COSTS AND BENEFITS OF STORED RICE INSECT MANAGEMENT METHODS

By

LIANFAN SU

Bachelor of Science in International Trade and
Economics
Nanjing Agricultural University
Nanjing, China
2004

Master of Science in International Studies
Oklahoma State University
Stillwater, OK
2006

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MANAGEMENT METHODS

Dissertation Approved:

Dr. Brian D. Adam

Dissertation Adviser

Dr. B. Wade Brorsen

Dr. Jayson L. Lusk

Dr. Kevin M. Currier

Outside Committee Member

Dr. Sheryl A. Tucker

Dean of the Graduate College

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CHAPTER I

CONSUMERS' PREFERENCE FOR RICE STORED WITH DIFFERENT INSECT INFESTATION LEVELS AND ALTERNATIVE INSECT MANAGEMENT METHODS

Introduction

Due to the rising U.S. Asian and Hispanic population and the health benefits associated with consumption of rice, U.S. rice consumption has more than doubled since the 1980s (Setia et al. 1994). This shift from primarily export markets to domestic markets, together with increased demand of high quality rice, has encouraged rice producers and millers to focus more on rice quality.

According to U.S.A. Rice Federal's 2009-10 U.S. rice domestic usage report, 59% of U.S. domestic rice consumption is used directly without further processing. Because rice is mainly consumed as a whole grain, physical attributes of rice, such as appearance, texture, and color are important to rice consumers (Webb, 1985). These physical attributes can be affected during storage; insect infestation can significantly reduce the quality of rice, and thus its economic value (Cogburn, 1977; Patel, Stout and Fuxa, 2006).

The two main insect control methods during storage are chemical-based approaches and Integrated Pest Management (IPM). Traditional chemical-based pest management controls insects with routine application of pesticides. IPM is a balanced use of multiple control tactics – biological, chemical, and cultural – as is most appropriate for a particular situation in light of careful study of all factors involved. Consumers demand high quality rice, and may value environmentally-conscious processing methods. To meet consumers' demand, rice processors may want to increase efforts to protect rice in storage and processing from insects, especially with methods apply less or no chemicals, but the extent to which consumers can recognize the results of these efforts, and the amount they are willing to pay for them, are unknown.

The objective of this study is to determine the value consumers place on rice stored with more effective insect control methods, and the value they place on using IPM storage methods rather than routine fumigation.

This study measures consumers' willingness to pay for rice that is of higher quality because of less insect infestation level, and their willingness to pay for rice that is stored using an IPM approach to control insects rather than a conventional chemical-based approach. Since most consumers do not have an opportunity to express in the marketplace any preference they may have for products stored using IPM approaches, there are no historical data available permitting a statistical evaluation of consumer preferences for such products. As a result, this study uses an experimental auction and a discrete choice experiment to elicit consumer willingness to pay (WTP). Several studies have used these methods to elicit consumers' WTP for certain attributes of various agricultural products (Alfnes et al., 2006; Bryan et al., 1996; Feuz et al., 2004; Jaeger et al., 2004; Feldkmap, Schroeder, and Lusk, 2005; Lusk et al., 2001; Lusk et al., 2004; Lusk and Schroeder, 2004, 2006; Magnnsson and Cranfield, 2005; Yue et al., 2006). Both methods are incentive compatible, which means both methods can make participants truly reveal their preference for product attributes

Rice quality is based on both objective and subjective criteria (Setia et al., 1994), and the information participants received during experiments may change their behaviors (Keller and Staelin, 1987; Lusk et al., 2004; Mueller et al., 2010). Thus we conducted a sensory taste panel to determine consumer's preference for rice with various insect control levels. Then several rounds of 2^{nd} price auctions and discrete choice experiments were conducted to elicit consumers' WTP for rice with different insect control levels and for storage using alternative insect control approaches under alternative scenarios. In one scenario, participants made their decision based on only their subjective taste evaluation of the rice samples. In the second scenario, we provided participants with information about the insect infestation level to check how this objective information affects values participants place on rice products. For both scenarios, information on the insect management methods (IPM vs. non-IPM) was provided to consumers.

Determining consumer's preference for rice with different insect infestation level and insect control methods can provide rice elevator managers a better understanding of consumers' preference and the economic benefit associated with alternative insect control methods. Combining this benefit information with the cost associated with different insect control methods can help managers select the most profitable insect control method.

Conceptual Framework

A person's value of a good that he or she does not own can be measured by willingness to pay (WTP) to purchase the goods (Lusk and Shogren, 2007). Here, the insect control levels and storage methods of rice are known, and consumers' choice of any rice product leads to a fixed combination of insect infestation level and storage methods, so we can derive consumers' WTP under certainty.

An auction can be used to directly reflect consumers' WTP for different rice quality levels and storage methods, but there are many factors that influence how participants bid in the auction which may bias their bids from the true value they place on the product. Lusk and Shogren (2007) showed that an auction mechanism that separates what people say from what they pay can make participants bid their true value for the products. One auction that does that is a 2^{nd} price auction, in which the person who has the highest bid wins the auction, but instead of paying the bid price, the winner only pays the amount of the second highest bid. Therefore, we used a 2^{nd} price auction to elicit consumers' WTP for alternative samples of rice.

Lusk and Shogren (2007, page 21) proved the incentive compatibility of 2^{nd} price auction in the following way. Let V_i represent the value individual i places on a good and b_i is the bid he submits. In a 2^{nd} price auction, the market price p is the 2^{nd} highest bids, and is unknown to bidders when they submit their own bids, so it is a random variable. If the person wins the auction, he derives utility from the difference between his value for the good and the market price, which is $U_i(V_i - P)$. If he does not win the auction, his monetary value from bidding is normalized to zero. To maximize the expected utility, the participant's objective function is expressed as:

(1.1)
$$\max_{b_i} E(U_i) = \max_{b_i} \int_{p_l}^{b_i} U_i(V_i - P)dG_i(P) + \int_{b_i}^{p_u} U_i\,(0)dG_i(P)$$

where, $G_i\ (p)$ is the cumulative distribution function of participant *i*'s expectation about the price with support (P_l , P_h), which is the lower and upper bound of the market price of this good. The first integral is the case in which he wins the auction while the second integral is the case in which he loses the auction. Normalizing $U(0)=0$, the optimal bid can be found by taking the derivative of the expected utility function with respect to b_i and setting the derivative equal to zero which yields:

(1.2)
$$\frac{\partial E(U_i)}{\partial b_i} = U_i(V_i - b_i)g_i(b_i)=0$$

where, $g_i(p)$ is the probability density function associated with $G_i(p)$.

This equation is solved when $b_i=V_i$, which suggests that the bidder's expected utility is maximized when he submits a bid equal to his value for the goods. His optimal strategy is independent of his risk preferences, the number of rival bidders, initial wealth levels, or any of the other bidders bidding strategies.

WTP also can be derived from a choice experiment. In a choice experiment, participants maximize their expected utility by choosing the rice product that they prefer. So, their WTP for different rice products is expressed in two categories: buy and not buy. Since their WTP are not directly stated, we need an indirect utility function, U (P, y, A), to derive their WTP, where *U* is the person's utility of having a good, *P* is the price of the good, y is the person's income, and A is different attributes of goods. Then the choice experiment participant's objective function is expressed as:

$$\max_{j=1,\ldots,n} E\left(U_{ij}\right) = \max_{j=1,\ldots,n} E(U_{ij}\left(P_j, Y_i, A_j\right) \tag{1.3}$$

$$U_{ij} = V_{ij} + \epsilon_{ij} \tag{1.4}$$

where, *j* is the participant's choice of rice product with certain price and quality levels among all *n* choices, $U_{ij}\left(P_j, Y_i, A_j\right)$ is participant *i*'s utility of choosing rice product *j*, $V_{ij}$is the systematic portion of utility and it is assumed to be linear in attributes A_j, and $\epsilon_{ij}$is the error term.

Consumers are assumed to choose the rice product that provides the highest utility. Thus the probability that individual *i* chooses rice product *j* is:

$$Prob\left\{V_{ij} + \epsilon_{ij} \geq V_{ik} + \epsilon_{ik}; \text{for all } k \neq j\right\} \tag{1.5}$$

WTP can be expressed as the amount a person is willing to pay that makes the person indifferent between choosing alternative attribute levels. Now assume a consumer considers a change in an attribute from level A_0 to A_1. The value of this change to the consumer is derived by determining the magnitude of WTP such that the following equality holds:

$$U_{i1}(P, A_1, Y_i - WTP) = U_{i0}(P, A_0, Y_i) \tag{1.6}$$

Thus, this participant's WTP for rice with different quality levels and storage methods is the amount of money that, when subtracted from his income, makes him indifferent between changing the attribute of the rice from A_0 to A_1.

Materials and Experimental Design

Participants

A total of 112 participants were recruited on and off Oklahoma State University campus though emails and flyers. Summary statistics in Table I-1 show that 57% of participants were female; 40% were Asian, and since most participants were from the university, participants had a young age and high educational level. 56% of participants were aged 20 to 30, 77% of participants were with bachelor's or higher degrees, and 63% of participants have the annual household income between $20,000 and $40,000. The sample represents a wide range of demographics, with age ranging from 20 to above 60, education ranging from high school to PhD degree, income ranging from below $20,000 to above $100,000, and rice consumption and purchase ranging from zero times per year to once a week. The majority of the participants were rice eaters, eating rice once every two weeks. The participants also answered questions related to their strength of concern about the environment, worker health and pesticide resistance problem; on average they expressed high concerns on these problems.

Products

The rice samples used were milled long-grain rice provided by Rice Land Foods Inc, a farmers' cooperative business group in Arkansas. Three treatments were applied to the rough rice by Frank Arthur at the Center for Grain and Animal Health Research (CGAHR), USDA-ARS: 15 samples of approximately one kilogram each were infested with 200 adult lesser grain borers (LGB), 15 samples were infested with 20 adult LGB, and 10 samples were used as a control, with zero adult LGB added. After eight weeks, allowing the adult insects to grow, insects and non-rice material were removed, rice samples were frozen to kill any internal infestation, and the rice was milled suitable for human consumption. Dockage, whole kernels, milling yield and color were measured for each sample.

Information

Both storage and insect infestation information were provided to participants in the experiments. These two kinds of information were given at different stages of the experiments. Most consumers were not familiar with rice storage methods. Immediately after they tasted the rice samples and evaluated the rice according to their own taste experience, an explanatory sheet with detailed information about the IPM and conventional chemical-based methods was provided. Participants took a short quiz after reading through the storage information sheet check their understanding of both methods. They were told that they should assume both methods are equally effective in insect control. Most participants expressed concerns about the environment, worker safety, and pesticide resistance issues in the survey, so we hypothesized that consumers' willingness to pay for rice stored using IPM method would be higher than WTP for rice stored under regular methods, when the two methods are equally effective.

Additional objective information was provided to test whether participants' WTP would differ from making decisions based only on their own subjective taste evaluation. After completing several rounds of the auction and choice experiment, we provided quality information related to amount of potential damage due to insect infestation. Rice that had zero insect infestation was termed "superior quality," rice that had been infested with 20 insects/kg was termed “high quality,” and rice that had been infested with 200 insects/kg was termed “good quality.” We expected that consumer willingness to pay for different insect infestation levels when they do not have the information mainly depend on their taste evaluation, but providing them objective information may change their preference and increase their willingness to pay for higher quality rice and reduce their willingness to pay for low quality rice.

Product evaluation

The color of rice is one of the main factors of grading rice quality (United States Department of Agriculture, 2005) and L^* a^* b^* color space are commonly used to evaluate color of rice (Tan, et al., 2001; Juliano, 1985). L^* indicates lightness (100 = white and 0 = black); a^* indicates redness-greenness (positive = red); and b^* indicates yellowness-blueness (positive = yellow). We used the L^*index to measure the effect of insect infestation levels on whiteness of milled rice.

Milling yield is the percentage of whole kernel milled rice obtained from rough rice. It is one of the measures affecting rice grades. Rice insects, especially lesser grain borer, heavily damage rice kernels (Ranalli et al., 2002). We expected that high insect infestation levels would significantly reduce rice milling yield.

Sensory taste panel

In the taste panel we used three rice samples of different insect infestation levels; each assigned a different 3-digit random number: Rice537, Rice258, and Rice741. Participants were to rate the samples using a 9-point scale where 1= extremely undesirable and 9 = extremely desirable.

Following the procedures described in a sensory analysis for cooked long-grain rice conducted by Muellenet (2000), samples were cooked for 22 min in Panasonic household-grade steam rice cookers with a 1:2 rice to water volume ratio, and immediately mixed and fluffed using a plastic fork. Participants were instructed how to taste the rice and complete the evaluation form. Next, participants were served the first sample of the rice, and asked to evaluate the samples for each of four sensory characteristics: appearance, flavor, texture, and overall acceptance and this was repeated for the second and third samples. In taste experiment, the order in which the sample are given can affect the behavior of participants, to counteract this, a counterbalanced design was used here with serving orders of rice completely randomized over participants to reduce the order effects.

Experimental auction

The rice samples used in the auction and choice experiment varied in insect infestation levels. And participants were told that assumed one group of rice were stored under conventional methods, and the other group were stored under IPM method, and both methods are some effective in insect control. With two storage methods (IPM methods and conventional methods), and three insect infestation levels (0, 20, and 200 LGB/kg), there were six combinations of rice products for which consumers could bid. First, consumers bid based on their taste evaluation. We used three-digit random numbers for three rice samples with the three different insect infestation levels, and added three samples that were the same as the other three except that they were designated as having been stored using IPM methods. Thus, the participants were instructed to bid on rice samples 537, 258, and 741, as well as on IPM537, IPM258, and IPM741.

After conducting several rounds of the auction, Extra information about the rice insect infestation levels and the objective quality levels of the samples 537, 258 and 741, were provided to participants, and another round of auction was conducted to test how participants' behavior changed with this extra information.

Choice experiment

Same participants participated in choice experiment. The same six rice samples were used, using two different price levels as anchors, so that there were $2^6 = 36$ choice combinations. SAS was used to generate a fractional factorial design with eight choice scenarios. As with the auction, participants first made their choice based on their own taste evaluation, and then were provided with extra information on insect infestation levels, so that they made their choices based on a combination of their subjective evaluation and objective information.

Procedures

A sensory taste panel was conducted to test the extent to which consumers could detect differences among rice samples with different quality levels. Then, five rounds of 2nd price auction and two rounds of choice experiments were conducted to determine participants' preferences for alternative rice products. Four rounds of auctions and one round of choice experiment were conducted first based on participants' own taste evaluation, and then one round of auction and choice experiment were conducted given participants' extra rice product quality information. Figure I-1 shows a schematic of the entire procedure.

Participants were solicited through in-person and email invitations, offering $20 compensation for approximately one hour's participation. They were assigned a random identification number, and instructed to taste and rate three rice samples.

After participants finished ranking the three rice samples, they were given $2 in coins and informed that they would have an opportunity to purchase one of the rice samples in an auction as well as in a choice experiment. In both the auction and the choice experiment, participants bid on six rice samples. Before asking the participants to bid, they were provided a written brief statement on the difference between IPM and conventional pest management, and the statement was read aloud to them.

Participants retained the sheet on which they had recorded their evaluation of the rice samples. The procedures for the 2nd price auction were explained to the participants, encouraging them to bid exactly the amount they believe the product is worth to them, because if they were to "win" a binding auction, they would be obligated to purchase the rice at the winning price, the second highest bid. Participants were then given bid sheets and asked to submit sealed bids for each rice sample simultaneously. Participants indicated their bid for each rice sample on a bid sheet labeled with the participant's and samples' unique identification numbers. We conducted four rounds of auctions. For each round and each rice sample, the winner's identification number and the winning price (the second highest bid) were displayed for all participants to see.

After four rounds of auctions, the choice experiment was conducted. Using the six rice samples and their evaluation record sheets, each participant was instructed to complete a selection sheet labeled with his or her unique identification number. The selection sheet listed eight shopping scenarios, with each scenario having all six types of rice listed at various price levels and a "none" option. The procedures for the choice experiment were explained to participants, including instructions that they should truthfully indicate which rice/price combination (or none) they would like to choose, because if their identification number were to be selected at the end, they would be obligated to purchase the rice they selected at the associated price in the randomly selected binding scenario at the end.

For both the auction and the choice experiment, the participants were informed that although they had been given $2 in coins with which to purchase rice they had "won," if any, they were free to bid more than that amount if they wished, but that if they won the bid and the price was more than $2, they would be obligated to use money they had brought with them. Conversely, they were informed that if they did not win a bid, the $2 was theirs to take home with them.

After the participants finished four rounds of auctions and one round of choice experiment, they was informed the actual quality levels of each rice sample and asked them to bid on one more action round and to do one more round of choice experiment based on that information. At the end of the entire experiment, a number was drawn between one and five to determine the binding auction round, and a number between one and six was drawn to determine the binding rice sample. The participant bidding the highest price for this rice sample in this auction round paid the second highest price bid for this rice sample in this round and received a pound of that rice, while the other participants paid nothing and got no rice. Then a number between one and two was drawn to determine the binding round in the choice experiment, and a number between one and eight was randomly drawn to determine the binding scenario. Then one participant's identification number was randomly selected (we took out the auction winner's identification number to make sure one participant did not purchase more than one pound of rice.) The selected participant purchased the rice that he chose in that binding round and binding scenario at the price listed. At the end of the experiment, participants were asked to complete a short survey on their demographic information and their rice purchasing habits. Copies of solicitation emails and flyers, experiment instructions, evaluation forms, and bid sheets are provided in an appendix.

