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PREDICTORS OF FARMERS' WILLINGNESS TO ADOPT ARTIFICIAL POLLINATION INNOVATION IN COCOA: IMPLICATIONS FOR SUSTAINABLE COCOA PRODUCTION IN GHANA

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ABSTRACT

Artificial Pollination Technology (APT) is one of the current efforts implemented to ensure sustainable bean production in Ghana. The study examined the beneficiaries' perceived effectiveness of a piloted artificial pollination technology, and identified the best predictors of cocoa farmers' willingness to adopt the piloted APT in a district in the Eastern, Ghana. A total of 315 beneficiaries were interviewed for the study using structured interview schedule. The majority (80%) of the respondents perceived APT to be highly effective in increasing their yield after the APT. There was a statistically significant difference of approximately 50% increase in the yield of cocoa farmers' before and after the APT project. The majority (64%) of the respondents were willing to adopt APT after the pilot. The binary logistic regression analysis showed that seven predictors (age of cocoa farmers; educational level; number of cocoa farms; perceived complexity of APT; pruning of cocoa farm before pollination; pollination of farms at the recommended age; and pollination of hybrid variety) significantly contributed between 38.4% to 54.4% of the variance in cocoa farmers' willingness to adopt APT with "pollinating of recommended variety (hybrid)" being the overall best predictor (Odd ratio =2.9). The study recommends educating and training cocoa farmers on planting of hybrid cocoa for pollination, to increase their yields in cocoa production. Future research could also explore the use of robotic 'insects' in the pollination of cocoa flowers to ensure precise pollination of flowers, assist human workers performing laborious work and ensure sustainable cocoa production in Ghana and other cocoa growing regions.

Keywords: Cocoa Farmers; Artificial Pollination Technology; Willingness to adopt; Precision Pollination. Ghana; Sustainable Cocoa Production.

INTRODUCTION

Agriculture, for many years, plays a vital role and formed the backbone of Ghana's economy. The agricultural sector's contribution through foreign exchange to Ghana's GDP is more than one fifth of the country's total annual GDP (World Bank Group 2018). Cocoa (*Theobroma cacao* L.) has been one of the major industrial cash crops cultivated in Ghana with a huge contribution to the Ghanaian economy of West Africa for some years in terms of exports. For instance, cocoa has continually accounted for almost half of agricultural exports (Breisinger et al. 2011). The Eastern region is one of Ghana's seven demarcated cocoa producing regions in Ghana (Bosompem 2015). Akim Oda is one of the cocoa producing districts in the eastern region of Ghana. The district is the leading producer of cocoa in the eastern region. The introduction of Artificial Pollination Technology (APT) in 2017, to boost cocoa production in Ghana, has helped to improve yields of cocoa beans produced in the districts in the Eastern Region of Ghana (2021 Mar. 30. personal communication with P.K.O. Attah). Wongnaa et al. (2021) defined Artificial pollination technology as the mechanical process facilitated by human beings to pollinate plants.

The artificial Pollination Technology project is one of the eight components of the Productivity Enhancement Programme (PEP) being undertaken by the Ghana Cocoa Board in the country. The purpose of the artificial pollination technology is to complement the natural pollination carried out by insects. This would help pollinate more cocoa flowers to produce more pods from the same land size to get more yields twice the tonnage it used to produce (ESIA 2015).

Previous initiatives implemented by Ghana Cocoa Board to enhance cocoa production included the Cocoa Diseases and Pests' Control Programme (CODAPEC), popularly known as mass spraying, control of the Swollen Shoot Virus Disease (CSSVD), and the Cocoa High Technology Programme (CHTP) (Bosompem et al. 2011). The industry continued to experience diminishing returns in yields of cocoa beans after the implementation of aforementioned programmes. Also, some of the aforesaid like the CODAPEC and CSSVD) also focus on the use of pesticides that tends to kill natural pollinators of cocoa, subsequently and fruit set and yield (Umeh et al. 2022). For example, Kwapong and Frimpong-Anin (2013), reported the possible impact of insecticides on the populations of the main cocoa pollinators (midges) and consequently fruit-set. Insecticides (Confidor) application on cocoa to control cocoa capsid (*Distantiella theobroma)* tend to limit the abundance of the prime pollinators which affect fruit-set and subsequent yield of cocoa. Therefore, there is increasing evidence that the current production difference (yield gap) is due to inadequate pollination.

Studies showed that the cocoa yield can substantially increase when flowers of cocoa trees are artificially pollinated. This is because, only 10% out of thousands of cocoa flowers were produced annually when naturally pollinated **(**Groeneveld et al. 2010). Artificial pollination of cocoa plants in Sulawesi (Indonesia) provided firsthand verification of the pollination gap. Their study found that there was about 40% increase in cocoa flowers pollinated (Claus et al. 2018). One of the current efforts to boost cocoa production in Ghana is the artificial pollination technology project, undertaken in all the cocoa region in the country. Studies conducted on artificial pollination technology in some cocoa producing countries in the world have showed benefits of the technology in increasing yields of farmers to approximately 11.5 bags/ha (735.7 kg/ha) in cocoa production (Latifah et al. 2016; Toledo-Hernández et al. 2020; Wongnaa et al. 2021). However, a rigorous attempt has not been made to assess the perception cocoa farmers have about the effectiveness of ATP. Rogers (2003) has stated that the perceptions of people (farmers') about a programme are very significant in adoption and sustainability of a programme or an innovation in a social system. Also, the willingness of cocoa farmers in eastern part of Ghana to adopt the APT after the initial piloted project has not been critically assessed to inform policies and decision making in the cocoa industry.

Objective of the paper

The main objective of the research was to examine the perceived effectiveness of the artificial pollination technology among cocoa farmers, and to identify the best predictor(s) of cocoa farmers' willingness to adopt APT in the study area. The results of the study could serve as a bases for further training and development of pollinators and farmers for successful implementation and scale-up of the APT in Ghana and West Africa. It could also serve as a step in developing precision pollination technology for sustainable cocoa production.

LITERATURE REVIEW/CONCEPTUAL FRAMEWORK

The study adapted two theories of innovation. These are: (1) the diffusion of innovation theory by Rogers (1983), and (2) the expanded Rogers' attributes of innovation model by Moore and Benbasat (1991). In addition, other factors that affect the cocoa farmers' willingness to adopt a new technology such as the effectiveness of APT, demographic and farm-related characteristics, and the perceived attributes of the technology (Rogers 1983) were also considered. A brief description of artificial pollination technology as used in the study is also discussed.

