the risk involved with the adoption of a new technology, we may expect a negative relationship between 'GM papaya adoption' and 'agriculture as the main source of income.' In other words, farmers whose livelihoods depend almost entirely on income from farming might be less likely to adopt the GM papaya.

New technologies in agriculture are considered risky (Griliches, 1957; Sunding & Zilberman, 2001). Risk perception may be even more pronounced when the new technology is a GM crop with no or limited market presence. Several studies dealing with GM crop adoption have modeled risk through very diverse factors, including the debt-to-asset ratio (Fernandez-Cornejo & McBride, 2002), expected liability (Breustedt et al., 2008), and knowledge about GM energy crops (Keelan et al., 2009). For example, knowledge about GM crops may be helpful to minimize risk. Guehlstorf (2008) found that when public institutions and private companies provide scientific information about GM crops, growers' perception of risk about GM crops decreases. It is expected that knowledge about GM crops will have a positive effect on GM crop adoption.

Although either logit or probit models can be employed in these types of analysis, the probit model and its variants has been the preferred option in recent studies evaluating the adoption of a GM crop in an *ex-ante* setting (Breustedt et al., 2008; Keelan et al., 2009; Kolady & Lesser, 2006).

Breustedt et al. (2008) estimated a multinomial probit model to explore the *ex-ante* adoption of GM oilseeds by German growers. They found that profit expectations, grower demographics, production experience, and farm characteristics were the main factors driving the adoption of GM rape oilseed, and had a positive and significant relationship with the likelihood of GM rape oilseed adoption.

Keelan et al. (2009) also evaluated the *ex-ante* adoption of GM crops by Irish growers. They estimated a probit model to establish which characteristics may influence the adoption of GM crops. It was found that farm size, agricultural experience, and soil type had a positive and significant effect over the likelihood of Irish growers adopting GM crops.

Empirical Model and Data

Because the decision to adopt a new technology can be considered a dichotomous choice problem, empirical estimation involves the use of limited dependent variable models. These types of models estimate the probability of growers' willingness to adopt the new technology based on selected characteristics. Following recent studies (Breustedt et al., 2008; Keelan et al., 2009) on the adoption of GM crops in an *ex-ante* setting, we use the probit model for the empirical estimation.

The data used in the present study were obtained from an online survey conducted from November 2013 to February 2014 using Qualtrics software. The survey was distributed online to 60 members of the South Florida tropical fruit growers' association. A total of 42 surveys were returned, but only 30 surveys were completed, resulting in a response rate of 50%. The sample included 21 current and former papaya growers, representing 37% of the papaya growers in South Florida. While the sample size may seem small, according to the 2012 US Census of Agriculture, there are 57 active papaya growers in South Florida (USDA, National Agricultural Statistics Service [NASS], 2012). To estimate the adoption of the new GM papaya cultivars the following probit model is specified and estimated:

$$Y = \mathbf{X\beta} + \varepsilon \tag{1}$$

The dependent variable Y consists of a binary variable that takes the value of one (1) if the grower is willing to grow the new GM papaya cultivars, and takes the value of zero (0) otherwise. The vector $\mathbf{X}$ corresponds to a vector of independent variables that explain growers' willingness to grow the new GM papaya cultivars, including growers' demographics and farm and risk characteristics. The vector $\boldsymbol{\beta}$ represents unknown parameters to be estimated. The term ε represents the error term which is assumed to be normally distributed. Table 1 presents a description of the variables used in the present study.

Variables related to the grower demographics include age, educational level, and previous experience growing papaya. Age is a dummy variable that takes the value of one if the grower is 60 years old or older and zero otherwise (age is chosen as the dummy variable because most of the respondents fall into two of four groups). Table 1 shows that 65% of the survey respondents are 60 years old or older.

Educational level is a binary variable that takes the value of zero if the grower has a bachelor's degree or less, and takes the value of one if the grower has a grad-

Table 1. Summary statistics for the variables included in the model (n=30).

Variable	Description	Mean	Std. dev.	Min	Max
Dependent variable					
GM adoption	Willingness to adopt new GM papaya cultivars	0.617	0.493	0	1
Independent variables					
Age	Age of grower	0.656	0.482	0	1
Educ	Educational level of grower	0.323	0.474	0	1
Exp	Experience growing papaya	0.617	0.493	0	1
Size	Size of the farm in acres	29.16	36.18	2	118
Inc_agr	Agriculture is main income source	0.424	0.501	0	1
GM_knw	GM knowledge	0.323	0.474	0	1

uate degree. About 32% of the respondents have graduate (or advanced professional) degrees. Previous papaya growing experience is a dummy variable that takes the value of zero if the grower has no previous experience growing papaya, and takes the value of one if the grower has grown papaya in the past. About 62% of the survey respondents have experience growing papaya.