Empirical Model

Models for rice color and milling yield

$L^* a^* b^*$ color space was used to evaluate the color of rice samples with different insect infestation levels, and milling yield for each rice sample was calculated after the milling process. Simple regressions were used to measure the association between insect infestation levels and rice color, specifically the whiteness of rice (L^*), and rice milling yield. The adult lesser grain borer put at the beginning of the treatment produce progeny, which leads to feeding damages and then affect the milling yield. Thus, the relation between progeny and milling yield is also checked:

(1.7) $$L_i = \alpha_0 + \alpha_1 HI_i + \alpha_2 MI_i + \varepsilon_i$$

(1.8) $$MY_i = \beta_0 + \beta_1 HI_i + \beta_2 MI_i + \epsilon_i$$

(1.9) $$MY_i = \gamma_0 + \gamma_1 P_i + \delta_i$$

where L_i is the L^* index of the i^{th} rice sample, MY_i is the milling yield of i^{th} rice sample, HI_i is a dummy variable for high insect infestation level, equal to 1 if the i^{th} rice sample had a high insect level (initially infested with 200 insects/kg) and 0 otherwise, MI_i is a dummy variable for medium insect infestation level, equal to 1 if the i^{th} rice sample had a medium insect infestation level (initially infested with 20 insects/kg), and 0 otherwise, P_i is the progeny population of ith rice sample, and $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$, $\epsilon_i \sim N(0, \sigma_\epsilon^2)$, and $\delta_i \sim N(0, \sigma_\delta^2)$are the random individual effects for the i^{th} rice samples.

Model for taste evaluation

In the taste panel, participants were asked to taste, in a randomized order, samples of the three different qualities of rice and evaluate them for appearance, texture, flavor and overall acceptance. A random effects model was used to explain how consumers' taste evaluations of four rice characteristics are explained by the quality levels of the rice samples. Tukey's studentized range tests are also conducted to test how consumers taste evaluations for all three rice samples are different from each other.

(1.10) $$Taste_{ij}^{A,T,F,O} = \alpha_0^{A,T,F,O} + \alpha_1^{A,T,F,O} HI_j + \alpha_2^{A,T,F,O} MI_j + \varepsilon_i + \epsilon_{ij}$$

where, $Taste_{ij}^{A,T,F,O}$ is consumer i's evaluation of the j^{th} rice sample in appearance, texture, flavor and overall acceptance, respectively, HI_j and MI_j are the same as defined before, $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$ is the random individual effect for the i^{th} participant that captures the correlation between the taste evaluation of three rice samples made by the same participant. $\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$ is the residual error term that is not captured by consumer demographics variables.

Model for 2^nd^ price auction

The auction bids can be directly interpreted as consumers' WTP. We use three sets of variables to explain the variation in WTP. First is the variation in the product quality attributes. Second is the variation in socio-demographics and consumers' attitudes. Third is the variation in the experiment. Based on this the following econometric model is estimated to explain consumers' WTP for the rice in the auction:

(1.11) $$WTP_{ij} = BID_{ij} = b_0 + \alpha \boldsymbol{X}_j + \beta \boldsymbol{Y}_i + \gamma \boldsymbol{Z}_{ij} + \eta_i + \varepsilon_{ij}$$

where WTP_{ij} is individual i's WTP for product j, BID_{ij} is individual i's bid for product j, $\boldsymbol{X_j}$ is a vector of product quality attributes for product j, including objective insect infestation levels, ZI_j and MI_j, and insect control method, IPM_j. ZI_j and MI_j are indicator variables for rice with zero and medium insect infestation levels, IPM_j is indicator variable for rice storage method, IPM_j takes the value of 1 if rice sample j is maintained with IPM method and 0 otherwise, $\boldsymbol{Y_i}$ is the vector of the individual i's socio-demographic information, including participants' gender, race, age, income, how often they eat rice and their attitudes towards environment, worker safety, and pesticides resistance issues and their taste evaluation of the j^{th} rice sample, $\boldsymbol{Z_{ij}}$ is a vector of design variables, including information, $INFO_i$, and the interaction between information and quality attributes, $INFOZI_{ij}$ and $INFOMI_{ij}$. $INFO_i$ is an indicator variable for information that takes the value of 1 if quality information is provided to individual i and 0 otherwise; $INFOZI_{ij}$ and $INFOMI_{ij}$ are interaction between information and insect infestation levels; $\eta_i \sim N(0, \sigma_\eta^2)$ is the random individual effect for the ith participants that captures the correlation between the bids made by the same participant. $\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$ is the residual error term.

In auction experiments, many zero bids were observed and the normality test showed that bids were left-censored, due to participants could not submit negative bids. To fix this problem, a left- censored Tobit model is used to estimate the parameters.

Model for Discrete Choice Experiment

In the discrete choice experiment, instead of bidding directly how much they valued each rice sample, participants had to choose among alternative rice/price combinations. Participants' willingness to buy rice with different quality levels and storage methods is expressed as two categories, choose and not choose. Because the respondent variables do not directly reflect consumers' WTP, a random utility model was used to derive participants' WTP. Suppose a participant's utility function can be expressed as:

(1.12) $$U_{ij} = V_{ij} + \epsilon_{ij}$$

where; U_{ij} is consumer *i*'s utility from choosing rice product *j*, V_{ij} is the systematic portion of the utility function determined by the rice attributes and ϵ_{ij} is a stochastic element.

The systematic portion of consumer *i*'s utility of choosing rice product *j* is:

(1.13) $$V_{ij} = \beta_1(HI_{ij}) + \beta_2(MI_{ij}) + \beta_3(LI_{ij}) + \beta_4(HIIPM_{ij}) + \beta_5(MIIPM_{ij}) + \beta_6(LIIPM_{ij}) + \beta_7(Price_{ij})$$

where, $(Price)_{ij}$ is price faced by consumer *i* for rice product *j*, and ξ_{ij} is an error term. All other variables are dummy variables indicating rice products with different attributes: β_1 to β_6 are utility of having the corresponding rice products compared to not choosing any rice product.

The parameters β in equation (1.11) can be estimated by maximizing the log-likelihood function:

(1.14) $$LLF = LLF = \sum_{i=1}^{N} \sum_{j=1}^{7} \left(C_{ij} * ln\left(Prob_{ij}\right)\right)$$

where, C_{ij} =1 if rice product *j* is chosen by consumer *i* and 0 otherwise, $Prob_{ij}$ is the probability of product *j* being chosen.

When ϵ_{ij} in equation (1.12) are independent and identically distributed across the J products and N consumers with an extreme value, the probability of consumer *i* choosing rice product j is:

(1.15) $$Prob_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^{J} e^{V_{ij}}}.$$

Participant *i*'s value of choosing was set to 0, and the value of choosing rice product *j* was V_{ij} . For example, participant *i*'s WTP for rice sample with high insect infestation level and stored with non-IPM method can be calculated by setting the following equality holds:

(1.16) $$V_{i,HI} = \beta_1 * 1 + \beta_7 (Price_{i,HI}) = V_{i,0} = 0$$

(1.17) $$WTP_{i,HI} = -\beta_1/\beta_7$$

Results

Effect of insects on rice quality

Rice color and milling yield were applied in this study as a standard evaluation for rice quality. The rice products used in this study varied only in different amounts of insect infestation during storage. Rice color and milling yield were tested for each rice product with alternative insect infestation level to determine the effects of insects on rice quality. Table I-2 shows that there is no significant difference in color measurement between zero insect infestation and 20 insects/kg insect infestation. But compared to zero insect infestation, the rice with 200 insects/kg had an L^* index of whiteness 2.34 points higher than the L^* index for zero insect.

Table I-3 and I-4 presents the effect of insects and progeny on rice milling yield. Compared to zero insect infestation, both high and medium insect infestations were associated with reduced milling yield of the rice. The milling yield of rice with high and medium insect infestations were 5.4% and 3.3% lower, respectively, than the milling yield of rice with zero insect infestation. The progeny population and milling yield is negatively related, more progeny leads to lower milling yield, which is consistent with our expectation.

Taste evaluation of alternative qualities of rice

Participants were required to taste and evaluate three rice samples that varied only by level of insect infestation during storage to determine whether regular customers can distinguish the quality differences that may be associated with insect infestation. Table I-5 presents participants' taste evaluation points for three rice samples in appearance, texture, flavor and overall acceptance with a 9-point scale. The data shows that on average, participants ranked the rice with zero insect infestation highest only in appearance, but in terms of texture, flavor and overall acceptance, participants preferred the rice with medium insect infestation. For all four characteristics, though, participants preferred the rice with highest insect level least compared with the other two rice samples. But the magnitudes of differences in these evaluations between high, medium, and low insect levels were very small. To determine whether participants' taste evaluation for three rice samples were significant, we conducted an ANOVA-F test and the results show that for appearance, texture, flavor and overall acceptance, participants' taste evaluation for three different rice samples were not significantly different. A Tukey's studentized range test was applied to verify these results. Table I-6 indicates that the 95% confidence intervals of the taste evaluation of four characteristics of three different quality rice samples are overlapping, which is consistent with the results of the ANOVA F test – participants on average cannot discern differences among these rice samples. A random effects model were used to test whether participants' evaluation points for appearance, texture, flavor and overall acceptance were associated with insect levels (model 1.8), and failed to reject the null hypothesis using an overall F test. In general, participants could not discern a difference among rice samples that varied only in insect infestation levels during storage.

Participants' WTP derived from 2nd price auction and choice experiment

Non-hypothetical 2nd price auction and choice experiments were used here to determine participants' WTP for rice products that varied in insect infestation level during storage, and insect control methods. Our study was non-hypothetical: participants were informed that they would pay real money for the one-pound rice samples if they won the bids. Table I-7 presents participants' WTP derived from both auction and choice experiments. Both auction and choice data show that without extra quality information, participants' WTP for three rice samples were very close, with a slightly higher WTP for rice with zero insect infestation. Providing them with quality information, though, significantly changed participants' preferences, increasing their WTP for rice with lower insect levels and reducing their WTP for rice with higher infestation levels. The auction data shows that after receiving the quality information, participants' WTP for superior quality rice (zero insect infestation) jumped from $0.80 per pound to $1.07 per pound, their WTP for high quality rice (20 LGB/kg insect infestation) increased from $0.77 per pound to $0.87 per pound, and their WTP for good quality rice (200 LGB/kg insect infestation) decreased from $0.75 per pound to $0.68 per pound, which indicates that providing participants quality information affects their WTP.

Although IPM and conventional insect control methods are assumed to be equally effective in insect control during the storage, participants showed strong preference for rice stored under IPM methods. Results of both auction and choice experiments show that on average participants were willing to pay 6 cents extra per pound for rice that is stored with IPM methods across all three levels of rice quality.

Effects of insects, storage methods and demography factors on participants' WTP

Auction data directly shows how much participants value different rice products that varied in amount of insect infestation and storage method. We used a censored Tobit model and a random utility model to analyze the auction and choice data to check how those variables affect participants' WTP for rice. Effects of participants' demographic background and their concerns on environmental, worker safety and pesticide residuals on their WTP for different rice products were checked. Table I-8 shows that the coefficient for rice with zero insect infestation is positive, and for medium insect infestation is negative, but both are insignificant. This is consistent with the results of the taste evaluation: on average participants could not discern differences among the different qualities of rice based only on their own evaluation. On the other hand, the positive and significant coefficient on taste indicates that participants who expressed taste preferences for particular rice samples, whether or not they were correlated with insect infestation, were willing to pay $0.10 more for every one point increase in their overall acceptance of the rice products. The interaction terms between quality levels and information indicate that participants that had been given rice quality information bid $0.28/lb. more for rice that had had zero insect infestation, and $0.14/lb. more for rice with medium insect level than for rice with the highest amount of insect infestation.

The effects of participants' demographics on their WTP are all significant. Female and Asian participants were willing to pay less for all rice products compared with male and non-Asian participants, older people were willing to pay more for rice compared with younger people, and people who ate rice more frequently were willing to pay a higher price for rice. The only insignificant demographic effect is income: perhaps the price is too low relative to income to have a significant effect The signs of participants' attitude towards human health and pesticide resistance issue are positive, which indicates the more people care about human health and pesticide resistance issues, the more they are willing to pay for rice stored with IPM methods.

Table I-9 presents the results from the choice experiment measuring participants' WTP for the rice products. The coefficients for each rice product represent the relative preference for each rice choice compared with the "none" option, the omitted choice option. All coefficients are positive, which means participants on average were willing to pay to purchase each of the rice products compared with purchase nothing. Odds of choosing the rice with zero insect infestation were higher than the odds of choosing rice with medium and high insect levels, which indicates that participants preferred rice with zero insects most, but the magnitudes of the coefficients are very similar, so that calculated WTP measures are very similar. The results also show that the odds of participants choosing rice stored with IPM methods were much higher than for rice stored with conventional methods. Providing information about quality increased the odds of choosing rice with low insect levels and decreased the odds of choosing rice with high insect levels. All these results are consistent with the auction results.

Discussions and Conclusion

The objective of this study is to examine the effects of insect infestation during storage on rice quality and to determine participants' willingness to pay for improved insect control methods, both IPM and non-IPM. L* color index and rice milling yield were used as objective standards for rice quality level. A blind sensory taste panel was used to test whether typical consumers could taste effects of insect infestation during storage. Non-hypothetical auction and choice experiments were used to elicit participants' preference for rice products of varying insect infestation levels and insect control methods during storage, under the conditions of with and without providing them objective rice quality information.

The USDA rice grading system focus on color, broken kernels, and milling yield. In our study, we used the L* color index to determine color of the rice samples. Results show that insect infestation level has little effect on the whiteness of milled rice. USDA official testing of the samples provided measures of broken kernels for each sample, statistical analysis of these measures showed that higher insect infestation levels were associated with more broken kernels per sample. Correspondingly, since broken kernels reduce milling yield, the milling yield tests indicate that higher levels of insects during storage reduce rice milling yield.

In order to test whether regular rice consumers can distinguish differences in rice quality associated with insect infestation during storage we conducted a sensory taste panel and the result shows that although individual participants expressed clear preferences for a particular sample, averaging these individual preferences resulted in no statistical difference in preferences for the three qualities of rice.

One reason for the insignificant differences may be that participants' tastes for rice are very subjective. Higher insect infestation is associated with more broken kernels.Rice with more broken kernels are significantly sticker once cooked (Saleh and Meullent, 2006), and people who prefer sticky rice will value this rice most. Also, in our experiments, some participants were not regular rice eaters and may not have had the ability to discern differences in rice quality.

In some rounds of the auction and choice experiment, participants were given additional objective information about the quality of each rice sample. Extra information changed participants' behaviors dramatically. Without information, participants bid or chose based on their own taste evaluation; since on average all three rice samples tasted similar to them, their average WTP for the rice samples were similar. However, when provided with objective rice quality information, participants significantly increased the value they placed on rice with lower insect levels and reduced the value they placed on rice with higher insect levels. One reason may be that participants did not have much knowledge about rice and were not very confident in their own evaluation, but when they were provided with objective information about quality from a trustworthy source, they placed more weight on the information than on their own taste evaluation.

Participants valued IPM methods much higher than conventional methods, given that both methods are equally effective in controlling insects during storage. This higher WTP for IPM methods is linked to participants' positive attitudes toward IPM methods compared to conventional methods. Since IPM approaches prefer non-chemical treatment methods, using chemical treatments when other approaches are not effective, participants concerned about worker safety and pesticide residual are more willing to pay for IPM methods.

Although participants prefer rice stored with better insect control and using IPM insect control methods, there is currently no third-party grading system or standard that gives consumers information about rice insect infestation levels or storage practices. As a result, rice storage firms have difficulty gaining economic benefit from providing rice that is of higher than normal quality. This does not imply that insect control during storage is unnecessary, since insect level affects not only rice quality levels but also quantities. Also, rice with live insects is graded as "sample grade" and is not allowed for human consumption. It does imply, though, that there may be gains from achieving higher levels of insect control if information about the higher quality can be provided to consumers.

Similarly, we found that for each quality level of rice considered, participants were willing to pay a premium for rice stored with IPM methods. On average, participants were willing to pay 6 cents more for one pound of rice stored with IPM methods instead of conventional methods. If costs of using IPM methods are less than these benefits, and if IPM methods are at least as effective as non-IPM methods, storage firms would gain from adopting IPM methods. For the third article of this dissertation, costs of IPM methods will be evaluated and compared to the benefits calculated here. This will provide storage firms information to select the methods that maximize their objectives.

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Appendix

Informed Consent Forms

This project is conducted by Dr. Brian Adam, Professor in Department of Agricultural Economics, Oklahoma State University, and Lianfan Su, research assistant in Department of Agricultural Economics, Oklahoma State University.

This study is part of an effort to learn about people's preferences for rice quality and how its wholesomeness is maintained after harvest. Rice quality is very important to consumers, and how the rice is stored after harvest will affect its quality. Two methods –an experimental auction and a choice experiment will be used to derive your willingness to pay for rice with different quality levels and storage methods.

First, you will be asked to taste three different types of rice that have been stored under a range of conditions, which may affect quality levels of rice, and then evaluate them. Because all of the rice used in this experiment has been processed after storage and meets the same food quality standards as if it were sold in a grocery store, the investigators believe that there are no health risks from eating this rice and that there are no risks associated with this project which are greater than those ordinarily encountered in daily life.