Description of Artificial Pollination Technology in Cocoa farms

Artificial pollination technology is the mechanical process facilitated by human beings to pollinate plants. Artificial pollination technology takes place when human intervention is involved in the pollination process (Wongnaa et al. 2021). It is often used as a solution to the problems associated with natural pollination (Vera-Chang et al. 2016; Toledo-Hern´andez et al. 2020). It complements the natural pollination which is being carried out by insects. The technology is utilized to increase the quantity and quality of fruits on trees (Forbes and Northfield 2017) with the prime focus of contributing to increase in cocoa bean yields.

The trained human pollinators manually pick male flowers through the use hand-held instruments called forceps and subsequently pollinate the female flower with the same instrument. The pollinators pick about twenty male flowers at a time for the pollination to prevent the destruction of the flowers when more are taken. The cocoa extension agent or the Master Pollinator shares the demarcated area among the number of pollinators. The pollinators are respectively given ropes with different colours for identification purposes to know the performance and skills levels of each pollinator.

The pollinated farms are revisited within two to four days after pollination to check the success of the pollination. No spraying of agrochemicals is done within few days after the pollination to avoid the damage of the pollinated flowers.

The diffusion of innovation (DOI) theory

Diffusion of innovation theory is based on the five (5) main variables that determine the rate of adoption of an innovation among members of a social system over time. These are: (a) perceived attributes of the innovation, (b) type of innovation-decision, (c) nature of communication channels diffusing the innovation at various stages in the innovation-decision process, (d) nature of the social system in which the innovation is diffusing, and (e) the extent of change agents' promotion efforts in the innovation diffusions (Rogers 1983). According to Rogers (1983), most studies on adoption have reported that the perceived attributes of innovation has accounted for between 48 to 87 percent variance in adoption of technologies. Much attention has not been given to the remaining four (4) variables by most scholars who have worked on diffusion. Therefore, to clarify the variance of adoption, the Diffusion of Innovation theory has focused on perceived attributes of innovation (namely: relative advantage, compatibility, complexity, trialability, and observability).

The expanded Rogers' attributes of innovation model by Moore and Benbasat (1991)

Moore and Benbasat expanded Rogers' (1983) five perceived attributes of innovation into eight perceived characteristics of innovation and finally included two (voluntariness and image) unique perceived characteristics of innovation to expand the Rogers' (1983) model (Moore and Benbasat 1991) Voluntariness explains the degree to which an innovation is perceived to be willing accepted by the individual adopters without any force on the users (Moore and Benbasat 1996).

Cocoa farmers' perceived attributes of APT in cocoa production

This paper considers the application of two theories to the study. The diffusion of innovation theory by Rogers' which has five attributes of innovations that affect the individual's likelihood of adoption namely (a) relative advantage (usefulness), (b) compatibility, (c) complexity, (d) trialability, and (e) observability (Rogers 1983). Voluntariness and Image were added later as an expansion of Rogers' five attributes of innovation by Moore and Benbasat (1991). Only voluntariness was involved in the study since image has been noticed to be embedded in Rogers' attributes of 'relative advantage' (Rogers 1983). Therefore, six major individual's perceived characteristics of APT were conceptualized in this study namely;

- Relative advantage: is defined as the degree to which an individual perceived APT to better than the existing practices and ideas such as the natural pollination.
- Compatibility: Compatibility refers to the degree to which APT is perceived as compatible with the current values, past experiences and needs of the potential adopters in a social system.
- Complexity: Robinson (2009) defined complexity based on Roger's explanation as the degree to which a new technology is perceived as relatively complex to understand and use

- Trialability: is the degree to which an innovation may be experimented with a limited bias.
- Observability: Rogers (2010) found observability as the degree to which the individual adopter finds it easy to see the outcomes of a new technology.
- Voluntariness: Voluntariness can be defined as the extent to which the individual is willing and ready to the accept and apply a new idea.

Out of the six attributes of innovation, only voluntariness is expected to have negative effects on cocoa farmers' willingness to adopt APT (Moore and Benbasat 1996; Rogers 1983; Aubert et al. 2012).

The demographics and farm-related characteristics of cocoa farmers

The study focused on the following demographics and farm-related factors such as sex, age of a farmer, educational level, experience in farming, household size, farm size, yield that affect the rate of adoption of technology (Rogers 2003; Bosompem 2019). The demographics and farm-related variables are expected to either positively or negatively affect cocoa farmers' willingness to adopt. For instance, farmer's age, age of cocoa farm, number of cocoa farms a farmer owned**,** and household size are expected to have negative effects on cocoa farmers' willingness to adopt APT (Danso-Abbeam et al. 2014; Bosompem 2019; Wongnaa et al. 2021). Years of farming experience, educational status, sex (1=male), farm size on the other hand, positively affect cocoa farmers' willingness to adopt APT (Djokoto et al. 2016; Bosompem 2019; Amfo and Ali 2020, Umeh et al. 2022, Asante at al. 2023).

Applications of artificial pollination technology (APT)

The pollinators and pollination in agriculture has received a lot of attention throughout the years (Gemmill-Herren et al. 2014; Wurz et al. 2021). Cocoa (*Theobroma cacao* L.) is mainly pollinated by ceratopogonid midges (*Forcipomyia spp*.). However, other insect species will also pollinate cocoa flowers when these midges are scarce. Cocoa, unlike some other plants, is not self-pollinating although both male and female parts are found in the same flower. Since, self-pollination is not possible in cocoa, pollinating agents are therefore needed to facilitate the pollination process (Frimpong, Kwapong, Gemmill-Herren and Gordon,2011). APT has been applied in several ways in countries on different crops. Firstly, the use of humans as pollinators for artificial pollination of crops such as cocoa, apples and tomato on a large scale in some countries like Indonesia. The human used their hand, with the help of forceps, to transfer pollens from the anther of the male flower to the stigma of the female flower of a plant (Partap and Ya 2012; Ozores-Hampton 2017; Claus et al. 2018). Lastly, APT has been applied by the use of robotic pollinators in the context of decreasing populaces of insect and other natural pollinators, especially in the United State. The robotic pollinator (bee or insects) was used to pollinate a pink and white lily with three large flowers which occupy a center-screen against the backdrop of a sterile- looking white room with an indistinct piece of technical equipment in the background" (Nimmo 2022). Studies found that robotic pollinators could be a key to the sustainability of global agriculture for fertilization of large varieties of crops that currently depend upon insect pollination **(**Chechetka et al. 2017). The use of robotics can augment or assist human workers performing laborious work such manual hand pollination of cocoa flowers (Zhang and Karkee 2021). Chechetka et al. (2017) had also explored the fundamental chemistry for ionic liquid gels (ILGs) in artificial pollination using radio wave-controlled robots.