Farm size is a continuous variable that indicates the size of the farm in acres. To test for the existence of a threshold level, the variable size squared is included in the model to measure the likelihood of adoption diminishing at some point. Farm size in the survey ranges from 2 acres to 118 acres, with an average value of 26 acres.

Growers were asked whether agriculture was their main source of income. The variable takes the value of one if 75% or more of their total income comes from agriculture and zero otherwise. About 43% of the respondents indicated that agriculture was their main source of income.

Previous knowledge about a particular innovation may help to minimize the risk of adopting it. In the present study, we relate risk to knowledge of GM crops. To evaluate growers' GM crop knowledge, they were asked whether they considered themselves knowledgeable about GM crops such as corn and soybean. GM knowledge is a dummy variable, where a value of one indicates that the grower is knowledgeable of GM crops and zero otherwise. Table 1 shows 32% of the respondents are knowledgeable about GM crops.

Table 2. Estimation results of the probit model on the probability of adoption of GM papaya.

Variable	Coefficient	Standard error	Z- statistic
Constant	–1.238	0.864	–1.43
Age	–0.049	0.695	–0.07
Educ	2.251**	0.924	2.43
Exp	–1.078	1.271	–0.85
Size	0.103**	0.052	1.97
Size squared	–0.001**	0.0004	–2.30
Inc_agr	1.804	1.409	1.21
GM_knw	1.310	1.147	1.14
Loglikelihood	–10.606		
LR chi^2 (7)	15.28		
Pseudo R2	0.418		

*** Significant at 5% level*

Table 3. Marginal effects of the probit model on the probability of adoption of GM papaya.

Variable	Coefficient	Standard error	Z- statistic
Age	–0.016	0.227	–0.07
Educ	0.525***	0.153	3.42
Exp	–0.329	0.326	–1.01
Size	0.034**	0.016	2.05
Size squared	–0.0003**	0.0001	–2.45
Inc_agr	0.492*	0.297	1.66
GM_knw	0.355	0.235	1.51

**** Significant at 1% level, ** significant at 5% level, * significant at 10% level*

Results and Discussion

Estimation results of the probit model are presented in Table 2. The average marginal effects of the model are presented in Table 3. Model adequacy based on the likelihood ratio test indicates that the model is statistically significant at the 5% level. The marginal effects relate to a one-unit change in the variable for continuous explanatory variables, while the marginal effect for a binary explanatory variable is the discrete change in probability when the dummy variable changes from zero to one when all other explanatory variables are kept at their observed value.

To begin, we examine the variables related to grower demographics. The variable age has the expected nega-

Table 4. Probability of GM papaya cultivar adoption based on education and GM knowledge.

Characteristics	Adoption likelihood
Without a graduate degree and unknowledgeable about GM crops (0, 0)	0.362
Without a graduate degree but knowledgeable about GM crops (0, 1)	0.679
With a graduate degree but unknowledgeable about GM crops (1, 0)	0.862
With a graduate degree and knowledgeable about GM crops (1, 1)	0.966

tive sign. In our sample, where more than half of the growers are 60 years old or older, this is not statistically significant. One explanation is that younger growers may be more willing to try GM crops because of their longer time horizon to gain experience. Empirical evidence of age as an important predictor of GM crop adoption is inconsistent; Alexander and Van Mellor (2005) and Breustedt et al. (2008) support age as a predictor, while Kolady and Lesser (2006) and Keelan et al. (2009) do not.

Grower's education has the expected positive sign and is statistically significant, meaning that a grower's educational level influences the adoption of GM papaya for commercial production. The marginal effect indicates that growers with graduate degrees are 53% more likely to grow GM papaya compared to those with less education, keeping all other variables constant. Our results are consistent with studies conducted by Breustedt et al. (2008) and Krishna and Qaim (2008), who found a positive and significant relationship between GM crop adoption and grower's educational level.

The estimated coefficient for the variable "experience growing papaya" is negative despite expectations that growers with previous experience with the crop were more likely to adopt the new GM cultivars given their familiarity with the PRSV disease. Neither is it statistically significant, indicating that previous experience with the crop is not a significant factor behind the adoption decision.

The farm-size estimated coefficient has the expected positive sign and it is statistically significant at the 5% level, indicating that growers with larger farms are more likely to adopt GM papaya cultivars. The marginal effect for this variable indicates that a one-acre change in farm size increases the probability of GM papaya adoption by 0.03%. Breustedt et al. (2008) and Keelan et al. (2009) also found a positive and significant relationship between GM crop adoption and farm size. The coefficient of the squared term for the farm-size variable is negative and significant at the 5% level, confirming the existence of a threshold effect at a farm size of 47 acres. The implication of this finding is that the positive impact of farm size on the likelihood of adopting the technology is likely to hold up to the threshold level of farms with an area of up to 47 acres.