Then you will be asked to complete a survey about your normal rice eating habits and your knowledge of rice storage methods. Next you will be asked to participate in an experimental auction, in which you will bid on several different kinds of rice. One of the types of rice will be chosen after the auction and the winner of the auction will purchase this rice. Finally, you will participate in a choice experiment, in which you will be given several choice sheets listing several types of rice at different prices and you can choose the one you like. One round will be randomly selected, and you will purchase the rice you choose in that round. The taste panel will take about 15 minutes, the auction will take about 30 minutes, and the choice experiment will take about 15 minutes, the whole study will last around one hour.

There are no risks associated with this project which are greater than those ordinarily encountered in daily life. Results from the study will be used to help rice producers and processors make better decisions about how to improve the quality of their products. By understanding what people know and want, they can do a better job at providing the kind of rice that consumers such as you prefer.

You will be assigned a random number, all the surveys and experiments are anonymous and your name is in no way linked to the response. Your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. I want to assure you that the information you provide will be kept strictly confidential and used only for the purposes of this research.

$20 will be given to you in appreciation of your help in this study. This $20 will be delivered at the end after you complete the whole study. For the auction and choice experiments parts, an additional $3 in coins will be given to you to purchase the rice products.

Your participation is completely voluntary; if you do not wish to participant in the experiment, please say so at any time. Non-participants will not be penalized in any way.

If you have any questions or comments about this research, you may contact Dr. Brian Adam, Professor, 413 Ag Hall, Stillwater, OK, 74078, 405-744-6854 or brian.adam@okstate.edu, or Lianfan Su, Research Assistant, 522, Ag Hall, Stillwater, OK, 74078, 405-744-9988, or lianfan.su@okstate.edu.

If you have questions about your rights as a research volunteer, you may contact Dr, Shelia Kennison, IRB Chair, 219 Cordell North, Stillwater, OK, 74078, 405-744-3377 or irb@okstate.edu.

I have read and fully understand the consent form. I sign it freely and voluntarily. A copy of this form has been given to me.

______________________________ ______________________________

Signature of Participant Date

I certify that I have personally explained this documents before requesting that the participant sign

______________________________ ______________________________

Signature of Researcher Date

Introductory Instructions

Thank you for agreeing to participant in today's session. As you entered the room, you should have been given $20 and a packet. You should also have been assigned an ID number, which is located on the upper right hand corner of the packet. You will use this ID number to identify yourself during this research session. We use random numbers in order to endure confidentiality.

Before we begin, I want to emphasize that your participation in this session is completely voluntary. If you do not wish to participate in the experiment, please say so at any time. Non- participants will not be penalized in any way. I want to assure you that the information you provide will be kept strictly confidential and used only for the purposed of this research.

In today's session, we are interested in your preference for several different kinds of rice. First, you will have a chance to taste three different kinds of rice samples which may be of different quality levels. The three rice samples are labeled by different random three digit numbers. After you taste them, please evaluate them and complete the taste evaluation form.

In the packet we give to you, you will find a survey which will ask you some questions about your rice consumption and your understanding of rice storage methods. This survey is anonymous and your name is in no way linked to the responses. After finishing all experiments, please complete the survey.

I will now begin going through a set of instruction with you and will read from this script so that I am able to clearly convey the procedures. Importantly, from this point forward, I ask that there be no talking among participants. Failure to comply with these instructions will result in disqualification from the experiment.

Oklahoma State University Study on Consumers' Preferences for Rice with Different Quality Levels and Storage Methods

This is the first part of our survey. We would like some background information about you. The survey is anonymous and your name is in no way linked to the responses.

1. What is your gender?
   - Male
   - Female

2. What is your race?
   - White
   - Hispanic
   - African American
   - Asian
   - Other

3. Which is the highest level of education you have obtained?
   - High school or below
   - Associate degree
   - Bachelors degree
   - Master degree
   - Doctoral degree or higher

4. What is your approximate annual household income before taxes in 2008?
   - Less than $20,000
   - $20,000 to $39,999
   - $40,000 to $59,999
   - $60,000 to $79,999
   - $80,000 to $99,999
   - $100,000 or more

5. What is your present age?

- 20-30
- 31-40
- 41-50
- 51-60
- Above 61

Now we would like some information on your rice consumption and your understanding of rice storage management.

6. How often do you purchase rice?

- About once a week
- About every two weeks
- About once a month
- A few times a year
- About once a year
- Never

7. How often do you eat rice?

- About once a week
- About every two weeks
- About once a month
- A few times a year
- About once a year
- Never

8. How well do you understand the description of the two approaches of insect control in rice?

- I understand it very well
- I understand a little
- I don't understand it at all

Thank you for your help!

Instructions for Rice Tasting Evaluation

Now you will have a chance to taste three samples of rice that have been stored under different conditions, which may or may not affect the rice quality. You will be given three rice samples which are labeled with three random digit numbers. The label is randomly assigned to each rice samples, and is not related to the rice storage methods or quality levels. All the rice used is suitable for human consumption.

Each rice sample will be presented on a separate plate. You will be served the first sample of rice, which is identified with a number. You will taste and rate the rice sample for appearance, flavor, texture, and overall acceptability. Then the second and third samples of the rice will be served, and you again will evaluate the sample for each of the four sensory characteristics. You will take a 2-minute break after each sample evaluation and a cup of water to drink to refresh your month.

When you are evaluating rice samples for appearance, flavor, texture, and overall acceptability, a 9-points hedonic scale will be used for ranking. The scale range from 1 (the rice is **very undesirable** for appearance, flavor, texture, and overall acceptance) to 9 (the rice is **very desirable** for appearance, flavor, texture, and overall acceptance).

Taste Panel Evaluation Form

Rice ID:

ID:

Please rate the rice sample, which are labeled with different number, for appearance, flavor, texture, and overall quality. Use the following scales: 1=extremely undesirable and 9=extremely desirable for appearance, flavor, texture, and overall quality.

Appearance:

Extremely undesirable ⟶ Extremely desirable

1 2 3 4 5 6 7 8 9

Flavor:

Extremely undesirable ⟶ Extremely desirable

1 2 3 4 5 6 7 8 9

Texture:

Extremely undesirable ⟶ Extremely desirable

1 2 3 4 5 6 7 8 9

Overall Acceptance:

Extremely undesirable ⟶ Extremely desirable

1 2 3 4 5 6 7 8 9

Explanation of IPM and regular rice storage methods

Maintaining wholesomeness of rice in storage depends on controlling temperature and moisture content of the grain, maintaining cleanliness, and preventing insect damage. One management approach to prevent insect damage is to control insects with routine application of pesticides. Research indicates that fumigants, a commonly used form of pesticide, likely don't directly affect humans because they leave no residual, but they may negatively affect humans, particularly workers, if application is not conducted correctly. Also, over time, insects may develop resistance to the pesticides.

Another approach is integrated pest management (IPM). IPM is a balanced use of multiple control tactics – biological, chemical, and cultural – as is most appropriate for a particular situation in light of careful study of all factors involved. Thus, while conventional pest management typically uses regular applications of pesticides, IPM programs evaluate the need for treatment and apply treatments considering both effectiveness and risk as needed. Sampling or monitoring is used to determine how many and what kinds of insects are present and to guide the application of control methods. Less risky and non-chemical actions are taken first, and additional pest control methods, including chemical pesticides, are employed only when needed.

Assume that both IPM and non-IPM approaches are equally effective in controlling insect and maintaining wholesomeness of grains, and that rice choices that you will bid on are each in a one-pound package. Before you start to bid, three dollars in coins will be given to you.

Are there any questions before we begin?

Instructions for 2nd Price Auction

Now that you have had the chance to learn how the auction will work, we are interested in your preferences for six different kinds of rice. Each of you should have tasted and received an information sheet describing the pest management method different rice use.

We will give you the opportunity to participate in an auction to purchase the rice you desire. We will conduct an auction for each kind of rice. In a moment, you will be asked to indicate the most you are willing to pay for each of the rice samples by writing bids on the enclosed bid sheets.

(1) First, each of you has been given a bid sheet in your packet. On this sheet you will write the most you are willing to pay for each kind of rice.

(2) After you've finished writing your bids, one for each kind of rice, the monitor will collect the bid sheets.

(3) In the front of the room, each of your bids will be ranked from highest to lowest for each kind of rice.

(4) The highest bidders will win the auction but will pay the 2nd highest bid amount for that rice.

(5) For each kind of rice we will write the winning participant's bidder number and the winning price on the chalkboard for everyone to see.

(6) After posting the prices and winning bidder numbers, we will reconduct the auction

for 4 additional rounds.

(7) At the completion of the 5th round, we will randomly draw a number from 1 to 5 to determine the binding round. For example, if we randomly draw the number 2, then we will ignore outcomes in all other rounds and only focus on the winning bidders and price in round 2. Importantly, all rounds have an equal chance of being binding.

(8) After the binding round has been determined, we will randomly draw a number from 1 to 6 to determine which rice to actually sell. Importantly, all rice has an equal chance of being selected.

(9) Once the binding round and the kind of rice have been determined, the winning bidders will come forward and pay the 2nd highest bid amount for the winning rice. All other participants will pay nothing and will not receive any rice.

Important Notes

(10) You will only have the opportunity to win an auction for one kind of rice. Because we randomly draw one binding round and one kind of selected rice, you cannot win more than one pound of rice. That is, under no bidding scenario will you take home more than one pound of rice from this experiment.

(11) The winning bidder will actually pay money to obtain the winning rice. This procedure is not hypothetical.

(12) In this auction, the best strategy is to bid exactly what it is worth to you to obtain each of the six kinds of rice. Consider the following: if you bid more than the rice is

worth to you, you may end up having to buy rice for more than you really want to pay. Conversely, if you bid less than the rice is really worth to you, you may end up not winning the auction even though you could have bought rice at a price you were actually willing to pay. If you win the bid, you will get the rice you desire at a price lower than you were willing to pay. Thus, your best strategy is to bid exactly what each kind of rice is worth to you.

(13) It is acceptable to bid $0.00 for any kind of rice in any of the rounds.

Instructions for the Choice Experiment

Now that you have had the chance to learn how the choice experiment will work. We are interested in your preferences for six different kinds of rice. Each of you should have tasted and received an information sheet describing several different kinds of rice.

We will give you the opportunity to participate in a choice experiment to purchase the rice you desire. We will give you a choice sheet that lists all six rice samples at different price levels. Each kind of rice is available in a one-pound package.

(1) First, each of you has been given a choice sheet in your packet. There are eight different shopping scenarios listed on your choice sheet. For each shopping scenarios, you will choose the rice you are willing to purchase.

(2) After you've finished choosing the rice, the monitor will collect the choose sheets.

(3) We will randomly draw a number from 1 to 8 to determine the binding scenarios. For example, if we randomly draw the number 2, then we will ignore all other scenarios and only focus on the scenario 2. Importantly, all scenarios have an equal chance of being binding.

(4) After binding scenario has been determined, we will randomly draw a number among your ID number. If your ID number is selected, you must purchase the rice that you chose in that binding scenario at the price listed. For example, if we selected participant 11, his choose in scenario 2 is the rice labeled 57IPM, and the price for 57IPM was $0.80, then participant 11 would pay $0.80 and he would receive the rice 571IPM. Everybody has an

equal chance of being selected.

Important notes:

(1) You will only have the opportunity to purchase one pound of rice, since we randomly draw one binding round. That is, under no scenario will you take home more than one pound of rice from this experiment.

(2) If your ID number is randomly selected, you will actually pay money to obtain one pound of rice that you chose. This procedure is not hypothetical.

(3) In this choice experiment, the best strategy is to choose the rice at the price level at which you are really willing to purchase.

(4) It is acceptable to choose the option NONE in any choice round.

Auction bid sheet

ID:

Practical Round

I would like to bid $______ for the rice 537.

I would like to bid $______ for the rice 537 IPM.

I would like to bid $______ for the rice 258.

I would like to bid $______ for the rice 258IPM.

I would like to bid $______ for the rice 741.

I would like to bid $______ for the rice 741IPM.

Choice sheet

ID: Round:

Scenario 1:

I would like to choose…	Rice						
	Rice 537 $0.80	Rice 537IPM $0.80	Rice 258 $0.80	Rice 258IPM $0.80	Rice 741 $1.20	Rice 741IPM $1.20	None
	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	☐	☐	☐	☐	☐	☐	☐

Scenario 2:

I would like to choose…	Rice						
	Rice 537 $0.80	Rice 537IPM $0.80	Rice 258 $1.20	Rice 258IPM $1.20	Rice 741 $0.80	Rice 741IPM $0.80	None
	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	☐	☐	☐	☐	☐	☐	☐

Scenario 3:

I would like to choose…	Rice						
	Rice 537 $0.80	Rice 537IPM $1.20	Rice 258 $0.80	Rice 258IPM $1.20	Rice 741 $0.80	Rice 741IPM $1.20	None
	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	☐	☐	☐	☐	☐	☐	☐

Scenario 4:

I would like to choose…	Rice						
	Rice 537 $0.80	Rice 537IPM $1.20	Rice 258 $1.20	Rice 258IPM $0.80	Rice 741 $1.20	Rice 741IPM $0.80	None
	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	☐	☐	☐	☐	☐	☐	☐

Scenario 5:

I would like to choose…	Rice						
	Rice 537 $1.20 ⇩ ☐	Rice 537IPM $0.80 ⇩ ☐	Rice 258 $0.80 ⇩ ☐	Rice 258IPM $1.20 ⇩ ☐	Rice 741 $1.20 ⇩ ☐	Rice 741IPM $0.80 ⇩ ☐	None ⇩ ☐

Scenario 6:

I would like to choose…	Rice						
	Rice 537 $1.20 ⇩ ☐	Rice 537IPM $0.80 ⇩ ☐	Rice 258 $1.20 ⇩ ☐	Rice 258IPM $0.80 ⇩ ☐	Rice 741 $0.80 ⇩ ☐	Rice 741IPM $1.20 ⇩ ☐	None ⇩ ☐

Scenario 7:

I would like to choose…	Rice						
	Rice 537 $1.20 ⇩ ☐	Rice 537IPM $1.20 ⇩ ☐	Rice 258 $0.80 ⇩ ☐	Rice 258IPM $0.80 ⇩ ☐	Rice 741 $0.80 ⇩ ☐	Rice 741IPM $0.80 ⇩ ☐	None ⇩ ☐

Scenario 8:

I would like to choose…	Rice						
	Rice 537 $1.20 ⇩ ☐	Rice 537IPM $1.20 ⇩ ☐	Rice 258 $1.20 ⇩ ☐	Rice 258IPM $1.20 ⇩ ☐	Rice 741 $1.20 ⇩ ☐	Rice 741IPM $1.20 ⇩ ☐	None ⇩ ☐

Table I-1. Variable Definitions and Summary Statistics

Variable	Definition	Average
Ethnic	1 if Asian; 0 if others	0.41 (0.49)
Gender	1 if Female; 0 if Male	0.57 (0.50)
Education	Education level of respondent 1=high school or below; 2=associate degree; 3=bachelor's; 4=master's; 5=doctor's degree or higher	3.17 (1.28)
Income	Household income level 1=less than $20,000; 2=$20,000 to $39,000; 3=$40,000 to $59,999; 4=$60,000 to $79,999; 5=$80,000 to $99,999; 6=$100,000 or more	2.26 (1.59)
Age	1=20-30; 2=31-40; 3=41-50; 4=51-60; 5=above 60	1.94 (1.26)
Rice eat	How often does respondent eat rice 1=never; 2=once a year; 3=few times a year; 4=once a month; 5=every two weeks; 6=more than once a week	4.87 (1.43)
Environment	Respondent's level of concern level about environmental issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.41 (0.66)
Safety	Respondent's level of concern about worker safety issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.47 (0.59)
Resistance	Respondent's level of concern about pesticide resistance issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.52 (0.58)

Note: numbers in parentheses are standard deviations

Table I-2. Effects of Insect Level on Rice Color L* Index

Independent variable	Coefficient and Standard Error	P-value
Intercept	71.677** (0.199)[a]	<0.0001
High insect level	2.341** (0.256)	<0.0001
Medium insect level	-0.150 (0.256)	0.5372

**statistical significance at the 0.05 level or lower.
[a] Standard errors are in parentheses

Table I-3. Effects of Insect Level on Rice Milling Yield

Independent variable	Coefficient and Standard Error	P-value
Intercept	0.645** (0.0059)[a]	<0.0001
High insect level	-0.054** (0.0077)	<0.0001
Medium insect level	-0.033** (0.0077)	0.0001

**statistical significance at the 0.05 level or lower.
[a] Standard errors are in parentheses

Table I-4. Effects of Progeny on Rice Milling Yield

Independent variable	Coefficient and Standard Error	P-value
Intercept	72.066** (0.3436)[a]	<0.0001
Progeny	-0.0013** (0.0002)	<0.0001

**statistical significance at the 0.05 level or lower.
[a] Standard errors are in parentheses

Table I-5. Consumers Taste Evaluation for Different Quality Rice in Appearance, Flavor, Texture and Overall Acceptance with a 9-point Scale

Taste Evaluation	Appearance	Flavor	Texture	Overall Acceptance
Zero Insect Level	6.32 (1.61)[a]	5.78 (1.83)	6.13 (1.72)	6.06 (1.71)
Medium Insect Level	6.20 (1.57)	5.81 (1.77)	6.17 (1.77)	6.13 (1.74)
High Insect Level	6.13 (1.76)	5.77 (1.82)	5.83 (1.86)	5.96 (1.78)

[a] Standard errors are in parentheses.