Effectiveness of artificial pollination technology in cocoa production.

In the context of this study, “effectiveness” is defined as the degree at which the implementation of the Artificial Pollination Technology has brought about change in increase in yields and income to support the livelihoods of the beneficiary farmers. Several studies have reported a positive contribution on effectiveness of cocoa production programs with an increasing yields and income of cocoa farmers (Kumi and Daymond 2015; Tsiboe et al. 2016; Attipoe et al. 2021). Only trained pollinators perform the pollination exercise on the cocoa farms. The APT involves activities such as weeding before pollination, pruning before pollination, pollination of hybrid variety, regular availability of a farmer to monitor the pollination, counting of cherelles and cocoa pods after pollination. For APT to effective, there should be proper implementation of all these activities.

MATERIALS AND METHODS

The study was mainly quantitative with the use of cross-sectional correlational survey design. The population for the study was all cocoa farmers’ whose farm(s) were pollinated by the trained pollinators from the start (2017/2018) of the project to 2019/2020 cocoa production season in the Oda Cocoa District in Eastern Ghana.

Some fundamental elements of climate that define limits for agricultural operations are rainfall, humidity, temperature, photoperiod, and altitude, which interact to give the local weather conditions (Seidu 2018). Agriculture in Ghana is influenced by changes in rainfall and temperature, as well as extreme weather events and growing seasons. Optimal meteorological conditions are required at every stage of cocoa production. Aneani and Ofori-Frimpong (2013) reported that the study area has rainfall and temperature of 1784mm and (25-27) degree Celsius respectively at 61m altitudes with semi-deciduous rainforest vegetation. According to Opoku-Ameyaw et al. (2010), areas with rainfall between 1100mm and 3000mm per annum help cocoa to grow very well. Optimal production can be attained in areas with annual rainfall between 1500-2000mm. The following link provides climate pattern from 2015 to 2023 which covers the years in when the APT i.e. 2017-2020 (https://weatherspark.com/y/42310/Average-Weather-in-Akim-Oda-Ghana-Year- Round#Figures-Humidity) The hot season lasts for 2.7 months, from January 13 to April 4, with an average daily high temperature above 93°F. The hottest month of the year in Akim Oda is February, with an average high of 95°F and low of 75°F. The cool season lasts for 3.2 months, from June 9 to September 14, with an average daily high temperature below 87°F. The coldest month of the year in Akim Oda is August, with an average low of 72°F and high of 85°F. The *wetter season* lasts *7.8 months*, from *March 17* to *November 10*, with a greater than *41%* chance of a given day being a wet day. The month with the most wet days in Akim Oda is *June*, with an average of *22.1 days* with at least *0.04 inches* of precipitation.

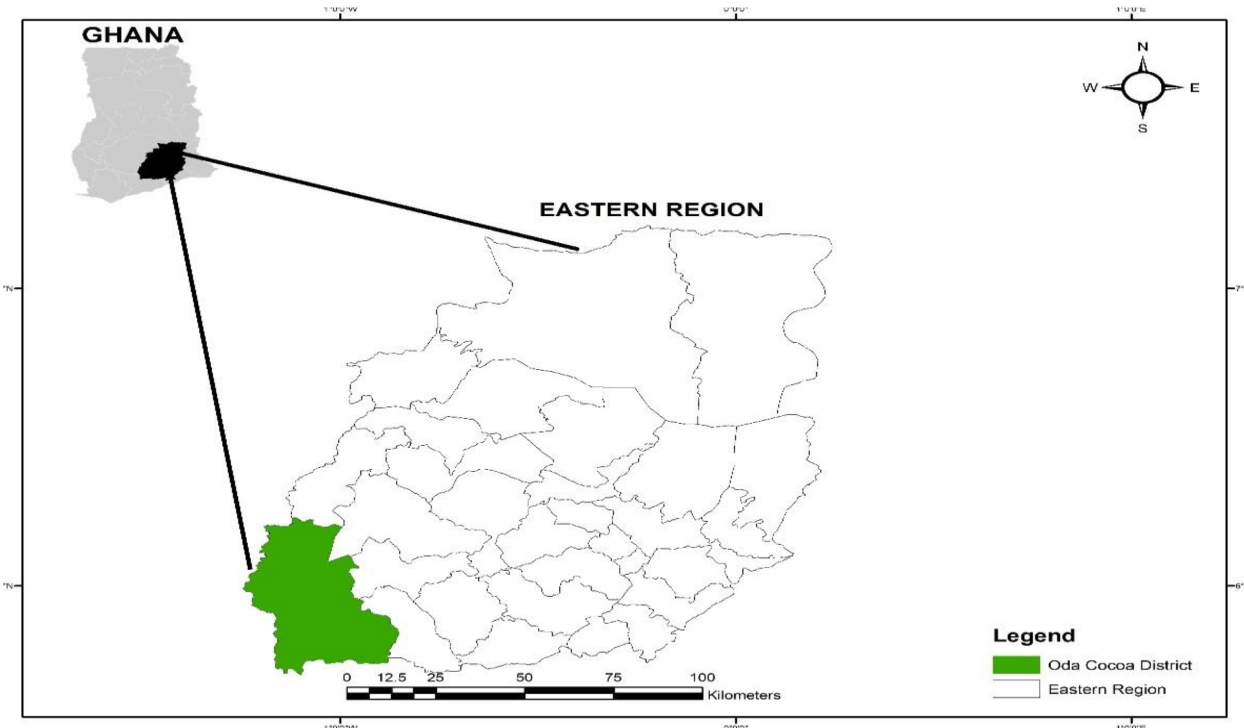

Figure 1: Map of Ghana showing the study area. Source: Author's Construct (2021)

The period for the application of the artificial pollination technology on cocoa farms starts from May to October. The period for the pollination is found within the significant rainy season from April to June and again in September to November, with a dry period is between Decembers to February in the Akim Oda Cocoa District (Aneani et al. 2012). Cocoa farmers had their yields increased because their farms were pollinated under conducive climatic conditions at that time to contribute to increase in cocoa beans yield.

Youths within the ages of 18 to 35 were trained and employed by Ghana Cocoa Board (COCOBOD) to pollinate farmers' farms for free of charge. Approximately 1318 cocoa farmers' farms were pollinated in the study area. Proportionate stratified sampling technique was used to select 315 cocoa farmers in tens (10) out of the twenty-eight (28) cocoa growing operational areas in district based on their geographical locations using Krejcie and Morgan table with the error margin of 0.05 (Payne and McMorris 1967; Krejcie and Morgan 1970). A pilot study was conducted in a nearby cocoa district (Asamankese District) within the Eastern Region to pretest the interview schedule used for the data collection. The instrument was reliable based on standardized Cronbach's Alpha (Hinton et al. 2014).