The variable "agriculture is main source of income" does not have the expected negative sign, nor is it statistically significant. This suggests that this is not a factor in the decision to adopt GM papaya cultivars. Finally, risk measured as "GM knowledge" by growers has the expected positive sign, but it is not significant. This indicates that while more knowledge could lead to an increase in the likelihood of adopting GM crops, the effect is not statistically significant.

Although an examination of the marginal effects of the individual explanatory variables offers useful insights as to how an individual factor is likely to influence the probability of adoption of the GM technology, further insight can be gleaned by estimating and comparing the probability of adoption for specific groups of farmers. Given the importance of a farmer's education regarding adoption decisions, we examined how educational level and knowledge about GM crops may impact the likelihood of adoption, keeping the other variables constant (Table 4). Specifically, we predicted, based on our sample, the likelihood of adopting the GM technology for the following four farmer groups: 1) farmers without a graduate degree and unknowledgeable about GM crops; 2) farmers without a graduate degree but knowledgeable about GM crops; 3) farmers with a graduate degree but unknowledgeable about GM crops, and; 4) farmers with a graduate degree and knowledgeable about GM crops. The results of our analysis as shown in Table 4 indicate the probability of adoption by each of the four groups. A farmer without a graduate degree and somewhat uninformed about GM crops had the lowest probability (36%) of adopting the GM technology, while a farmer with a graduate degree and knowledgeable about GM crops had the highest probability (97%) of adoption. Of interest was the fact that while having a graduate degree certainly increases the likelihood of adopting GM crops, of greater importance was the extent of a grower's knowledge about GM crops (GM knowledge). Thus in the situation where a farmer did not have a graduate degree but did have GM knowledge, the probability of adoption increased by 32%, keeping other factors constant. Likewise, in the situation where a farmer did have a graduate degree and had GM knowledge, the probability of adoption increases by 10%. The implication is that a well-targeted extension program centered on clearing up misinformation regarding GMOs is likely to increase the rate of adoption of GM crops.

Finally, based on the sample, our model indicated that there was a 64% chance of the growers adopting the GM papaya variety (95% CI: [0.51, 0.77]). The type of grower least likely to adopt the GM papaya was one who was over 60 years old, did not have a graduate degree, and was unfamiliar with GMOs. In contrast, the type of grower most likely to adopt the GM technology (99%) was characterized as one who was less than 60 years old, had a graduate degree, and was familiar with GMOs.

Summary and Conclusions

The present study assesses the factors that may influence the decision of South Florida tropical fruit growers to adopt GM papaya cultivars in an *ex-ante* situation. Results indicate that some factors related to grower demographics and farm characteristics are important predictors for the adoption of new GM papaya cultivars. Our findings are consistent with previous studies that evaluated the adoption of GM crops in an *ex-ante* setting.

Variables related to grower demographics included grower's age, level of education, and previous experience growing papaya. Although the role of age regarding GM crop adoption was inconsistent in previous studies, our present study results indicate that given the current demographics for South Florida tropical fruit growers, age is not an important adoption predictor. This finding is important given that the majority of tropical fruit growers in South Florida are older in age and, unlike the conventional wisdom would suggest, might be open to adopting this new technology.

Education definitely plays a significant role as a predictor of GM crop adoption; our findings suggest that growers with graduate degrees more fully understand the benefits associated with GM papaya cultivars. This bodes well for an extension program aimed at reducing some of the misinformation surrounding the use of GM crops. Previous experience growing papaya does not impact the likelihood of adoption of new GM papaya cultivars. It appears that South Florida fruit growers are flexible and may consider growing the new papaya cultivars given the right market incentives.

Farm characteristics used in the study included farm size and squared farm size. As has been the case with previous studies, farm size has a positive and significant effect on the likelihood of GM papaya adoption. Growers with larger farms have more resources and they are in a better position to deal with the risk associated with new technology adoption. Having a larger farm allows a grower to conduct trials with new technologies before moving to full-scale implementation. This is somewhat difficult in South Florida, where farm size and the decision to adopt GM papaya do not follow a linear pattern since most of the fruit production occurs on smaller farms.

Having the majority of income from agricultural activities is not an important factor in decisions regarding the adoption of the new GM papaya cultivars despite the risk associated with growing a new GM cultivar.

Increasing the knowledge about GM crops has a significant effect over the adoption of new GM papaya cultivars irrespective of educational level. While strong opposition to the adoption of new GM papaya cultivars is not anticipated, a well-targeted educational program explaining GM technology and addressing some of the misinformation is likely to further improve the rate of adoption of GM papaya cultivars.

Although the present study yielded some preliminary findings with respect to the likelihood of growers adopting the GM papaya, the sample size used is relatively small, suggesting the need for continuing investigation. In this regard, future research is needed to account for interested growers outside the existing population who may be interested in growing GM papayas, and to expand the sample. Additionally, to evaluate in more detail the likelihood of GM papaya adoption, it would be interesting to explore in more detail the relationship between PRSV damages and potential benefits of the new GM papaya cultivars.

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