Table I-6. Tukey's Studentized Range Test of Consumers' Taste Evaluation of Different Quality Rice Samples in Appearance, Flavor, Texture and Overall Acceptance

Group Comparison	Appearance	Flavor	Texture	Overall acceptance
	Simultaneously 95% C.I.	Simultaneously 95% C.I	Simultaneously 95% C.I	Simultaneously 95% C.I
High insect level - Medium insect level	-0.3863- 0.6565	-0.5992 –0.5452	-0.6090 –0.5190	-0.6237 – 0.4795
Medium quality – High insect level	-0.4674 – 0.5755	-0.5271 – 0.6172	-0.2307 – 0.8973	-0.3804 – 0.7228
Zero insect level – High insect level	-0.3322 – 0.7106	-0.5542 – 0.5902	-0.2757 – 0.8523	-0.4525 – 0.6507

TableI-7. Consumers' WTP in $ Per Pound Derived from 2nd Price Auction and Choice Experiment

WTP	Auction without Information	Auction with Information	Choice Experiment without Information	Choice Experiment with Information
Zero insect level	0.80 (0.73)[a]	1.07 (0.94)[b]	0.80 (0.03) [c]	1.01 (0.04)
Medium insect level	0.77 (0.65)	0.87 (0.71)	0.77 (0.03)	0.83 (0.03)
High insect level	0.75 (0.74)	0.68 (0.61)	0.76 (0.03)	0.58 (0.03)
Zero insect level with IPM	0.95 (0.71)	1.22 (0.93)	1.26 (0.05)	1.55 (0.06)
Medium insect level with IPM	0.87 (0.72)	0.99 (0.74)	1.19 (0.04)	1.14 (0.04)
High insect level with IPM	0.82 (0.80)	0.76 (0.66)	1.15 (0.04)	1.06 (0.04)

[a] Standard errors are in parentheses.
[b]Standard errors are calculated in the conventional manner.
[c]Standard errors are calculated by delta methods

Table I-8. Effects of Rice Attributes, Consumer Demographics, and Information on Consumers' WTP Using Censored Auction Data

Independent Variable	Coefficient and Standard Error	P-value
Intercept	-0.7671** (0.0881)[a]	<0.0001
Zero insect level	0.0386 (0.0269)	0.1521
Medium insect level	-0.001 (0.0269)	0.9714
Stored with IPM methods	0.0625** (0.0194)	0.0013
Taste	0.1006** (0.0058)	<0.0001
Information	-0.0337 (0.0435)	0.4381
Zero insect level with information	0.2842** (0.0597)	<0.0001
Medium insect level with information	0.1470** (0.0604)	<0.0001
Race	-0.1229** (0.0245)	<0.0001
Gender	-0.1169** (0.0217)	<0.0001
Income	0.0034** (0.0086)	0.6940
Age	0.1142** (0.0103)	<0.0001
Eat	0.0453** (0.0093)	<0.0001
Health	0.1130 (0.0262)	<0.0001
Resistance	0.0896 (0.0212)	<0.0001

**statistical significance at the 0.05 level or lower.
[a] Standard errors are in parentheses.

Table I-9. Effects of Rice Attributes and Information on Consumers' WTP Using Choice Experiment Data

Independent Variable	Coefficient and Standard Error	P-value
Zero insect level	2.4132** (0.2511)	<0.0001
Medium insect level	2.3153** (0.2548)	<0.0001
High insect level	2.2895** (0.2558)	<0.0001
Zero insect level with IPM	3.7370** (0.2269)	<0.0001
Medium insect level with IPM	3.5179** (0.2283)	<0.0001
High insect level with IPM	3.4041** (0.2293)	<0.0001
Zero insect level with information	0.4007** (0.2020)	0.0473
Medium insect level with information	-0.0258 (0.2274)	0.9096
High insect level with information	-0.7392** (0.2753)	0.0073
Zero insect level IPM with information	0.6394** (0.1338)	<0.0001
Medium insect level IPM with information	-0.3398** (0.1565)	0.0300
High insect level IPM with information	-0.4427** (0.1653)	0.0074
Price	-2.8820** (0.1929)	<0.0001

**statistical significance at the 0.05 level or lower.
*Statistical significance at the 0.10 level or lower.
[a] Standard errors are in parentheses.

Figure I-1: The Experimental Procedure

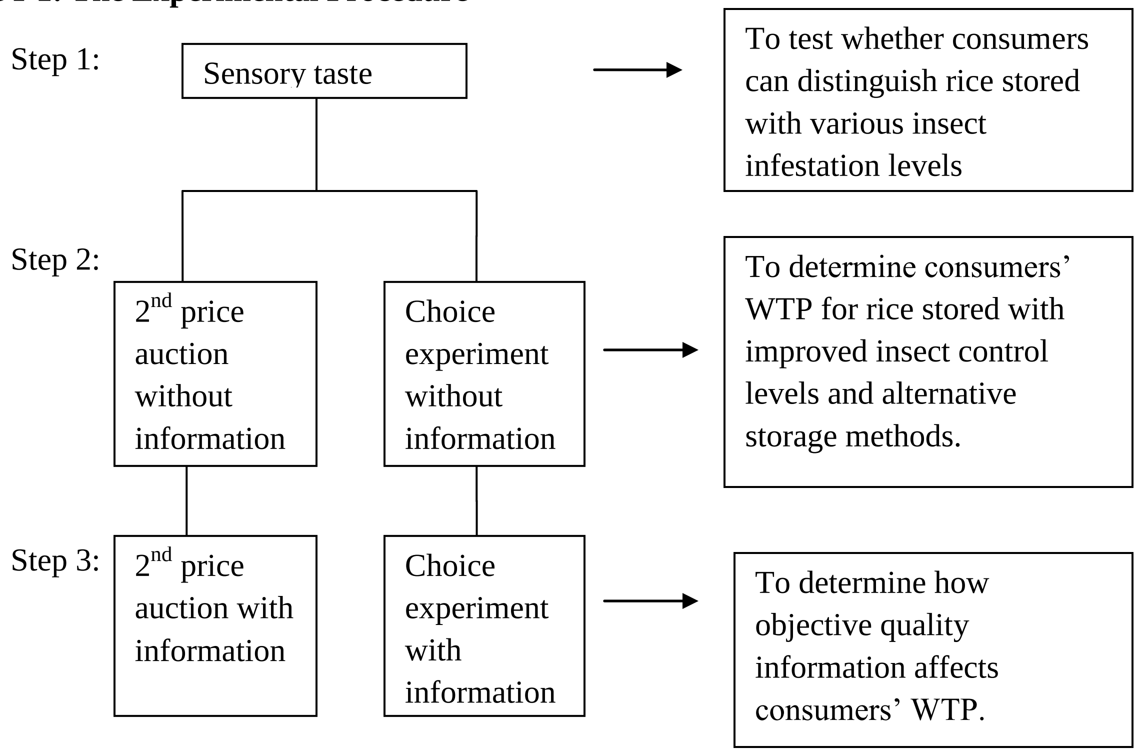


Figure I-2. Consumers Taste Evaluation for Alternative Qualities of Rice in Appearance, Flavor, Texture and Overall Acceptance

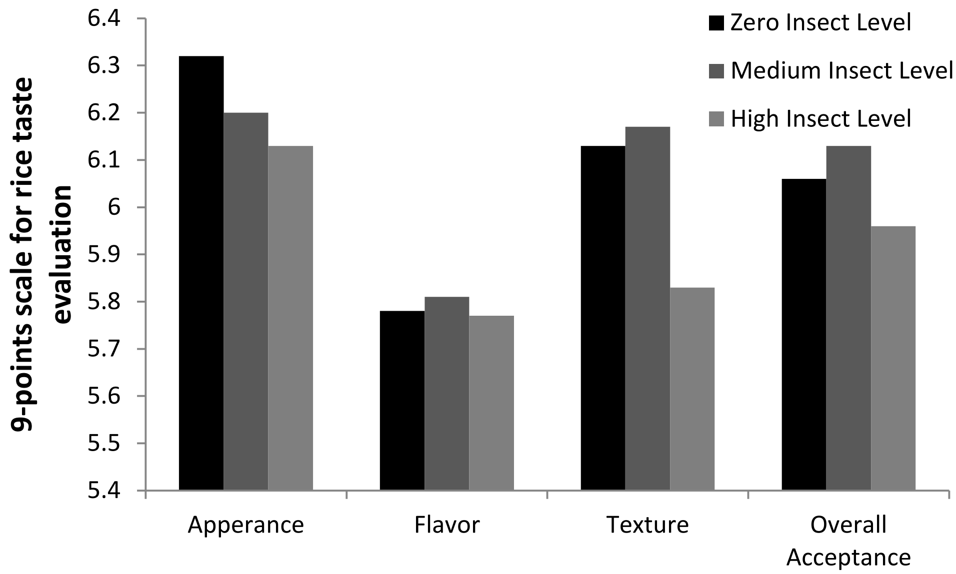


Figure I-3. Consumers' WTP Derived from 2nd Price Auction with and without Information

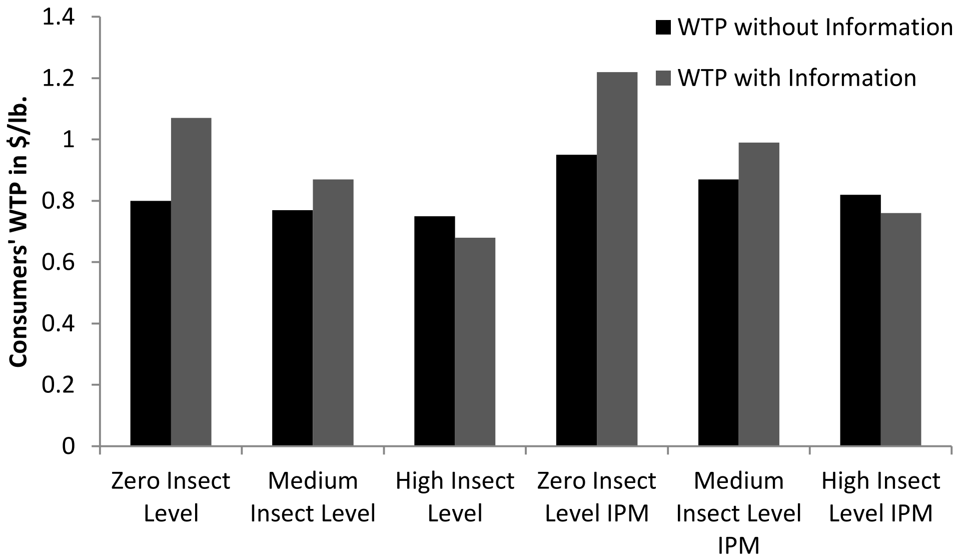
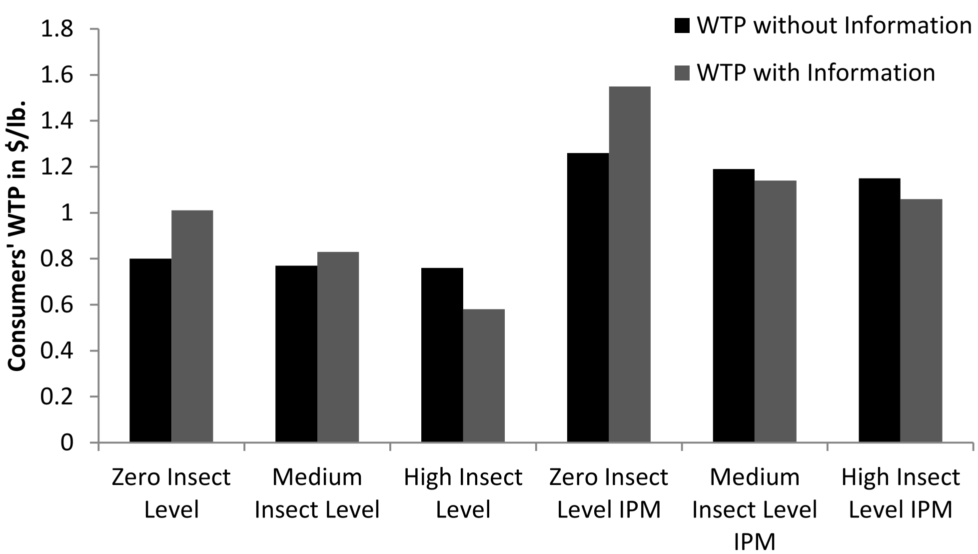


Figure I-4. Consumers' WTP Derived from Choice Experiment with and without Information



CHAPTER II

AUCTION VS CHOICE: CONSUMERS' WILLINGNESS-TO-PAY FOR RICE WITH IMPROVED STORAGE MANAGEMENT

Introduction

Experimental auctions and discrete choice experiment are widely used in consumers' preference studies. Several studies have used them, hypothetically or non-hypothetically, to elicit consumers' WTP for various agricultural product attributes (Bryan et al. 1996; Melton et al. 1996; Lusk et al. 2001; Feuz et al. 2004; Jaeger et al. 2004; Feldkmap, Schroeder, and Lusk, 2005; Alfnes et al. 2006). Some studies have discussed the incentive compatibility and limitations of both methods (Alfnes et al. 2005; Boyle et al. 2000; Corrigan et al. 2010; Lusk, and Schroeder 2004; Lusk and Norwood, 2005; Umberger, and Feuz 2004.). Experimental auctions yield point estimates of WTP directly. In order to truly reveal consumer value, the auction has to be incentive compatible, which requires an auction format (such as n^{th}-price auction) that may not be familiar to participants. Discrete choice experiments are easy for respondents to answer and more closely mimic consumers' real shopping experiences, but reveal WTP only indirectly and require assumptions about the form of the consumers' utility functions.

Comparisons of empirical WTPs derived from auction and choice experiments have given mixed results (Alfnes and Richertsen, 2007; Frykblom and Shogren 2000; Lusk and Schroeder 2004, 2006; Kimenju, Morawetz, and Groote 2006, Corrigan et al. 2010). Factors that lead to a divergence in auction and choice experiments may include the different value elicitation format (Alfnes and Richertsen, 2007; Lusk, and Schroeder, 2006) and the response format and experimental design used in choice studies (Frykblom and Shogren 2000.). However, these comparisons were based on the average WTP or WTP distributions derived from both methods and it remains an open question as to why the divergence exists.

Numerous studies have examined how various procedural and design issues affect consumers' behavior in either an auction or a choice experiment (Carlsson, Frykblom and Lagerkvist, 2007; Carlsson and Martinsson, 2008; Frykblom and Shogren 2000; Louviere, Hensher, and Swait, 2000; Lusk and Norwood, 2005; Lusk and Shogren, 2007.). However, less is known about the design issues which might explain the gap between behavior in auctions and choices. In this paper, we compare each individual's estimated WTP between non-hypothetical auction and choice experiment and investigate the effect of anchoring and information on differences in WTP estimates between the two methods.

Background

Rice is one of the main crops in United States. According to U.S.A. Rice Federal's 2009-10 U.S. rice domestic usage report, 59% of U.S. domestic rice consumption is used directly without further processing. Thus physical attributes of rice, such as appearance, texture, and color, are very important to consumers. Insect infestation can affect these physical attributes during storage, reducing the quality of rice and thus its economic value.

Lesser grain borer (*Rhyzopertha dominica)* is a common pest of stored grains and perhaps the most potentially destructive insect that infects stored rice (Luh, 1980). Their larvae feed inside the kernel until they mature into adults and burrow out of the kernel, damaging the kernels. This may reduce milling yield and the proportion of whole rice kernels. In addition, the insects' contact with the rice kernels may cause a displeasing odor, particularly if the insect population is large (Ranalli, 2002). Thus, both quantity and quality of rice may be reduced by these insects.

Current insect control methods during rice storage can be categorized into 1) conventional chemical-based pest management, and 2) integrated pest management (IPM), which is a balanced use of multiple control tactics – biological, chemical, and cultural – as is most appropriate for a particular situation in light of careful study of all factors involved. There are potential benefits of IPM associated with environment and human health, but few, if any, studies have empirically evaluated its value to consumers of stored products.

Conceptual Framework

This study determines whether consumers' WTP elicited from experimental auction and discrete choice experiments are equal, and determines if and how initial price level used in the discrete choice experiment and information provided to participants affects the difference between these two methods. The null hypotheses are:

1) $WTP^{AUCTION} = WTP^{CHOICE}$. Here $WTP^{AUCTION}$ is the mean WTP derived from auction data and WTP^{CHOICE} is the mean WTP derived from discrete choice experiment data. If we reject the null hypothesis, we conclude that the WTP derived from the auction and the choice experiments are not equivalent.

2) An increase in price level used in the choice experiment does not affect the difference in WTP derived from auction and choice experiments: $D = D^{HP}$. Here D is the difference in WTP derived from auction and choice experiments, $D = WTP^{AUCTION} – WTP^{CHOICE}$ and D^{HP} is the difference in WTP derived from the auction and choice experiments with a higher initial price level, where $D^{HP} = WTP^{AUCTION} – WTP^{CHOICE, HP}$. If we reject this null hypothesis, we conclude that initial price level used in the choice experiment is associated with differences in WTP derived from auction and choice experiments. Hypothesis 2 is, in essence, a test of whether anchoring affects WTP estimates in a choice experiment.

3) Providing participants more product information does not affect the difference in WTP derived from auction and choice experiments: $D^{INFO} = D$. Here D^{INFO} is the difference in WTP derived from auction and choice experiments when participants are provided extra product information, $D^{INFO} = WTP^{AUCTION,INFO} – WTP^{CHOICE, INFO}$. If we reject this null hypothesis, we conclude that the amount of information provided is associated with differences in WTP derived from auction and choice experiments. Hypothesis 3 is a test of whether providing extra information affects WTP inconsistency between the two methods.