A well-structured and content validated interview schedule was used to collect primary data from respondent cocoa farmers. The instrument comprised of four (4) major sections: i. perceived effectiveness of the APT among farmers, ii. level of perception of respondents on the various attributes of the APT, iii. Farmers perceived main challenges of the APT and iv. demographic and farm-related characteristics of beneficiary cocoa farmers. The items in section i were measured using a five-point Likert-type scale ranging from 1 to 5 i.e., least effective (1) to very high effective

(5). These items in section i considered the level of agreement of cocoa farmers on a statement related to perceived effectiveness of APT conceptualized and used in this research. Items in section ii were also measured in a five-point Likert-type scale ranging from 1 to 5 i.e., least agreement (1) to strongly agreement (5). These items in section ii focused on the level of agreement of farmers on statements related to the six attributes of APT (relative advantage, compatibility, complexity, trialability, observability, and voluntariness) conceptualized and used in this research. Twenty cocoa farmers were used to conduct a pilot study to pretest the structured interview schedule to check its reliability. The Cronbach's alpha reliability coefficient was used to check the internal consistency of the items of all Likert-type scales of the instruments (Pallant 2011). The results from the Cronbach's alpha coefficients of sections i and ii of the instruments ranged from 0.68 to 0.98 based on the standardized Cronbach's Alpha indicated that the instrument is reliable (Hinton et al. 2014). All the 315 (100% response rate) targeted interviews were successfully received.

With the help of IBM SPSS version 25, descriptive statistics, dependent sample t-test, and binary logistic regression were used to analyze cocoa farmers perceived effectiveness and identify the best predictor(s) of cocoa farmers' willingness to adopt APT. The independent variables [demographic and farm-related characteristics of cocoa farmers (8 predictors), perceived effectiveness of APT (9 predictors), and perceived attributes of APT (6 predictors)] were used to predict cocoa farmers' willingness to adopt APT (dependent variable).

Model specification of the binary logistic regression

The odds of an event occurring (a farmer willing to adopt APT measured as 1=adoption) is the probability that the event will occur divided by the probability that the event will not occur (i.e., a farmer not willing to adopt APT (Acquah 2013). Following Greene (2008), the probability y=1 occurs varies according to the values of the explanatory variables and specified the relationship as:

$$log\left[\frac{P(y=1)}{1-P(y=1)}\right] = logit[P(y=1)] = \beta_0 + \beta_j X_i + \varepsilon_i \qquad (1)$$

From the equation 1 above, $P(Y=1)$ is given by $P(Y=1) = \frac{e^{\beta_0+\beta_j X}}{1+e^{\beta_0+\beta_j X}}$

Where, ($\frac{P}{1-P}$) is the logit transformation. This is the value of the odds of the output (since odds $P/(1-P)$. whereas β_0 and β_j are the parameters to be estimated and   is a vector of the explanatory variables with the index *j*.

Moreover, $\frac{P}{1-P} = e^{(\beta_0+\Sigma\beta_j X_j}$ where P is the probability that Y=1 and 1-P is the probability that Y=0 and e is the exponential variable which is constant.

Based on the equation 1 above, the empirical model specification of equation 2 for the study is Y=1 defines a cocoa farmer would be willing to adopt APT which is measured as 1=adoption; and Y=0 also defines otherwise. The X defines the independent variables that explain the probability that a farmer would be willing to adopt APT which is also measured as 1= adoption and ε_j is error term. Therefore, we have the equation as:

$$Logit[P(Y_j = 1)] = \beta_{0i} + \beta_{i1}X_{i1} + \beta_{i2}X_{i2} + \beta_{i3}X_{i3} + \beta_{i4}X_{i4} + \beta_{i5}X_{i5} + \beta_{i6}X_{i6} + \beta_{i7}X_{i7} + \beta_{i8}X_{i8} + \beta_{i9}X_{i9} + \beta_{i10}X_{i10} + \beta_{i11}X_{i11} + \beta_{i12}X_{i12} + \beta_{i13}X_{i13} + \beta_{i14}X_{i14} + \beta_{i15}X_{i15} + \beta_{i16}X_{i16} + \beta_{i17}X_{i17} + \beta_{i18}X_{i18} + \beta_{i19}X_{i19} + \beta_{i20}X_{i20} + \beta_{i21}X_{i21} + \beta_{i22}X_{i22} + \beta_{i23}X_{i23} + \varepsilon_i \quad (2)$$

The dependent variable for the study was cocoa farmers' willingness to adopt AP technology which is undertaken by COCOBOD. This was measured as a dummy with 1 and 0 indicating willingness and not willingness to adopt APT respectively. The main sets of independent variables were:

Demographic and farm-related characteristics: ($X_1 – X_8$).

Farmers' Perceived Attributes of APT: ($X_9 – X_{14}$).

Farmers' Perceived Effectiveness APT: ($X_{15} – X_{23}$)

Table 1 presents the code and expected signs of the 23 independent variables (X_1-X_{23}) used in the regression equation.

Table 1. Codes, and expected sign of the independent variables used in the regression equation

A	**Demographic/farm related variables**	**Codes**	**Sign**
	Sex **(X_1)**	0=Male, 1=female	+
	Age at last birth day **(X_2)**	Numbers of years	-
	Educational level **(X_3)**	Ordinal scale	+
	Farming experience **(X_4)**	Number of years	+
	Household size **(X_5)**	Ratio scale	-
	Number of farms **(X_6)**	Ratio scale	-
	Age of pollinated farm **(X_7)**	Number of years	-
	Land size pollinated **(X_8)**	Number of acres	+
B	**Attributes of APT**	**Codes**	**Sign**
	Relative Advantage **(X_9)**	Interval Scale	+
	Compatibility **(X_{10})**	Interval Scale	+
	Complexity (Ease of Use) **(X_{11})**	Interval Scale	+
	Trialability **(X_{12})**	Interval Scale	+
	Observability **(X_{13})**	Interval Scale	+
	Voluntariness **(X_{14})**	Interval Scale	-
C	**Perceived effectiveness of APT**	**Codes**	**Sign**
	Pruning of farm before pollination **(X_{15})**	Interval Scale	+
	Applying fertilizer before pollination **(X_{16})**	Interval Scale	+
	Pollination of farm between 10-20 years **(X_{17})**	Interval Scale	+
	Pollination of hybrid variety **(X_{18})**	Interval Scale	+
	Selection of pollinators (18-35 years) **(X_{19})**	Interval Scale	+
	Use of five pollinators to pollinate an acre of farmland **(X_{20})**	Interval Scale	+
	Regular availability of a farmer to monitor the pollination **(X_{21})**	Interval Scale	+
	Visiting of pollinated farm for monitoring **(X_{22})**	Interval Scale	+
	Counting of cherelles and pods **(X_{23})**	Interval Scale	+

Multicollinearity diagnostic test

A multicollinearity diagnostic test was performed before the regression to find whether a predictor has a strong relationship with the other predictor(s) (Field 2013). The study used both Tolerance and Variance Inflation Factor (VIF) to identify multicollinearity. The tolerance values were between 0.395 and 0.869 and VIF values were between 1.151 and 2.533 show no significant multicollinearity that could bias the predictions. These values showed that no significant concern for multicollinearity since tolerance value less than 0.10 and VIF greater than 10 show that there a significant multicollinearity (Field 2013; Pallant 2020).

RESULTS AND DISCUSSION

Summary of cocoa farmers' demographic characteristics

The majority (about 78%) of the respondent cocoa farmers were males and about 94% have attained formal education. However, most of the farmers had low level of education since about 63% of them had attained basic education (Tables 2).

Table 2. Descriptive statistics of cocoa farmers' demographic characteristics

Variables	Categories	f	%	$\bar{X}$	SD
Sex (n=315)	Male	247	78.4		
	Female	68	21.6		
Age (Years) (n=315, Min=24, Max=82)	< 35 (youth)	30	9.5	51.0	11.7
	36-47 (young adult)	90	28.6		
	48-59 (old adult)	115	36.5		
	≥ 60 (aged)	80	25.4		
Educational level (n=315)	Non formal	20	6.3		
	Primary	44	14.0		
	Middle Sch./JHS	198	62.9		
	SHS	42	13.3		
	GCE 'O' level	4	1.3		
	Tertiary	7	2.2		
Marital status (n=315)	Married	275	87.3		
	Otherwise	40	12.7		
Household size (n=315, Min=1, Max=24)	≤ 10	272	86.3	7.6	3.6
	11-20	39	12.4		
	≥ 21	4	1.3		
Years of experience (n=315, Min=2, Max=49)	≤ 10	57	18.1	18.4	8.8
	11-20	174	55.2		
	21-30	55	17.5		
	31-40	25	7.9		
	≥ 41	4	1.3		

n=315

The results on the farmer's level of education (93.7% have received a formal education), which is higher than that of Okorley et al. (2014) who found 78% of cocoa farmers in the Western Region of Ghana. The result shows the mean farming experience of cocoa farmers was ($\bar{X}$=18.4, SD= 8.8) which is approximately the same as (Danso-Abbeam et al. 2014) who reported the average years of experience in cocoa farming to be 18 among cocoa farmers in Sefwi-Wiawso Municipality of Ghana.

About 87.3% of the respondents were married, and with the mean age of 51 years which is almost similar to the findings of Bosompem (2019) who reported that cocoa farmers in Ghana are still aged (mean= 52), with few (20%) below the age of 40 years. Hence, cocoa farmers are still aging (approximately 62%) were above 48 years with 38% of the cocoa farmers being both youth and young adults in cocoa production in the district. The results again show an average household size (mean =7.6, SD= 3.6) among cocoa farmers in district which is almost similar to the average household size of eight (8) which was reported by (Akrofi-Atitianti et al. 2018). Again, Agyei-Manu et al. (2020) found the average household size of seven (7) among respondent cocoa farmers in Upper Denkyira West District of Ghana.

The summary of the farm-rated characteristics of respondent cocoa farmers is also presented in Table 3.

Table 3. Descriptive statistics of farm-related characteristics of cocoa farmers

Variables	Categories	f	%	$\bar{X}$	SD
Age of pollinated trees (n=315)	10-15	259	82.2	13.0	3.5
Min=10, Max=40	16-20	53	16.8		
	≥ 21	3	1.0		
Farm size under cocoa (acres)	≤ 5	110	34.9	8.6	6.3
(n=315, Min=1, Max=65)	5.1-10	118	37.5		
	10.1-15	59	18.7		
	15.1-20	12	3.8		
	≥ 21	16	5.1		
Number of cocoa farms	≤ 5	287	91.1	3.0	1.7
(n=315, Min=1, Max=11)	6-10	27	8.6		
	≥ 11	1	0.3		
Number of times farm(s) has been pollinated.	1-2	251	79.7	1.8	0.8
(n=315, Min=1, Max=5)	3-4	62	19.6		
	≥ 5	2	1.2		
Farm size pollinated (acres)	≤ 3	279	88.6	2.0	1.4
(n=31, Min=1, Max=1)3	4-7	32	10.2		
	8-11	2	0.6		
	≥ 12	2	0.6		

n=315)

The result shows that the mean age of the pollinated cocoa trees was 13 years and with the majority of the trees (approximately 82%) aged between 10 to 15 years. This indicates that cocoa farms pollinated were within the required age (10 to 20) recommended by COCOBOD to maximize yield and income through application of APT (2021 April. personal communication with F. Eluwekeh). The result of the study is similar to studies conducted by Amfo and Ali (2020) who found 14 years as the mean age of cocoa farms in Bekwai district in the Ashanti Region of Ghana.

The majority of the cocoa farmers (34.9%+37.5% = 72.4%) had 10 acres (4.0 ha.) or fewer hectare(s) of farms size in the study area. The mean farm size of the cocoa farmers was (Mean= 8.6, SD= 6.3) acres (3.4 ha.). Amfo and Ali (2020) also reported mean cocoa farm size to be eight (8) ha, and Abbeam et al. (2014) reported a mean farm size of 7.98 acres (3.23 ha) among respondent cocoa farmers in their studies in Ghana. Even though, the majority (about 89%) of the cocoa farmers had 5 and below number of their farms separately pollinated at different locations, an average of 2.0 acres (0.8 ha.) of cocoa farmers' farm size were pollinated. The majority (about 91%) of the farmers had five (5) or less of cocoa farms separated at different locations in the district. This confirms Bosompem (2019) who found about 56% of respondent cocoa farmers had two (2) cocoa farms in his studies in Ghana. Also, the result indicates that most (about 80%) farmers had their cocoa farm(s) pollinated either once or twice within the 2 or so years.