Experimental Design and Procedures

The experiment was conducted at the Food and Agricultural Products Center (FAPC) at Oklahoma State University, during August 2010. Each session of experiments lasted approximately one hour and had 10-12 participants. In total 112 participants were recruited both on and off Oklahoma State University campus though email invitation and flyers, offering $20 compensation for their participation. Summary statistics in Table II-1 shows that 57% of participants were female and 40% were Asian.

Most of the participants were relatively young and well-educated – 56 percent were aged 20 to 30, and 77% had bachelor’s degrees or higher. Majority of the participants had a household income between $20,000 and $40,000.

Since we are interested in consumers’ preference for rice products, we focused on typical rice consumer, which explains the large Asian population in our sample. However, our sample represents a wide range of demographics, with age ranging from 20 to above 60, education ranging from high school to Ph.D. degree, income ranging from below $20,000 to above $100,000, and rice consumption and purchase ranging from zero times per year to once a week. The majority of the participants were rice consumers, eating rice once every two weeks. The participants also answered questions related to the strength of their concerns about the environment, worker safety and pesticide resistance problem – on average they showed a high level of concern about these problems.

Before the experiment, the participants tasted and evaluated three rice samples using a sensory taste panel format, they were required to evaluate rice sample in appearance, flavor, texture and overall acceptance using a 9-point scale. Prior to milling for human consumption, one set of samples had been infested with 200 adult LGB/kg (poor insect control), one set had been infested with 20 adult LGB/kg (average insect control), and one set had not been infested (excellent insect control). After eight weeks, the rice samples were frozen to kill any internal infestation. Then the rice was milled so that the final product was suitable for human consumption. The rice samples were cooked and served following the procedures described in a sensory analysis for cooked long-grain rice conducted by Meullenet et al. (2000). The serving orders of the rice samples were completely randomized over participants by using a counterbalanced design to reduce the order effects. Participants ranked the samples using a 9-point scale, where 1 is extremely undesirable and 9 is extremely desirable.

Then, the participants were given $2 in coins and informed that they would have the opportunity to purchase one of the rice samples through auctions or choice experiments. They were told that they could choose to buy rice that was the same in all respects as the rice they had tasted, but that was stored using an integrated pest management (IPM) approach. Thus, with three possible levels of pre-milling insect control levels, and two storage methods – IPM and non-IPM – the participants could choose from among six rice products. Before bidding began, participants were given a brief written statement on the difference between IPM and conventional pest management methods, and statement was read aloud to them. During bidding, participants retained the sheet on which they had recorded their evaluation of the rice samples.

Four rounds of 2nd price auction and one round of choice experiment were conducted to determine participants' preferences for alternative rice products, based on their prior taste evaluation. Then, another round of auction and choice experiment were conducted after providing participants objective information about the quality of each rice sample. Specifically, participants are told which rice sample that they ate was good quality (the one with low pre-milling insect control), which one was high quality (the one with average insect control), and which one was superior quality (the one with excellent insect control.) Same procedures were repeated with another group of participants, changing only the price level used in the choice experiment. Figure II-1 illustrates the experimental design. Participants completed a short survey on their demographic information and their rice purchasing habits before they left.

Economic Models

To test hypothesis one, that the auction and choice experiment yield different WTP, we compared the estimated WTP from both the auction and the choice experiment for each rice sample. Participants' auction bids for each rice sample can be directly interpreted as their WTP. We used three sets of variables to explain the variation in auction WTP: (1) variables explaining variation in rice attributes, including insect control level during storage (poor insect control, average insect control and excellent insect control) and storage management method (IPM vs. non-IPM); (2) variables for participants' socio-demographic characteristics and their attitudes towards environmental, pesticide resistance and worker safety issues; and (3) whether or not the participants had been provided with extra product quality information. We used the following econometric model to explain participants' WTP for the rice in the auction:

(2.1) $$WTP_{ij}^{*} = BID_{ij} = b_0 + \alpha \boldsymbol{X_j} + \beta \boldsymbol{Y_i} + \gamma \boldsymbol{Z_{ij}} + \eta_i + \varepsilon_{ij}$$

where WTP_{ij}^{*} is individual i's WTP for product j, and BID_{ij} is individual i's bid for product j. In an auction, participants cannot bid below zero, thus WTP* is a latent variable censored from below zero. $\boldsymbol{X_j}$ is a vector of product quality attributes for product j, including indicator variables for poor insect control level PC_j , average insect control level AC_j and the storage method IPM_j. IPM_j is 1 if rice j is maintained with IPM methods and 0 otherwise. $\boldsymbol{Y_i}$ is a vector of individual i's socio-demographic information, including gender, race, age, income, how often they eat rice and their attitudes towards the environment, worker safety and safety issues, and pesticide resistance issues and their taste evaluation of the j^{th} rice sample. $\boldsymbol{Z_{ij}}$ is a vector of design variable information $INFO_i$ and the interaction between information and quality attributes. $\boldsymbol{Z_{ij}}$ includes $INFO_{i,}$, which is 1 if extra information is provided and 0 otherwise, and $INFOPC_{i,j}$ and $INFOAC_{i,j}$, which are interaction terms between INFO and insect control levels PC_j and AC_j. $\eta_i \sim N(0, \sigma_\eta^2)$ is the random individual effect for the i^{th} participant that captures the correlation between the bids made by the same participant, and $\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$ is the residual error term. All the parameters in equation (2.1) were estimated using a left-censored Tobit model.

In the choice experiment, instead of bidding directly how much they valued each rice product, participants had to choose among alternative rice/price combinations. Their willingness to buy any particular combination is expressed as either choose or not choose. Because the response variables do not directly reflect participant's WTP, a random utility model was used to derive their WTP. Suppose a participant's utility function can be expressed as:

(2.2) $$U_{ij} = V_{ij} + \epsilon_{ij}$$

where U_{ij} is participant i's utility from choosing the j^{th} rice product, V_{ij} is the systematic portion of the utility function determined by the rice attributes and ϵ_{ij} is a stochastic element.

The systematic portion of participant i's utility of choosing rice product j is:

(2.3) $$V_{ij} = \beta_1 PoorControl_j + \beta_2 AverageControl_j + \beta_3 ExcellentControl_j + \beta_4 PoorControl\ IPM_j + \beta_5 AverageControl\ IPM_j + \beta_6 ExcellentControlIPM_j + \beta_{price} Price_{ij}$$

where $Price_{ij}$ is price individual i faced for rice product j in choice settings, and the dummy variables $PoorControl_j$, $AverageControl_j$, $ExcellentControl_j$, $PoorControl\ IPM_j$, $AverageControlIPM_j$ and $ExcellentControlIPM_j$ are dummy variables which denote, respectively, that the jth rice product is stored with poor insect control level, average insect control level, excellent insect control level, poor insect control level stored with IPM method, average insect control level stored with IPM method, and excellent insect control level stored with IPM method. The coefficients β_1 to β_6 represent the utility of having the corresponding characteristics compared to not having them.

The parameters β in equation (2.3) can be estimated by maximizing the log-likelihood functions:

(2.4) $$LLF = \sum_{i=1}^{N} \sum_{j=1}^{7} \left(C_{ij} * ln\left(Prob_{ij}\right)\right)$$

where C_{ij} = 1 if rice product *j* is chosen by consumer *i* and 0 otherwise, and $Prob_{ij}$ is the probability of rice product *j* being chosen, $Prob_{ij} = \exp(V_{ij}) / \sum_{j=1}^{7} \exp(V_{ij})$ where V_{ij} is calculated as in equation (2.3). Participants' WTP can be expressed as the amount a person will pay that makes the person indifferent between improving the quality of the good or keeping the same quality. We assume participants' value of choosing nothing in the choice set is zero and they are willing to pay a certain amount of money to choose one rice product compared to choosing nothing. For example, the value the consumer *i* places on rice product with poor insect control and stored under non-IPM methodis derived by determining the magnitude of WTP such that following equality holds:

(2.5) $$V_{i,poor\ control} = \beta_1 * 1 + \beta_{price} * Price_{i,poor\ control} = V_{i0} = 0$$

Solving this equality provides average of participants' marginal WTP for rice product with poor insect control and stored under non-IPM method as $-\beta_1/\beta_{price}$, where β_j and β_{price} are corresponding estimated coefficients for rice product *j* and price.

Normally, the WTP from the auction are the average direct bids while the WTP from the choice experiment are results from calculating expression (2.5) using the β parameters estimated from equation (2.3). These experiments do not include participants' demographic information, thus we only can estimate participants' average WTP for each rice product. However, in our study, to test the hypotheses with comparable WTP measures, each individual's WTP from auction and choice experiment are compared, so participants' demographic information, rice attributes, and information about product quality needed to be controlled.

To predict each individual's WTP from the choice model, we extended model (2.3) to model (2.6) by including all interaction terms between rice products and participants' demographic information.

(2.6)

$$V_{ij} = \beta'_1(PoorControl)_{ij} + \beta'_2(AverageControl)_{ij} + \beta'_3(ExcellentControl)_{ij} + \beta'_4(PoorControl\ IPM)_{ij} + \beta'_5(AverageControl\ IPM)_{ij} + \beta'_6(ExcellentControl\ IPM)_{ij} + \beta'_{price}(Price)_{ij} + \gamma_{ij}\boldsymbol{R_j Y_i}$$

where, $\boldsymbol{R_j}$ is the vector of all six rice products and $\boldsymbol{Y_i}$ is as defined in model (2.1). $\boldsymbol{R_j Y_i}$ are interaction terms between participants' demographics (gender, ethnic, education, age, rice-eating habits and attitudes towards environmental, worker safety and pesticide resistance issues) and all six rice products (*PoorControl*, *AverageControl*, *ExcellentControl*, *PoorControlIPM*, *AverageControlIPM,* and *ExcellentControlIPM*). The parameters β' are estimated in the same way the parameters β are estimated. This extended model can predict each participant's marginal WTP for each rice product by solving the following equality:

(2.7)

$$V_{ij} = \beta' + \gamma_{ij}R_jY_i + \beta'_{price} * Price_j = V_{i0} = 0$$

Participant *i*'s marginal WTP for rice product is $(\beta' + \gamma_{ij}R_jY_i)/\beta'_{price}$. We can predict each individual's predicted WTP for each rice product from auction data from equation (2.1). To test hypothesis one, we can directly compare these predicted WTPs from the auction and choice experiments.

Paired t-tests were used to compare the predicted average WTP from auction and choice models for each rice product. Two possible reasons are hypothesized for differences in the estimated WTP: (1) the different initial price levels used in the choice experiment and, (2) the amount of information about product quality participants are given. Two sample t-tests were used here to compare the difference between predicted WTP from the auction and choice experiments with different initial price levels and under conditions of providing extra product information. The following random effects model was used to test the effects of initial price levels and information on the differences between WTP predicted from auction and choice data:

$$D_{ij} = \alpha_0 + \alpha_1 PL_i + \alpha_2 Info_i + \beta Y_i + \gamma_i + \delta_j + \omega_{ij} \tag{2.8}$$

where D_{ij} is the difference between participant *i*'s predicted WTP from auction and choice experiment for rice product *j*, PL_i is the price level consumer *i* faced in choice experiment (PL_i = 1 when they faced a higher initial price level in choice experiment, 0 otherwise), $Info_i$ = 1 when consumer *i* was provided with extra rice quality information in the auction and choice experiment, 0 otherwise, Y_i are as defined before, $\gamma_i \sim N(0, \sigma_i^2)$ is the random effect with respect to different participants, $\delta_j \sim N(0, \sigma_j^2)$ is the random effect with respect to different rice products, $\omega_{ij} \sim N(0, \sigma_\omega^2)$ is pure random error term, and γ_i, δ_j and ω_{ij} are independent of each other.

Results and Discussion

A key result is that anchoring and the amount of product information provided in the choice experiment has a large effect on WTP measures from the choice experiments. As figure II-2 illustrates, participants' WTP for rice with excellent insect control measured under the low-price choice experiment is low compared to their WTP from the auction. However, doubling the initial price level (changing the anchor) makes WTP from the choice experiment much closer to WTP from the auction. Similarly, providing extra information to participants about product quality makes WTP from the choice experiment much closer to WTP from the auction. Doubling the initial price level along with providing extra product quality information increases WTP from the choice experiment to a level nearly equal to WTP from the auction. Details of this result and tests of the three hypotheses are explained in greater detail below.

Rice Taste Panel Results

Participants' average scores for appearance, texture, flavor and overall acceptance for three rice products with alternative stored insect control levels are presented in table II-2. Participants ranked rice stored with excellent insect control highest only in appearance, but in terms of texture, flavor and overall acceptance, participants preferred rice stored with an average insect control level. For all four criteria, participants preferred rice stored with poor insect control least. But, the magnitudes of differences among different insect control levels are very small. An ANOVA F test indicates that, on average, participants could not distinguish among the three insect control levels for rice for appearance, flavor, texture, and overall acceptance based on their own taste evaluation.

Comparison of WTP derived from auction and choice experiments

To test hypothesis one, we compared the average of each participant's predicted WTP values derived from the 2nd price auction (using model 2.1) and discrete choice experiment (using model 2.6). We used the same participants in both auction and choice experiment to make an in-sample comparison and real money to provide more incentive for participants to truly express the value they place on each rice product. Theoretically, both methods are incentive compatible and should yield similar WTP values within a given environment. However, when participants did not have any information on the objective quality level of the rice samples and valued rice products based only on their own taste evaluation, the empirical results from auction and choice experiments were very different. As shown in table II-3, in the auction, participants were willing to pay $1.03 for one pound of rice stored under regular insect control methods regardless of the initial insect control level, but in the choice experiment they only wanted to pay $0.59 for one pound of poor insect control rice stored with regular insect control methods, -$0.19 for average insect control level, and $0.06 for rice with excellent insect control.

Both methods showed that participants preferred rice stored with IPM methods to rice stored with conventional methods, but the magnitudes were different. In the auction, participants were willing to pay $0.03 extra for rice stored under IPM methods compared with rice stored under regular methods, but in the choice experiment they were willing to pay $0.86/pound more ($0.67 compared with $-0.19) for rice with average insect control level, and $0.75/pound more ($0.81 compared with $0.06) for rice with excellent insect control level.

Paired t-tests were conducted to test whether these differences are significant. Unlike the results of Lusk and Schroeder (2006), our results (table II-3) show that predicted WTP values from the 2nd price auction are significantly higher than the corresponding WTP values derived from the choice experiment for all six rice samples. Thus we can reject hypothesis one, and conclude that WTP estimates derived from auction and choice experiment are not the same

In both experiments, participants did not have the information of the real insect control levels in each rice sample but bid and choose based on their own taste evaluation. As noted above, participants on average could not distinguish differences in insect control levels among the rice products. The auction results are consistent with this finding: participants' WTP estimates for the three rice products were the same. In contrast, the choice experiment WTP estimates for rice stored under IPM methods were higher for average insect control level, and were erratic for rice stored under regular methods – highest for poor insect control level, lowest for average insect control level, and in between for excellent insect control level.

Effects of initial price level in choice experiment on difference in WTP between auction and choice experiment

Since auction WTP estimates were much higher than choice experiment WTP estimates, we examined the effect of doubling the initial price level, from \$0.4/lb and \$0.6/lb. to \$0.8/lb. and \$1.2/lb, in the choice experiment.

A likelihood ratio test was used to test whether changing initial price levels leads to similar WTP estimation from the choice experiment. The restricted model is model 2.3 with pooled data from the choice experiment with both higher and lower initial price levels, while the unrestricted models are the separate models from the choice experiment, one with higher initial price level and one with lower initial price level. Table II-4 shows the estimated coefficients of the unrestricted and restricted models. The null hypothesis is that estimated rice product parameters are equivalent across the three models: $H_0\colon \beta_1^{HP} = \beta_1^{LP}, \dots, \beta_6^{HP} = \beta_6^{LP}$.

The test statistic is 222 (2*(1958.53-1787.94)), and the critical chi-square value with four degree of freedom at 99% confidence level is 13.3. Comparing the test statistics with the critical chi-square value, we reject the null hypothesis and conclude that predicted WTP values changed when initial price level in the choice experiment was doubled.

To test whether doubling the initial price level in the choice experiment reduced the discrepancy between predicted WTP values from the auction and the choice experiment, we calculated the differences as predicted WTP from the auction minus predicted WTP from the choice for low initial price level (Diff = $WTP^{AUCTION}$ - WTP^{CHOICE}) and high initial price level ($Diff^{HP}$ = $WTP^{AUCTION,HP}$ - $WTP^{CHOICE,HP}$). A two-sample t-test was used to test whether the discrepancy between auction and choice experiments are significantly reduced. The results indicate that doubling the initial price level in the choice experiment (1) significantly changed the predicted WTP values, and (2) it substantially reduced the discrepancy in WTP between the auction and choice experiment.

As shown in table II-5, WTP derived from choice experiments are dramatically changed by doubling the initial price level in the choice experiment: by doubled the initial price levels, participants' WTP derived from choice experiment are increased for most of the rice products. For rice stored under regular methods, participants' WTPs increased $0.71/lb and $0.80/lb for rice with excellent and average insect control level, and decreased $0.04/lb for rice with poor insect control level. For rice stored under IPM methods, participants' WTP estimates increased $0.32/lb, $0.41/lb. and $0.43/lb. for rice with excellent, average and poor insect control levels. This increase in choice experiment

WTP reduced the differences between the two methods. This reduction in difference between the two methods was significant for each rice products except poor insect control level rice stored under conventional methods. Thus, we reject null hypothesis two and conclude that different initial price levels used in choice experiment affects the WTP derived from the choice experiment, reducing the difference between WTP derived from auction and choice experiments. Doubling the price level also made the WTP estimates more realistic, with no negative values and with similar values across products.