Perceived effectiveness of Artificial Pollination Technology (APT)

The cocoa farmers' perceived effectiveness of APT were assessed based fifteen (15) series of activities that beneficiary farmers had to perform as part of the adoption of the programme (see Table 4).

Table 4. Mean perceived effectiveness of the activities of APT

Activity	f	%	$\bar{X}$	SD
Weeding before pollination	314	100	4.61	0.69
Pollination of hybrid variety	274	87	4.61	0.64
Pollination of farm between 10-20 years	301	96	4.57	0.62
Use of 5 pollinators to pollinate an acre of farmland	276	88	4.57	0.65
Pruning of farm before pollination	314	100	4.52	0.64
Counting Cherelle and pods to estimate pollination success	282	90	4.51	0.72
Application of fertilizer before pollination	310	98	4.49	0.65
Selection of youth pollinators (18-35 years of age)	312	99	4.47	0.69
Visiting of pollinated farm for monitoring	299	95	4.41	0.78
Spraying of insecticides after pollination	309	98	4.38	0.82
Pollination within the recommended time of the day	307	97	4.38	0.78
Spraying of fungicides after pollination	289	92	4.29	0.85
Accessibility of farm by vehicle	234	74	4.23	0.84
Selection of a cooperative member to be trained on APT	68	22	3.92	1.00
Regular availability of a farmer to monitor the pollination	257	82	3.84	1.02
Weighted Mean ($\bar{X}$w)	-		4.42	0.40

Scale: 5= Very High Effective (VHE), 4= High Effective (HE), 3= Fairly Effective (FE), 2= Low Effective (LE), 1= Least Effective (LE). n=315

The results are arranged in decreasing order of means of responses from respondents as presented in Table 4. The majority of the farmers perceived the series of activities in connection with the APT to be ‘highly effective’ (mean ranges from 4.49 to 3.84), with the rest of the activities to be “very high effective” (mean ranges from 4.61 to 4.51) in contributing to increasing their output.

The cocoa farmers perceived a) weeding before pollination ($\bar{X}$=4.61, SD=0.69), b) pollination of hybrid variety ($\bar{X}$=4.61, SD=0.64), c) pollination of farm aged between 10-20 years ($\bar{X}$=4.57, SD=0.62), d) pollination of an acre of farmland by five pollinators ($\bar{X}$=4.57, SD=0.65), e) pruning of the farm before pollination ($\bar{X}$=4.52, SD=0.64), and f) counting Cherelle and pods to estimate the success after pollination ($\bar{X}$=4.51, SD=0.72) to be “very high effective” in contributing to the effectiveness of APT in success of the pollination process and subsequently their increasing yields. The introduction of the APT made the district the leading producer of cocoa in the Eastern Region of Ghana. In the 2019/2020 cocoa season, the number of bags of cocoa beans produced and graded in Akim Oda Cocoa District was estimated to be *21,488 metric tons of bags* out of the total estimated amount of *89,275 metric tons of bags* of cocoa beans produced in the Eastern Region of Ghana (2021 Mar. 30 personal communication with P.K.O. Attah). This study confirms that of Attipoe et al. (2021) who reported that a positive effect contribution to Cocoa Life Project (CLP) extension service by Cooperative for Assistance and Relief Everywhere (CARE) significantly increased participating famers’ yield by 14.3% in their study area.

Generally, respondent cocoa farmers perceived APT activities to be ‘highly effective’ ($\bar{X}$=4.42, SD=0.40) in contributing to increasing their yields. Tsiboe et al. (2016) reported an increased yield by 32%, 34%, 50%, and 62% among cocoa farmers in Ghana, Cote d’Ivoire, Nigeria, and Cameroon respectively when a Cocoa Livelihood Program which aimed at supporting smallholder coca producers was been introduced in those countries. The results of the study imply that the adoption of APT by cocoa farmers is possible when the activities underlining is properly taken into consideration by the farmers to contribute to an increase in their farm yields in every cocoa production season.

Estimated Impact of the APT on the yield of beneficiary farmers.

Table 5 presents the estimated yield of farmers before and after artificial pollination technology was applied in their farm(s).

Table 5. Dependent sample t-test of estimated yield of farmers before and after APT.

Cocoa season (years)	Frequency	$\bar{X}$ yield (bag/acre)	SD	MD	t-ratio	Sig.(1tailed)
2017/2018 – 2019/2020	303	15.1	15.2	4.9	10.57	0.000*
2016/2017	303	10.2	9.2			

*p<0.025 n=315 1 bag = 64kg

The results in Table 5 indicate a statistically significant (0.000) difference between the mean yield of cocoa farmers ($\bar{X}$ = 10.2 bags/acre, SD=9.2) before the commencement of the APT and the mean yield of cocoa farmers ($\bar{X}$= 15.1 bags/acre, SD= 15.2) after the application of APT on their farm(s). This implies that APT significantly increased yields of cocoa farmers by approximately 50% per 0.4ha, which is within the anticipated yields increase of 45% to 70% per 0.4ha by COCOBOD after farmers' farms had been pollination (2022 Mar. 30 personal communication with F. Oppong).

The result of the study confirms that of Wongnaa et al. (2021) who reported that adopters of the APT had an increasing yield of 11.5 bags/ha (735.7 kg/ha) at the end of the cocoa production season (both major and minor seasons) in the Amenfi District of the Western North Region of Ghana. The estimation of an increasing yield difference of 12.2bags/ha would be gained when a hectare of cocoa farm is pollinated. This result would be higher than that of Wongnaa et al. (2021) who had a yield increase of 11.5 bags/ha. This implies that the APT has the potential for increase in yield and income of cocoa farmers who would adopt APT in cocoa production.

Cocoa farmers' willingness to adopt APT in cocoa production

The majority (approximately 64%) of the respondent farmers were willing to adopt artificial pollination technology. Wongnaa et al. (2021) also reported an average probability of 50% of participants adopting the artificial pollination technology in cocoa production in the Amenfi District of the Western North Region of Ghana. This has implications for the future of APT in cocoa production in the district. The other 36% of the respondents were not willing to adopt the future APT because of issues with old age as a farmer, eye problems, unfavourable weather conditions, and other challenges associated with the artificial pollination.

Table 6. Willingness to adopt APT by cocoa farmers in cocoa production

Willingness	Frequency	%
Willing	200	63.5
Not	115	36.5
Total	315	100

n=315.

Best predictors of cocoa farmers' willingness to adopt the APT in cocoa production.

The results in Table 7 presents the model summary which explained between 38.4% (Cox Snell R-Square) and 54.4% (Negalkerke R-Square) of the variations in cocoa farmers' willingness to adopt APTs (see Appendix A for all the 23 predictors used in the model**)**.

Table 7. Binary logistic regression of the best predictors of cocoa farmers' willingness to adopt APT in cocoa production.

Predictor	B	S. E	Wald	Sig.	Odds ratio	95% C.I for odds ratio
Constant	-1.333	4.110	.105	.746	.264	
Demographic/farm related factors:						
Age	-.154	.035	19.412	.000	.858	.801 - .918
Educational level	.696	.275	6.396	.011	2.006	1.170 - 3.440
Number of farms	.436	.154	7.997	.005	1.547	1.143 - 2.093
Perceived attributes of APT:						
Complexity (ease of use)	.756	.259	8.530	.003	2.130	1.282 - 3.537
Effectiveness of APT:						
Pruning of farm before pollination	.913	.395	5.336	.021	2.491	1.148 - 5.404
Pollination of farm age (10-20 years)	-1.189	.514	5.361	.021	.304	.111 - .833
Pollination cocoa of hybrid variety	1.057	.497	4.533	.033	2.878	1.088 - 7.616

Model Summary

	Value	Sig
Cox Snell R-Square	0.384	-
Negalkerke R-Square	0.544	-
Omnibus test of model Chi-square	86.780	.000
Hosmer and Lemeshow Test	5.878	.661
-2 Log likelihood	132.416	-

n=315. $p<0.05$. C.I = Confident Interval.

Farmer's age as a predictor of cocoa farmers' willingness to adopt APT

The age of cocoa farmer was found to be a statistically significant and negative predictor (β= -.154) of cocoa farmers' willingness to adopt APT. This implies that older cocoa farmers are less likely to adopt APT in cocoa production. Therefore, younger cocoa farmers are more likely to adopt the APTs in the future. Also, the odds ratio of 0.86 shows that for every additional increase in age, respondent cocoa farmers were .86 times less likely to adopt APTs in the future.

The results from the study confirm that of Wongnaa et al. (2021) who reported that age was statistically significant and had negative impact on adoption of artificial pollination technology in Western Ghana.

Educational level as a predictor of cocoa farmers' willingness to adopt APT

The educational level of a farmer was found to be a significant demographic factor that effects the adoption of new technology (Tey and Brindal 2012). The educational level of respondent farmers was found to be a positive predictor (β = .696) and statistically significant with cocoa farmers' willingness to adopt APT. This means that cocoa farmers who had higher levels of education are more likely to adopt APT in cocoa production. The odds ratio of 2.0 also indicates that for every additional level of education, respondent cocoa farmers were 2.0 times more likely to adopt APT in the future.

The result is similar to Aneani et al. (2012), who reported educational status to be positive and statistically significant to the adoption of hybrid cocoa varieties in Ghana. Adebayo et al. (2022) also found education as positive driver of farmers' decision to adopt cocoa technologies in Nigeria. However, the result is contrary to that of Bosompem (2019) who found the educational level of cocoa farmers to be negative and significant factor in cocoa farmers' willingness to adopt precision agricultural technology in cocoa production. Also, years of education had no significant effect on the adoption of artificial pollination in Western Ghana (Wongnaa et al. 2021). The positive result in this research may indicate how farmers with a higher level of education observed the benefits of the APT as increasing their yield and income in cocoa production. Education has also been found to increase adoption of precision agricultural technologies worldwide (Paustian and Theuvsen 2017)

Number of cocoa farm(s) as a predictor of cocoa farmers' willingness to adopt APT

The "number of cocoa farms", a farmer owns was the only farm-related factor that was identified to be a statistically significant and positive predictor (β= .436) of cocoa farmers' willingness to adopt APT. This implies that farmers who have two (2) or more cocoa farms are more likely to adopt APTs than farmers who have only one (1) cocoa farm. The odds ratio (1.5) indicates that for every additional increase in the number of cocoa farms owned by farmers, respondent cocoa farmers were 1.5 times more likely to adopt APTs in the future.

The result of this study is contrary to previous study on agricultural technology in Ghana. For instance, the number of farms owned by farmers in Ghana is expected to hinder the potential adoption of agricultural technology in cocoa production, since the several number of farms they have are located in different places (Bosompem 2019). The number of cocoa farms as a predictor of farmers' willingness to adopt APT may be as a result of cocoa farmers having the opportunity to try the APT on one farm to observe the benefits of the APT. This may serve as a basis of committing other farms to the technology if they observe the initial benefits of the technology.

Complexity (ease of use) as a predictor of cocoa farmers' willingness to adopt APT

Complexity (ease of use) was the only perceived attributes of APT that was found to be statistically significant and positive predictor **(**β= .756) of cocoa farmers' willingness to adopt APT, with an odds ratio of 2.130. The findings of this study imply that cocoa farmers who see APT as easier are two times more likely to adopt APT in the future in cocoa production than those who do not.

Dan et al. (2019) reported complexity had a positive effect and was statistically significant to the adoption of agricultural technology among farmers in German. However, the result is contrary to Lee et al. (2011), who found complexity to be significant with a negative impact on the respondents' intention to use a new technology.

Pruning of farm before pollination as a predictor of cocoa farmers' willingness to adopt APT

Pruning of farm before pollination was found to be a positive predictor **(**β= .913) and statistically significant to cocoa farmers' willingness to adopt APT, with an odds ratio of 2.49. This implies that cocoa farmers who had their farm(s) pruned before pollination are about 2.5 times more likely to adopt the APT in cocoa production.

Pruning helps to eradicate epiphytes and deadwood to improve aeration for proper growth and effective functioning of tree crops such as cocoa trees (Akrofi-Atitianti et al. 2018). The positive relationship observed may probably be due to how respondent cocoa farmers highly perceived pruning of farm before pollination as an important activity for effective APT to increase their yields and income in cocoa production.

Pollinating of farm aged between 10-20 years as a predictor of cocoa farmers' willingness to adopt APT

Pollinating of farm aged between 10-20 years" was identified to be a negative predictor **(**β= -.1.189) and statistically significant to cocoa farmers' willingness to adopt APT. The odds ratio of .304 implies that cocoa farmers who had their farm(s) pollinated beyond the recommended cocoa farm age of pollination would be 0.3 times less likely to adopt APT in the future in cocoa production. The recommended age of cocoa trees that should be pollinated to ensure optimal production is between 10-20 years.