Figure II-3 summarizes participants' WTP discrepancy between two methods when different initial price levels are used in choice experiments. Doubling the initial price level used in the choice experiments substantially reduced WTP discrepancy between the two methods for all rice products.

Effects of amount of information on difference in WTP between auction and choice experiments

To test hypothesis three, whether providing participants more information affects the WTP discrepancy between the two methods, we conducted another round of auction and choice experiments, in which we provided participants extra objective information about the quality levels of each rice sample. The predicted WTP measures from auction and choice experiments with and without information are presented in table II-6.

From table II-6, providing additional information has a similar effect on both auction and choice experiments: when participants were provided with objective information about rice quality, their WTP for rice with excellent and average insect control levels increased, while their WTP for rice with poor insect control level decreased. Also, providing extra information changed participants' preference ordering under the choice experiment to be consistent with preference ordering under the auction – excellent insect control level preferred to average insect control level, which is in turn preferred to poor insect control level.

Figure II-4 illustrates the effect of information on participants' WTP measures derived from the choice experiment. Without extra product information, participants' WTP measures for rice with three insect control levels are inconsistent with their preference order from the taste evaluation, and the WTP for rice with average insect control is actually negative. When they are given extra quality information, their WTP measures become consistent with the insect control levels of the rice products, and are all positive.

Two-sample t-tests were conducted to determine whether differences between predicted WTP values from the auction and the choice experiment with information ($DIFF^{INFO} = WTP^{AUCTION,INFO} - WTP^{CHOICE,INFO}$) and without information ($DIFF^{NOINFO} = WTP^{AUCTION,NOINFO} - WTP^{CHOICE,NOINFO}$) are statistically significant. Table II-7 indicates that the effect of providing more information varied across the six rice products. For rice with low and high insect levels stored using conventional methods, and for rice with high insect levels stored using IPM methods, providing participants more information did not significantly affect the difference in WTP between auction and choice experiments, but for the other rice products providing extra information increases the discrepancy.

To test the combined effects of doubling the initial price level and providing extra information, a random effects model was used with price level, extra information, and demographic factors as independent variables, and difference in predicted WTP between auction and choice experiments as the dependent variable, pooling all six rice products. In table II-8, the estimated intercept is 0.45, which indicates that with a low initial price level in the choice experiments, participants' WTP from auction bids for one pound of rice is $0.45 higher than their predicted WTP from the choice experiment. With a higher initial price level, though, the difference in WTP is reduced by $0.44, leaving a net difference of $0.01. Thus, with a higher initial price level, the WTP values derived from auction and choice experiments were nearly the same.

Table II-8 also shows that all of the demographic factors considered except education level were statistically related to the difference in WTP between auction and choice experiments.

Compared to male participants, females behaved more consistently between auction and choice experiments. To the extent that females are the main food purchasers, they may be more familiar with the price of rice. Similarly, Asian participants behaved more consistently between auction and choice than non-Asian participants. Asian participants may have had a better understanding of rice products compared with non-Asian participants. More Asian than non-Asian participants were regular rice eaters, and may have had a better understanding of how much the rice products were worth to them so that their WTP values were not influenced as much by the different value-eliciting mechanisms.

People with lower income levels exhibited smaller difference in WTP between auction and choice experiments. Low income participants may have been more price conscious and more cautious when they bid on the rice products. Older participants exhibited a larger difference in WTP than younger participants, possibly because they found the experimental procedures more difficult to understand.

Conclusions

In this study, a non-hypothetical 2^{nd} price experimental auction and a discrete choice experiment were conducted to determine participants' WTP for rice products with varying insect infestation levels and insect control methods, and compared the elicited WTP values derived from both mechanisms. To make the WTP derived from both mechanisms comparable, a censored Tobit model was used for the auction bids and an indirect utility model was used for the choice experiment results. Individual WTP values predicted from both models was compared to test whether the two elicitation mechanisms yielded equivalent results. Our study shows that participants' WTP in a 2^{nd} price auction were significantly higher than their corresponding WTP predicted from a choice utility model. The results in 2^{nd} price auction are more consistent with participants' real preference while the predicted WTP of each individual from choice experiment are not in the same order of their stated preference. A possible reason for this inconsistency in choice experiment in our case is that participants, especially those who are not regular rice consumers, could not easily distinguish the difference in rice quality levels. As a result, the values they placed on the rice products may have been more easily influenced by different value eliciting methods we used. When participants are provided with objective quality information, the behaviors in auction and choice were more consistent.

This study also investigated potential reasons for the WTP inconsistency between auction and choice experiments. Results show that when participants faced different price levels in choice experiments, or when they were provided additional information about the rice products, their behavior changed. Doubling the initial price level used in the choice experiment substantially reduced the discrepancy in WTP between the two mechanisms. Providing additional information about the products reduced the discrepancy but by a smaller amount. Providing additional information also made preference ordering consistent between auction and choice experiments.

Differences in participant demographics were associated with differences in behavior in these experiments. In general, participants who were more familiar with the products behaved more consistently between the mechanisms. Specifically, the WTP discrepancies were smaller for female and Asian participants.

Our findings suggest that the WTP estimates derived from auction and choice experiments can differ significantly, and that the differences vary with price level used in the choice experiment as well as with amount of product information provided to the participants. Participant behavior is susceptible to mechanism design in choice experiments. Further studies should be cautious in selecting a price range when using choice experiments and should provide consumers more product information to help them have better product valuation. Also, since participants' demographic backgrounds affect how they behave in the experiments, recruiting participants who are familiar with the interested products and who are able to learn the mechanisms quickly may provide more reliable results regardless of the value-eliciting mechanisms used..

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Table II-1. Variable Definitions and Summary Statistics

Variable	Definition	Average
Ethnic	1 if Asian; 0 if others	0.41 (0.49)
Gender	1 if Female; 0 if Male	0.57 (0.50)
Education	Education level of respondent 1=high school or below; 2=associate degree; 3=bachelor's; 4=master's; 5=doctor's degree or higher	3.17 (1.28)
Income	Household income level 1=less than $20,000; 2=$20,000 to $39,000; 3=$40,000 to $59,999; 4=$60,000 to $79,999; 5=$80,000 to $99,999; 6=$100,000 or more	2.26 (1.59)
Age	1=20-30; 2=31-40; 3=41-50; 4=51-60; 5=above 60	1.94 (1.26)
Rice eat	How often does respondent eat rice 1=never; 2=once a year; 3=few times a year; 4=once a month; 5=every two weeks; 6=more than once a week	4.87 (1.43)
Environment	Respondent's level of concern level about environmental issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.41 (0.66)
Safety	Respondent's level of concern about worker safety issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.47 (0.59)
Resistance	Respondent's level of concern about pesticide resistance issues 1= not concerned; 2=somewhat concerned; 3=very concerned	2.52 (0.58)

Note: numbers in parentheses are standard deviations.

Table II-2. Participants' Taste Evaluation for Rice with Three Insect Control Levels in Appearance, Flavor, Texture and Overall Acceptance (9-point scale)

Taste Evaluation	Excellent Insect Control	Average Insect Control	Poor Insect Control	P-Value of ANOVA F test
Appearance	6.32 (1.61)[a]	6.20 (1.57)	6.13 (1.76)	0.6793
Flavor	5.78 (1.83)	5.81 (1.77)	5.77 (1.82)	0.9827
Texture	6.13 (1.72)	6.17 (1.77)	6.13 (1.74)	0.3211
Overall Acceptance	6.06 (1.71)	6.13 (1.74)	5.96 (1.78)	0.7642

[a] Standard errors are in parentheses.

Table II-3. Comparison of Predicted Willingness to Pay ($/pound) for All Rice Products Derived from Auction and Choice Data

Different Rice Products	$WTP^{AUCTION}$ [a]	WTP^{CHOICE} [a]	Difference	Test
Excellent insect control	1.03 (0.29)[b]	0.06 (0.54)	0.97 (0.74)	<0.0001[c]
Average insect control	1.03 (0.28)	-0.19 (0.64)	1.21 (0.77)	<0.0001
Poor insect control	1.03 (0.31)	0.59 (0.20)	0.44 (0.30)	<0.0001
Excellent insect control IPM	1.09 (0.29)	0.81 (0.24)	0.28 (0.37)	<0.0001
Average insect control IPM	1.09 (0.31)	0.67 (0.35)	0.42 (0.45)	<0.0001
Poor insect control IPM	1.09 (0.31)	0.65 (0.38)	0.44 (0.34)	<0.0001

[a] $WTP^{AUCTION}$ and WTP^{CHOICE} are point predicted consumers' WTP from auction and choice models.
[b] numbers in parentheses are standard errors.
[c] p-values for the two-tailed t-test of H_0: $WTP^{AUCTION}=WTP^{CHOICE}$.

TableII-4. Multinomial Logit Estimates for Choice Experiment with Higher Price Level (HP) and Lower Price Level (LP).

Rice Attributes	Model 1(HP)	Model 2(LP)	Model 3 (Pooled)
Price	-2.66	-3.66	-2.10
Excellent insect control	2.20	1.47	1.76
Average insect control	2.11	0.72	1.15
Poor insect control	2.09	1.82	1.62
Excellent insect control IPM	3.36	3.26	2.94
Average insect control IPM	2.82	3.00	2.51
Poor insect control IPM	3.04	2.97	1.62
LL	-1265.86	-522.076	-1958.53
#Obs	4818	3026	7842

Table II-5. Effects of Higher Initial Price in Choice Experiment on Difference in Predicted Participants' Willingness to Pay ($/pound) between Auction and Choice Data

Different Rice Products	WTP^{AU}	WTP^{CHLP}	WTP^{CHHP}	$DIFF^{HP}$	$DIFF^{LP}$	Difference[a]	Test
Excellent insect control level	1.03 (0.31)[b]	0.06 (0.54)	0.77 (0.20)	0.27 (0.34)	0.97 (0.73)	-0.70 (0.52)	<0.001[c]
Average insect control level	1.03 (0.28)	-0.19 (0.64)	0.61 (0.42)	0.40 (0.43)	1.21 (0.78)	-0.81 (0.58)	<0.001
Poor insect control level	1.03 (0.29)	0.59 (0.20)	0.55 (0.43)	0.42 (0.50)	0.44 (0.30)	-0.02 (0.44)	0.8748
Excellent insect control level IPM	1.09 (0.31)	0.81 (0.24)	1.13 (0.38)	-0.03 (0.37)	0.28 (0.34)	-0.31 (0.36)	<0.001
Average insect control level IPM	1.09 (0.31)	0.67 (0.35)	1.08 (0.33)	0.001 (0.53)	0.42 (0.45)	-0.42 (0.50)	<0.001
Poor insect control level IPM	1.09 (0.29)	0.65 (0.38)	1.08 (0.13)	-0.04 (0.34)	0.43 (0.40)	-0.47 (0.36)	<0.001

[a] Difference is difference between differences of predicted participants' willingness to pay from auction and choice models with different initial price levels: Difference=$DIFF^{HP}$-$DIFF^{LP}$.
[b] numbers in parentheses are standard errors. [c] p-values for the two sample t-test of H_0: $DIFF^{HP}=DIFF^{LP}$.

TableII- 6. Participants' WTP ($/Pound) Derived from Auction and Choice Experiment With and Without Extra Information

WTP	Auction without info.	Auction with info.	CE without info.	CE with info.	CE (HP)[a] without info.	CE (HP) with info.
Excellent insect control level	1.03 (0.31)[b]	1.07 (0.94)[c]	0.06 (0.54)[d]	0.54 (0.03)	0.77 (0.20)	1.01 (0.04)
Average insect control level	1.03 (0.28)	0.87 (0.71)	-0.19 (0.64)	0.46 (0.03)	0.61 (0.42)	0.83 (0.03)
Poor insect control level	1.03 (0.29)	0.68 (0.61)	0.59 (0.20)	0.30 (0.02)	0.55 (0.43)	0.58 (0.03)
Excellent insect control level IPM	1.09 (0.31)	1.22 (0.93)	0.81 (0.24)	0.99 (0.06)	1.13 (0.38)	1.55 (0.06)
Average insect control level IPM	1.09 (0.31)	0.99 (0.74)	0.67 (0.35)	0.86 (0.06)	1.08 (0.33)	1.14 (0.04)
Poor insect control level IPM	1.09 (0.29)	0.76 (0.66)	0.65 (0.38)	0.67 (0.04)	1.08 (0.13)	1.06 (0.04)

[a] CE(HP) stands for choice experiment with doubled initial price level.
[b] numbers in parentheses are standard errors
[c] Standard errors for auction bids are calculated in the conventional manner.
[d] Standard errors for WTPs derived from choice experiment are calculated by delta methods.

Table II-7. Effects of Extra Information on Difference in WTP ($/Pound) between Auction and Choice Experiment

Different Rice Products	$DIFF^{INFO}$	$DIFF^{NOINFO}$	Difference	Test
Excellent insect control level	0.71 (0.58)[b]	0.45 (0.44)	0.26 (0.52)	0.0002[c]
Average insect control level	0.60 (0.39)	0.72 (0.71)	-0.12 (0.57)	0.1221
Poor insect control level	0.61 (0.51)	0.55 (0.63)	0.06 (0.57)	0.4537
Excellent insect control level IPM	0.30 (0.68)	0.13 (0.43)	0.16 (0.57)	0.0306
Average insect control level IPM	0.27 (0.48)	0.13 (0.54)	0.14 (0.51)	0.0427
Poor insect control level IPM	0.09 (0.39)	0.06 (0.40)	0.03 (0.39)	0.5381
Pooled all rice products	0.43 (0.56)	0.34 (0.60)	0.09 (0.58)	0.0044

[a] Difference is difference between differences of predicted participants' willingness to pay from auction and choice models with and without extra information: Difference=$DIFF^{INFO}$-DIFF.
[b] numbers in parentheses are standard errors
[c] p-values for the two sample t-test of H_0: $DIFF^{HP}$=$DIFF^{LP}$.

Table II-8. Effects of Doubled Initial Price Level Used in Choice Experiment, Extra Information, and Demographic Factors on Difference in Predicted WTP between Auction and Choice Experiment

Independent variable	Coefficient and Standard Error	P-value
Intercept	0.4469* (0.1046)[a]	0.0079
Price level	-0.4424** (0.0245)	<0.0001
Info	0.0942 (0.0231)	<0.0001
Race	-0.1816* (0.0285)	<0.0001
Gender	-0.0756* (0.0244)	0.0020
Education	-0.0137 (0.0106)	0.1953
Income	0.0366* (0.0099)	0.0002
Age	0.1282* (0.0122)	<0.0001
Variance of Rice Products Random Effect	0.056	
Variance of Participants Random Effect	0.028	

[a] numbers in parentheses are standard errors
*statistical significance at the 0.05 level or lower

Figure II-1.Outline of Experimental Procedure

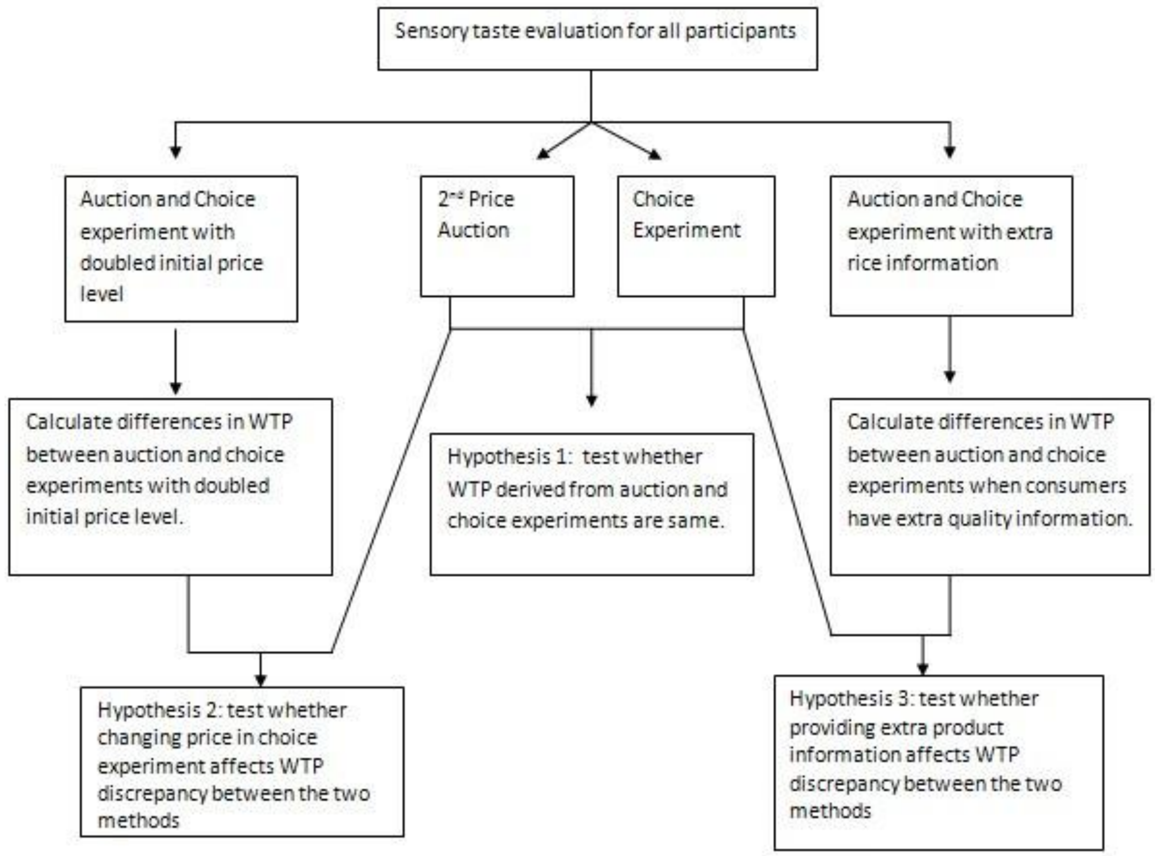


Figure II-2.Mean WTP for Rice with Excellent Insect Control from 2nd Price Auction, Low-Price Choice Experiment, and High-Price Choice Experiment, with and without Extra Product Information.