The result of the study is similar to that of Danso-Abbeam et al. (2014), who reported the age of cocoa farms to be negatively significant to cocoa farmers' willingness to invest in the adoption of agrochemicals in cocoa production. Other studies (Amfo and Ali 2020; Aikpokpodion and Adeogun 2011) revealed that old cocoa trees are major constraint in cocoa production for cocoa farmers.

Pollinating of hybrid cocoa variety as a predictor of cocoa farmers' willingness to adopt APT

Pollination of "hybrid cocoa variety" was also found to be statistically significant and positive predictor (β= 1.057) of cocoa farmers' willingness to adopt APT. The odds ratio of 2.878 indicates that cocoa farmers who have a hybrid cocoa farm(s) would be almost 3 times more likely to adopt APT in the future. This implies that cocoa farmers with hybrid cocoa farms will be more willing to adopt APT than those who have planted other cocoa varieties in cocoa production.

The findings of the study are contrary to Aneani and Ofori-Frimpong (2013), who found a negative relationship between cocoa yield and the adoption of hybrid variety in cocoa production. They also found that planting of a poor cocoa variety can decrease yield by 28.1kg/ha (Aneani and Ofori-Frimpong 2013). Robinson (2009) also reported that the adoption of cocoa hybrid technology is positively and significantly influenced by age of farmers in cocoa production in Oyo State.

CONCLUSION AND RECOMMENDATIONS

Conclusions

Respondent cocoa farmers generally perceived APT activities to be highly effective in increasing their yields and income in cocoa production. Cocoa farmers perceived that weeding, pruning, application of fertilizer, and selection of youth pollinators (18-35 years) before pollination to be very crucial activities at the initial stage of the pollination processing to enhance the effectiveness of the APT.

The artificial pollination technology brought about a significant improvement in the yields of cocoa farmers after their farms were pollinated. The result was statistically significant (0.000) after the APT had been applied for free of charge to farmers by COCOBOD at 0.05 alpha level.

The majority (about 64%) of the respondent cocoa farmers were willing to adopt the APT. The best predictor variables of cocoa farmers' willingness to adopt APT were the age of cocoa farmers, educational level, and number of farms, perceived complexity of APT, and pruning of farm before pollination, pollination farms of recommended age, and pollination of hybrid variety. Pollination of hybrid variety was the overall best predictor of cocoa farmers' willingness to adopt APT. Cocoa farmers who have their farms within the recommended age of coca farm and are of hybrid variety are more likely to adopt the APT.

Recommendations

COCOBOD and other stakeholders of APT should make policies that will inform strategic decision-making for proper implementation and adoption of APT by cocoa farmers since it increases yield of farmers in cocoa production. Cocoa Health and Extension Division (CHED) under COCOBOD should provide an experimental site in every cocoa district for a practical demonstration to educate and train cocoa farmers before they begin to take full responsibility to pollinate their farms. Efforts to consider the adoption of APT by cocoa farmers should focus on youth in cocoa production. CHED should provide better education to farmers on the usefulness of planting cocoa hybrid seedlings developed by Cocoa Research Institute of Ghana for pollination since cocoa hybrid have a great performance of increasing farmers' yields in cocoa production.

Efforts should focus on the development and implementation of robotic insects to properly pollinate flowers of cocoa trees at an increasing rate to improve yield of farmers in cocoa production. Future studies could access the livelihood impacts of APT among cocoa farmers who have planted hybrid variety to explain why they would adopt APT in cocoa production. Moreover, cocoa research institutions in Ghana and the West Africa enclave should explore the feasibility of using precision artificial pollination such as the 'robotic insects' or the use of the ionic liquid gels (ILGs) that allows the design of multifunctional composites that are controllable through simple combinations of constituent molecules to ensure precision pollination of cocoa flowers, improve fruit-set and ensure increase and sustainable productivity of cocoa farms.

DISCLOSURES AND DECLARATIONS

The authors sought informed consent from the respondents and participants before they were interviewed

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No funding was received for conducting this study. Also, the authors declare that there are no competing interests with regards to this research work

AUTHORS' CONTRIBUTION STATEMENTS.

Stephen Yeboah: Conceptualization, Methodology, Data collection and Analysis, writing original draft preparation

Martin Bosompem: Conceptualization, Methodology, Data Analysis, Writing part of The original draft preparation**,** Writing - Review & Editing**,** Supervision

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Appendix A: Predictors of cocoa farmers' willingness to adopt APT

Predictor	B	S. E	Wald	Sig.	Odds ratio	95% C.I for odds ratio
Constant	-1.333	4.110	.105	.746	.264	
Demographic/farm related factors:						
Sex	.289	.674	.184	.668	1.336	.356 – 5.005
Age	-.154	.035	19.412	.000	.858	.801 - .918
Educational level	.696	.275	6.396	.011	2.006	1.170 - 3.440
Years of experience	.009	.035	.066	.797	1.009	.943 – 1.080
Household size	.033	.066	.241	.623	1.033	.907 – 1.177
Number of farms	.436	.154	7.997	.005	1.547	1.143 - 2.093
Age of pollinated farm	.033	.096	.131	.718	1.034	.864 – 1.237
Number of acre(s) pollinated	-.154	.125	1.506	.220	.858	.671 – 1.097
Perceived attributes of APT:						
Relative advantage	.023	.429	.003	.957	1.024	.441 – 2.374
Compatibility	.096	.478	.041	.840	1.101	.432 – 2.808
Complexity	.756	.259	8.530	.003	2.130	1.282 - 3.537
Trialability	-.016	.271	.003	.953	.984	.579 – 1.673
Observability	.257	.261	.968	.325	1.293	.775 – 2.156
Voluntariness	-.424	.340	1.557	.212	.654	.336 – 1.274
Perceived effectiveness of APT:						
Pruning of farm before pollination	.913	.395	5.336	.021	2.491	1.148 - 5.404
Application of fertilizer before pollination	.238	.490	.236	.627	1.269	.485 – 3.318
Pollination of farm aged between 10-20 years.	-1.189	.514	5.361	.021	.304	.111 - .833
Pollination of hybrid variety	1.057	.497	4.533	.033	2.878	1.088 - 7.616
Selection of youth pollinators (18-35 years of age)	-.376	.383	.963	.327	.687	.324 – 1.455
Use of five pollinators to pollinate an acre of farmland	.298	.424	.492	.483	1.347	.586 – 3.095
Regular availability of a farmer to monitor the pollination	.039	.277	.019	.889	1.039	.604 – 1.790
Visiting of pollinated farm for monitoring	.160	.453	.125	.724	1.174	.483 – 2.855
Counting Cherelle and pods to estimate pollination success	-.181	.498	.132	.717	.835	.315 – 2.214

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