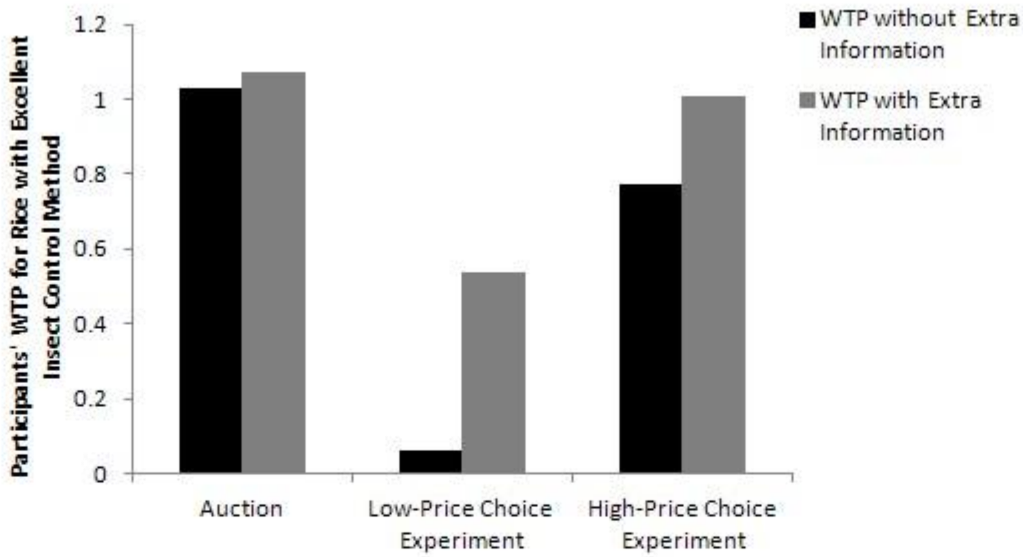


Figure II-3.Effect of Doubling Initial Price Level for Choice Experiment on WTP Discrepancy between Auction and Choice Experiment

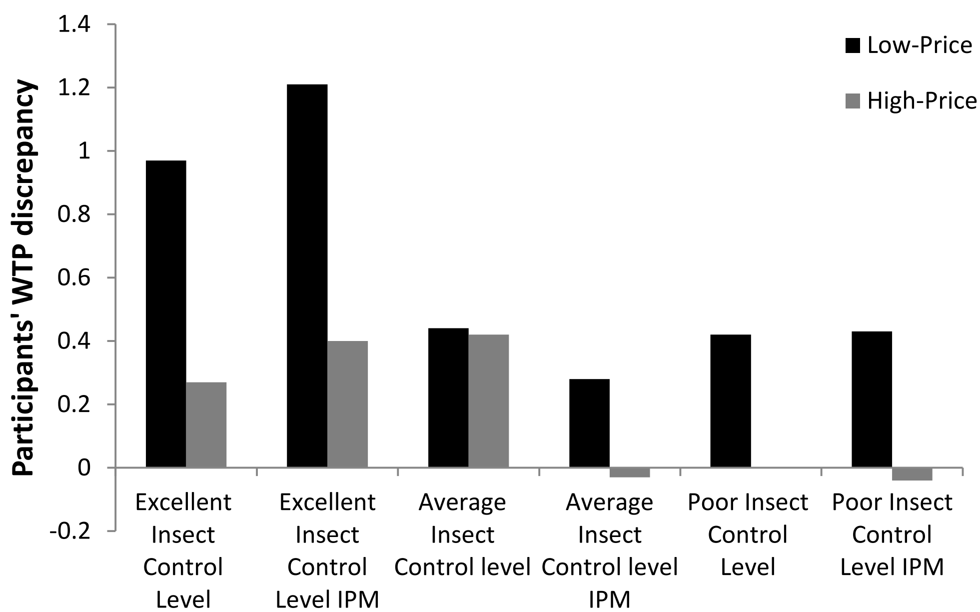
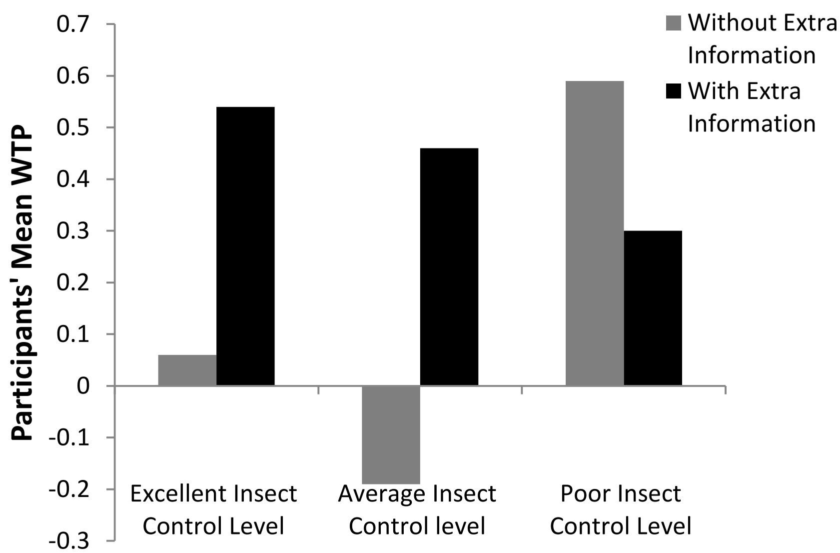


Figure II-4. Effects of Information on WTP for Rice with Three Insect Control Levels from Choice Experiment



CHAPTER III

COSTS AND BENEFITS OF CONVENTIONAL AND INTEGRATED PEST MANAGEMENT METHODS FOR CONTROLLING INSECTS IN STORED RICE

Introduction

Rice is the most important crop in the world today. Most rice is consumed directly as a whole grain without processing, so rice quality, particularly kernel wholeness, is important to rice consumers (Webb, 1985). Even though rice is the ninth largest economic crop in the United States, it is grown in four comparatively small regions: Arkansas Grand Prairie, Mississippi Delta, Gulf Coast, and Sacramento Valley of California. Categorizing by length of grain, the U.S. produces three kinds of rice: long grain, medium grain and short grain rice. Here, we focus on insect control in long grain rice, which accounts for 70% of U.S. rice production and is grown almost exclusively in the South (Setia et al., 1994).

Typical harvest months for rice are August and September (National Agricultural Statistics Service, 1997). When rice is stored in bins at harvest, the temperature of the rough rice inside the bin is generally in the range of 22 ℃ to 35 ℃, which is optimal for the growth and development of stored-grain insects (Fields, 1992; Howe, 1965).

Rice insects during storage can be roughly grouped as primary internal and secondary external feeders (Throne et al., 2003). Internal feeders either oviposit directly into the kernel or deposit eggs on the exterior of the kernel. This breaks the wholeness of rice kernels, which is a grading factor, and thus reduces the quality of rice. Secondary external feeders develop outside the kernel, and are less damaging then internal feeders.

The focus of this study is the effect of lesser grain borer (LGB) on stored rice quality. LGB is perhaps the most important internal feeder of stored grain because of its high dispersal and reproductive capabilities. LGB females oviposit on top of the rice grain, and then larvae bore inside the rice kernel. The larvae feed internally on the rice kernel and later bore out leaving a large hole in the kernel. This damage alone is enough to reduce the grade of rice. However such holes further cause problems by making the kernels more prone to breakage which will further reduce the value of the rice. (Brorsen, Grant, and Rister, 1984)

Calendar-based fumigation is widely used in the rice industry to control insects. The two most widely used chemicals are 1) chlorpyrifos-methyl (an organophosphate grain protectant) and 2) phosphine (a highly toxic fumigant). However, many species of stored-product insects, including LGB, have developed a resistance to chlorpyrifos-methyl (Athie and Mills, 2005; Pimentel et al., 2007). At the same time, consumers and regulatory agencies are increasingly concerned about food, environmental, and worker safety, in addition to insect resistance to pesticide. This challenges rice storage manager to adopt insect control method that applies less or no chemicals.

Integrated Pest Management (IPM) has been proposed as a way to reduce or eliminate the potential negative effect of pesticides on the environment and human health without harming profitability (Arthur and Flinn, 2000; Cornejo, 1996; Hagstrum and Flinn, 1996; Pimentel, 1978). IPM is a balanced use of multiple control tactics – biological, chemical, and cultural – as is most appropriate for a particular situation in light of careful study of all factors involved. Thus, while conventional pest management typically uses regular applications of pesticides, IPM programs evaluate the need for treatment and apply treatments considering both effectiveness and risk as needed. Sampling or monitoring is used to determine how many and what kinds of insects are present and to guide the application of control methods. Less risky and non-chemical actions are taken first, and additional pest control methods, including chemical pesticides, are employed only when needed.

Several kinds of IPM methods on various stored products have been discussed in previous studies, such as manual and controlled ambient aeration (Arthur, 1996; Arthur and Flinn, 2000; Arthur and Siebenmorgen, 2005; Arthur et al., 2008; Ranalli et al., 2002), refrigeration (Barbosa et al., 2011), sampling and monitoring (Adam et al., 2010; Flinn et al., 2010; Yigezu et al., 2008).

Temperature can greatly affect insect activity, including development, reproduction and survival (Howe, 1965). The optimal temperature for insect growth and development for lesser grain borer is from 25 ℃ to 33 ℃. Below 13 ℃, reproduction and growth and development effectively cease and above 38 ℃ most stored insects die (Fields, 1992). Manual aeration (fans are activated by turning a switch), controlled aeration (i.e., a thermostat turns on the fans when outside temperature is below grain temperature, and turns them off otherwise) and refrigeration (in which a refrigeration unit is used to chill the air and then sucked into the bin) can reduce the temperature to a level that significantly reduces insect activity.

However, for storage facilities that do not have aeration capabilities, sampling-based fumigation can be an alternative. Sampling-based fumigation periodically samples the grain and uses the sampling information and insect growth patterns to decide whether fumigation is necessary or not. Flinn et al. (2010) developed a decision support system to provide insect management information to grain storage managers. Instead of conducting routine fumigation, storage mangers could use the system to fumigate when insect densities exceeded economic thresholds. The authors assert that this method is effective and can reduce both the cost of pest management and the use of grain fumigant.

Despite increased consumer demands for reducing chemical use in food products, and regulatory restrictions on chemicals, many rice storage managers have hesitated to adopt IPM methods. The answer may be partly due to the cost of IPM methods compared to traditional chemical fumigation. For example although Barbosa et al. (2011) showed that refrigeration is an environmentally-friendly insect control method for stored rice, its cost is double that of alternatives. Adam et al. (2006) suggested that, compared to the higher treatment cost of routine fumigation, sampling based fumigation may lead to high "failure to control" cost.

However, although most studies have noted that good insect control and IPM method may yield economic benefits, few studies have attempted to quantify these benefits. One difficulty in measuring benefits from better insect control in rice is that there are no standard measures for insect loss. This contrasts with wheat, for example, which has a standard measure of insect damage (insect damaged kernels, or IDK) with a market-determined discount. Research on stored rice loss caused by storage insects has focused mainly on quantity losses such as the loss in milling yield and percentage of head rice, and on physical characteristics such as rice moisture content, water absorption ratio, cooked rice volume expansion, rice whiteness and viscosity (Cogbrun, 1976; Siebenmorgen et. al., 2008; Ranlli, Howell, and Siebenmorgen, 2003; Daniels et.al., 1998; Dillahunty, Siebenmorgen, and Mauromoustakos, 2001; Sugunya et. al., 2007). The monetary values of loss are also calculated based on the loss in quantity (Cogburn, 1976; Siebenmorgen et. al., 2008). No studies have measured the value that consumers place on good insect control in rice and on use of IPM methods in rice storage.

This study addressed these limitations by comparing the effectiveness and costs associated with various insect control methods, considering both treatment costs and costs of failing to control insects. The extra value consumers place on better insect control methods and IPM method is included in this comparison. The objective of this paper is to determine the optimal stored rice insect control method for rice elevators. To achieve this objective, this study compared the cost and benefits of simulated insect treatments: routine fumigation, aeration and sampling-based fumigation, where the latter two are considered components of an IPM approach to managing insects in stored rice.

Conceptual Framework

Both treatment costs and the costs of failing to control insects are considered. If the treatment cannot control the insects effectively and allows the insect population to grow beyond a particular level, the storage manager will lose money due to a sample-grade designation, loss of weight, or both. To maximize profit, a rice storage facility will choose the treatment with the minimum cost, which includes treatment cost and cost of failing to control.

Two components of cost are considered. The first is treatment cost, which includes costs of equipment, chemicals, and labor. This part is estimated using Lukens' economic engineering approach (2000) and Excel spreadsheets are used to calculate the costs. Included in this are benefits, or negative costs, from increasing consumer value by using particular treatment approaches. Specifically, Su et al. (2010) estimated consumers' willingness to pay (WTP) for rice stored using IPM rather than non-IPM control methods and found that, on average, consumers were willing to pay 6 cents per pound more for rice stored using IPM methods.

The second part is the cost of insect damage resulting from failing to control insects. It includes the cost of the loss in quantity and discounts resulting from insect damage. Quantity loss results from the feeding damages caused by LGB progeny. The negative effect of progeny on milling yield is checked in chapter 1, and the result is used here to calculate the milling yield loss. Then the monetary value of loss in quantity is computed by multiple the loss in milling yield by the milled rice farm level price. When LGB emerging from the kernels, causing broken kernels. Brorsen, Grant and Rister (1988) evaluated the effects of rice quality on price discount, and found that the price of broken kernels was about 1/3 of head rice. The discount associated with increase broken kernels due to insect infestation is computed by taking the difference between the value of head rice and broken kernels. (A sample grade discount is imposed if two or more grain-damaging insects are found in one kilogram of rice (Federal Rice Standard, 2005). Then fumigation is needed to kill the live insects to make the rice suitable for human consumption. This discount is assumed to be roughly equivalent to the cost of hiring a commercial firm to conduct a fumigation, plus costs of demurrage on rail cars and loss of facility use while the commodity is under fumigation.

It is assumed that a rice storage manager wishes to minimize the expected cost of alternative insect control methods in stored rice is

(3.1)

$$\min_{\lambda_i \in \{0,1\}, i=i,\dots,n} E(C_i) = \min(\lambda_1 E(C_1) + \lambda_2 E(C_2) + \cdots + (1 - \lambda_1 - \cdots - \lambda_{n-1} E(C_n))$$

where, $E(C_i)$ is the expected cost associated with insect control method i, λ_i is a discrete choice variable for the type of strategy i.

Given equation (3.1), the expected total cost under each stored insect control treatment is expressed as

(3.2) $$E(C_i) = TC_i + E(L_i) + E(D_i)$$

where $E(C_i)$ is the expected total cost of treatment i, TC_i is the treatment cost of treatment i, and $E(L_i)$ and $E(D_i)$ together are the "failing-to-control" cost of treatment i: $E(L_i)$ is the expected loss due to reduced milling yield from treatment i, and $E(D_i)$ is the expected market discount associated with reduced quality.

For each stored insect control method, the treatment cost is the total cost of equipment, electricity, labor and chemicals, expressed as

(3.3) $$TC_i = EQ_i + EL_i + LAB_i + CH_i$$

where, TC_i is same as defined before, EQ_i, EL_i, LAB_i, and CH_i are the equipment cost, electricity cost, labor cost, and chemical cost associated with the *i*th stored insect control strategy separately. An economic-engineering approach is applied here. Excel spreadsheets are used to calculate these costs associated with various stored insect treatments.

To estimate the failure-to-control cost, two steps are needed. First, we use an insect growth model to provide measures of insect population growth under alternative environmental conditions and insect control treatments. Then both loss in quantity and loss due to discount can be derived from the predicted insect population.

The insect growth model of Yang et. al (2010) is used here to predict insect population. Yang's insect growth model predicts the population of three stages of lesser grain borer: eggs, larva and adults, as a function of previous insect population, survival and reproduction rate. The insect survival and reproduction rates are determined by grain temperature and moisture as well as by choice of insect control method:

(3.4) $$I_{it} = f\left(I_{i,t-1,}S_{it}, R_{it}\right)$$

(3.5) $$S_{it} = g(temp_t, grain\ moisture_t, treatment\ i)$$

(3.6) $$R_{it} = h(temp_t, grain\ moisture_t, treatment\ i)$$

where I_{it} is the insect population on day t of stored insect treatment i, $I_{i,t-1}$ is the previous day's insect population, S_{it} and R_{it} are insect survival and reproduction rates on day t under treatment i, $temp_t$ is temperature on day t, $grain\ moisture_t$ is the grain moisture content in day t.

The loss in quantity of milled rice and any discount from failing to control insects are estimated from the insect growth model's predicted insect population at time of sale. The insect growth model predicts the number of progeny at the end of storage, and this progeny population can be used to compute the milling yield. The monetary value is calculated as the milling yield multiplied by the wholesale price of milled rice.

(3.7) $$E(L_i) = E(LOSSMY_i) * E(P_{MR})$$

(3.8) $$E(LOSSMY_i) = r(E(P_i))$$

where $E(L_i)$ is the expected loss in weight; $E(LOSSMY_i)$ is the expected milling yield loss of insect treatment i, which is a function of predicted progeny population under treatment i and $E(P_{MR})$ is the expected price of milled rice.

For the economic discount associated with poor insect control, the insect growth model assumed that one broken kernel resulting from each emerged adult LGB, and then calculated the percentage of broken kernels of the total rice. The economic discount associated with broken kernel is the reduced value of broken kernels compared to the head kernels. When the predicted insect population is larger than two adult insects per kilograms of rice at the end of storage, the rice is designated as sample grade, and cannot be sold for human consumption until the live insects are killed. Then fumigation is needed, and the number of fumigations required depends on the assumed effectiveness of fumigation and the model's prediction of total live insect numbers.

In chapter two, consumers' value placed on rice stored with alternative insect control methods are estimated, and the premium value consumers' place on IPM methods will be incorporated into this cost model.

(3.9) $$E(D_i) = E(\Delta BK_i) * [2/3 * E(P_{MR})] + FC * E(n_i) + E(IPMDiscount_i)$$

(3.10) $$E(\Delta BK_i) = p(E(I_i))$$

(3.11) $$E(n_i) = q(effect, E(I_i))$$

where $E(D_i)$ is the economic discount associated with treatment *i*; ΔBK_i is the changes in percentage of broken kernels under treatment *i*; 2/3 is the broken kernel discount estimated by Brorsen, Grant and Rister (1988), the value of broken kernels is around 1/3 or whole kernel; and P_{MR} is price of farm level milled rice; *FC* is the fumigation cost; $E(n_i)$ is the expected number of fumigations needed to kill the live insects; $E(IPMDiscount_i)$ is treatment *i*'s economic discount, and it is the negative value of consumers' willing to pay for rice that stored with IPM methods when treatment *i* is IPM method, and 0 otherwise ; *effect* is the assumed effectiveness of fumigation and $E(I_i)$ is the expected insect population predicted using Yang et al.'s insect growth model (2010).

Simulation and Procedures

Two commonly used IPM methods – aeration and sampling-based fumigation – were compared with conventional calendar-based fumigation. Aeration is primarily used to manipulate grain temperature. It moves the air through the grain by means of fans to lower or balance the temperature. It also can control the grain moisture, which is also a critical factor for insect activity. Arthur et al. (2008) compared manual aeration and controlled aeration of rice stored in Texas, and concluded that controlled aeration is more effective in reducing temperature and costs less than manual aeration, so only controlled aeration will be considered here. The fans are automatically turned on when the criteria for both temperature and air moisture are met. The average rice temperature and it is set at 60 ℉ (15 ℃) and the rice equilibrium moisture content (EMC) is set between 12.5% and 14.5%, varying with relative humidity and temperature during the storage period. So the fan is not turned on if the air humidity is too high, even though the temperature criterion is met.

Calendar-based fumigation is fumigating one or more times during storage at pre-determined dates rather than based on sampling. It can effectively kill the insects, but if fumigation is not needed it unnecessarily increases cost, increases potential for harmful exposure of workers to fumigant, and can increase resistance problems. Sampling-based fumigation uses monitoring and sampling to decide when fumigation is needed. Since fumigation is only conducted when necessary based on the sampling information, this approach can reduce the number of fumigations and associated costs and risks. However, it can also add unnecessary sampling costs if the number of required fumigations is not reduced by sampling (Adam et al., 2010).

The usual harvest dates for rice are in August, so the simulation assumes that rice is stored starting September 1 for three months until December 31st, for six months until

March 31st of the following year, or for ten months until July 31st of the following year. Costs of alternative insect control methods are compared for these three storage periods.

Simulation scenarios:

The model assumes a rice storage elevator with 10 bins, each containing 20,000 bushels of rice, located in Beaumont, Texas. Costs were calculated on a per bushel basis. Grain temperature on the starting date was set at 84 ℉ and the moisture content was set at 13%. Excel spreadsheets were used to calculate the total treatment cost of stored rice for several insect treatment strategies. Insect numbers, temperature, moisture, fan hours; and rice percentage loss were obtained from a web-based post-harvest grain management program, based on the insect growth model by (Yang et al., 2010).

Four strategies were simulated: (1) a no-treatment baseline; (2) automatic aeration, in which fans were automatically turned on when the grain temperature goes above 60 ℉ and the grain EMC level was between 12.5% and 14.5%; (3) sampling-based fumigation, in which fumigation was conducted when sampling detected 40 or more adult lesser grain borers per bushel of rice (1bushel = 20 kilograms, 40 adults/bushel = 2 adults/kilogram – this criterion was set according to USDA standards that designate rice with two or more adult (grain-damaging) insects per kilogram as sample grade, which cannot be sold for human consumption); (4) calendar-based fumigation, in which fumigation is conducted at predetermined dates.

For the sampling-based fumigation strategy, sampling was conducted on the date suggested by the insect growth model. For the calendar-based fumigation strategy, designated dates for fumigation were December 1 for storage ending December 31 or

March 31, and December 1 and June 1 for storage ending July 31. These fumigation dates were selected early enough that insect population would not grow large enough to cause damage before fumigation, yet late enough that insect population would not rebound enough to cause damage before sale or the next fumigation. The nine scenarios are listed in table III-1.

Treatment cost

The treatment cost of each approach is the sum of equipment cost, electricity cost, labor cost and chemical cost. Calculations were based on Luken's (2000) economic-engineering model.

The equipment cost is the cost of initial purchase of sampling, aeration, and fumigation equipments plus the interest cost of loans that used to purchase the equipment. Each piece of equipment is amortized over its expected useful life using the formula:

(3.12) $$\textit{Equipment Cost} = \textit{purchase cost of equipment}/PVIFA_{ni},$$

(3.13) $$PVIFA_{ni} = [1 - (1/(1 + i))^{n}]/i$$

$PVIFA_{ni}$ denotes present value interest factor for n years at i percent interest, where n is the usable life of the equipment and i is the interest rate on the loan. Dividing by *PVIFA* allocates the investment cost, including interest cost, equally over each year of the equipment's useful life. Since more than one fumigation may be conducted during a storage period, the yearly fumigation equipment cost is divided by the number of fumigations per year to get equipment cost per fumigation.

Electricity is the main cost of the controlled aeration strategy used in this study. The total fan operating hours can be predicted from the daily temperature, grain moisture level and storage loading and unloading dates. The web-based post-harvest grain management e-tool by Yang et al. (2010) calculates the total kilowatt hours consumed. The electricity cost is computed as following:

(3.14) $$Electricity\ cost = kilowatt\ hours * \$/kilowatt\ hr$$

(3.15) $$Total\ kilowatts = r(fan\ model, temperature, grain\ mositure)$$

Labor costs include training costs, wages and benefits, and liability insurance. Workers need to be trained to sample, identify, and record insects, and how to use toxic chemicals in fumigation. Training cost is divided into two parts: an annual training fee plus workers' wages. Labor costs associated with fumigation and sampling are calculated as:

(3.16) $$labor\ cost = (annual\ training\ fee\ per\ employee * number\ of\ employees + hourly\ labor\ cost * trainning\ hours * numbers\ of\ employee) + hourly\ labor\ cost * employee\ hours\ per\ task * numbers\ of\ emplyees$$

Chemical cost is the cost of fumigation materials: price per phosphine tablet multiplied by the number of tablets needed per bushel.

(3.17) $$Chemical\ cost = price\ per\ tablet * dosage\ per\ bu.$$

The treatment costs of the simulated strategies are presented in table III-2.

Insect population

The web-based post-harvest grain management program by Yang et al. (2010) was used to predict each day's insect population under each scenario using the daily temperature and moisture data during the storage periods.

There are four steps to predict the insect populations of each bin under alternative insect control strategies. First, storage start and end dates have to determined, this study picked three storage periods: Sep. 1st to Dec. 31st, Sep. 1st to following year's Mar. 31st, and Sep. 1st to following year's Jun. 31st. Then the storage location has to be chosen to input the daily temperature and moisture data. Data from Jefferson county in Texas with weather data from Beaumont Research Center weather station were used. The third step is to set up the bin configuration. The stored rice bin was assumed 10 ft in depth per bin, with initial grain temperature at 84 ℉ and initial moisture content at 12%. It was assumed that the insect infestation starts right after the storage, and that there was one adult lesser grain borer but no eggs or larvae at the beginning of storage. The last step is to choose the alternative insect control management methods.

For the no-treatment strategy, insects were assumed to grow and develop without any monitoring and treatment. Figures III-1 to III-9 present the daily grain temperature accumulated daily insect populations, and accumulated broken kernels under a no-treatment strategy for the three storage periods.

For controlled aeration, the average grain temperature was set as 60 ℉, and the EMC of rice was set between 12.5% and 14.5%. When both criteria were met the fan would be automatically turned on. And when the average temperature of grain dropped below 60 ℉ or the EMC of rice went above 14.5% or below 12.5% the fans would be automatically turned off. This program also predicted the total fan hours during the aeration and the kilowatt hours consumed using the weather and moisture data for various fan models. Figures III-10 to III-18 present the daily grain temperature, accumulated electricity usage in kilowatt hours; and accumulated daily insect populations under controlled aeration for three storage periods.

For sampling-based fumigation, after choosing the chemical material and effectiveness of fumigation, the web-based program suggested the date for fumigation. Fumigation was triggered when adult lesser grain borers/bushel exceeded 40, which was based on the FGIS threshold of two insects per kilogram. Here we assumed that sampling is perfect, so that sampling results are the same as the model's predicted number of insects. Based on the model's prediction of insect numbers, a fumigation decision could be made by comparing the predicted insect population with the 40 adults/bushel criteria. Figures III-19 to III-24 present the accumulated daily insect populations and daily accumulated broken kernel percentage under a sampling-based fumigation strategy for three storage periods.

For calendar-based fumigation, fumigations were conducted at specific dates with a specified effectiveness level. Figures III-25 to III-30 present the accumulated daily insect populations and daily accumulated broken kernel percentage under a calendar-based fumigation strategy for three storage periods.

Cost of failing to control

Poor insect control leads to loss in weight of milled rice, discount associated with broken kernels and extra fumigation cost if the number of adult insects is equal or larger than 2 per kilogram. For the loss in weight, predicted LGB progeny populations are used to compute the milling yield, using estimated model (1.9).The selling prices of milled rice in different states were obtained from ERS (Economic Research Service) 2010 Rice Yearbook. Multiplying the milled rice selling price by the predicted loss in milling yiled yields the monetary value of loss in weight.

The economic discount has three main parts: broken kernel discount, extra fumigation cost with 2 or more adults per kilogram; and the discount consumers place on the rice stored with the insect control methods that they disfavor. Yang et al (2010) insect growth model assumed that one emerged adult LGB caused one broken kernel and calculated the percentage of broken kernels. The discount of broken kernel is around 2/3 of the whole kernel price (Brorsen, Grant, and Rister, 1988). Broken kernel discount is computed as 2/3 of the monetary value of milled rice. The numbers of extra fumigations depend on effectiveness of fumigation and total live insect numbers. For example, if fumigation effectiveness is 95%, and there are 10 live adults per kilogram at the end of storage, then fumigation reduces the number of live insects to 0.5 per kilogram, so that one fumigation is sufficient. In contrast, if there are 50 live adults per kilogram at the end of storage, fumigation reduces the number of live insects to 2.5 per kilogram, and a second fumigation is necessary to reduce the number of live adult insects to less than 2 per kilogram.

There are currently no market discounts for rice stored with alternative insect control methods. However, as indicated in earlier chapters of this dissertation, Su et al. (2011), using non-hypothetical auction and choice experiment estimated the value consumers place on rice stored with alternative insect control methods, concluding that on average, consumers are also willing to pay 6 cents/pound more for rice stored with IPM methods than rice stored with conventional insect control methods.

In practice, there is no standard quality designation or a label to designate rice that is stored using IPM methods, for long-grain milled rice sold in the States. Although there is little chance that rice elevators will provide information to consumers on amount of prior insect infestation levels, with increasing concerns about chemical use in food, IPM labeling may become possible. In this study, the premium consumers place on IPM methods compared to non-IPM methods will be used to adjust the estimated costs and benefits of IPM storage strategies.

Results

Treatment cost

The treatment costs of alternative simulated insect control strategies are presented in tables III-3 to III-7 for controlled aeration, for one and two times of sampling-based fumigation and for calendar-based fumigation. The cost of aeration includes equipment cost and electricity cost. The total electricity usages in kilowatt hours for three storage periods are presented in figures III-11, III-14 and III-17. The average costs of controlled aeration for the three storage periods are 0.014$/bu., 0.014$/bu. and 0.015$/bu. For calendar-based fumigation, the cost includes equipment cost, labor cost, electricity cost and chemical cost. The average cost of one time of calendar-based fumigation is 0.017$/bu. and for two times of calendar-based fumigation is 0.027$/ bu. For sampling-based fumigation, when the sampling results suggesting fumigation is necessary, the treatment cost of sampling-based fumigation is the treatment cost of calendar-based fumigation plus the sampling cost, when the sampling results suggesting no fumigation is necessary, then it is the treatment cost of sampling. In our case, for rice stored until Dec.31st and rice stored until following year's March 31st, the sampling results on Nov. 14th suggested that fumigation was necessary. Then the treatment cost of sampling-based fumigation is 0.033$/bu. For rice stored until the end of July, two samplings were conducted and both results suggested that fumigations were required. The treatment cost of two times of sampling-based fumigation is 0.047$/ bu.

Among all simulated stored insect control strategies, the treatment cost of aeration is the least, regardless of storage periods. For sampling-based fumigation, the sampling results always suggested one or two times of fumigations are necessary, so the sampling-based fumigation treatment costs are higher than the costs of calendar-based fumigation because of the additional sampling cost.

Cost of failing to control – No Treatment

Table III-8 presents the percentage of damaged grain loss, total number of adult insects per bushel at the end of storage, extra fumigation cost and economic discount during alternative storage periods under the strategy of no treatment.

Figures III-1, III-4, and III-7 show the daily temperature of the stored rice with three storage periods when there is no treatment to control the insects. The average grain temperature at time of initial storage in Texas, September 1, was assumed to be 85 ℉. Since there was no aeration to control the temperature, the grain temperature declined at a very slow rate and was 70 ℉ at the end of December. During the winter, with low temperatures, the stored grain temperature decreased to 65 ℉ around January and February, but started to increase to 70°F at the end of following year's March, and hit 85 ℉ at the end of July. These warm temperatures provided hospitable environment for lesser grain borers to grow and develop.

As shown in figures III-2, III-5 and III-8, the insect population continued to increase during storage and the number of adult insects reached 288.87, 1270.34, and 31,828.16 per bushel at the end of the three storage periods, all of which are above the sample grade criterion of 40 adult insects per bushel, so fumigation was needed to kill the insects. The effectiveness of fumigation was assumed to be 95%. To bring the adult insect population lower than 40 adult insects/bu. the elevator needed to fumigate once for rice stored until Dec. 31st; twice for rice stored until March 31st, and three times for rice stored until July 31st. The extra costs of fumigation for the three storage periods were $0.016/bu., $0.026/bu., and $0.036/bu.

The increased number of adult and progeny LGB decreased the milling yield and increased the percentage of broken kernels. Table III-8 presents the failing-to-control cost when rice was stored without treatment for three storage periods. The total losses in milling yield were 0.067%, 0.042% and 3.702% while the broken kernels percentages were 0.17%, 0.58%, and 13.98% for three storage periods. According to the ERS 2011Rice Yearbook, the average selling price of milled rice in Texas is $26.67/cwt ($11.738/bu.). The losses in weight for stored rice without any treatment are $0.009/bu., $0.005/bu., and $0.435/bu. for the three storage periods. And the broken kernel discounts of stored rice without any treatment are $0.013/bu., $0.045/bu., and $1.094/bu. for three storage periods.

Cost of failing to control – controlled aeration

Table III-9 presents the percentage of grain damaged, loss in weight, total number of adult insects per bushel at the end of storage, extra fumigation cost and economic discount during the three storage periods under the strategy of controlled aeration.

Controlled aeration controlled the insects' growth for all three storage periods. As shown in figures III-10, III-13, and III-16, controlled aeration effectively reduced the grain temperature to a level low enough to reduce the lesser grain borer's activities. Figures III-12, III-15 and III-18 show the daily insect population during the three storage periods: the insect population grew at a much slower rate than when no treatment was applied and the population of adult lesser grain borers at the end of storage were 0.33/bu., 1.85/bu. and 3.64 per bu. under alternative storage periods, which were all less than the sample rice grade criterion of 40 adult insects per bu. Thus the rice was suitable for human consumption and no further fumigation was needed. Also, there was no grain damage and thus no loss in weight for rice stored under controlled aeration.

Controlled aeration is an IPM insect control method, and consumers are willing to pay extra for this method compared to calendar-based fumigation. The average extra value consumers place on IPM method is 6 cents per pound. The average selling price of milled long-grain rice in Texas is $26.67 /cwt, which is $0.27/lb and the selling price for long-grain rice in consumers' level is around one dollar per pound. We adjusted the extra 6 cents/pound value consumers place on rice that stored under IPM method to extra 1.6 cents/pound ($0.704/bu.) at the farm level. This extra value was treated as a negative economic discount associated with use of IPM methods in storage.

Cost of failing to control – sampling-based fumigation

Figures III-19, III-21, and III-23 present the population of egg, immature, adult and total insects under a sampling-based fumigation strategy for the three storage periods. For rice stored until the end of December and rice stored through March, the population of less grain borer continued to grow during storage. The insect growth model predicted that the number of adult lesser grain borers reached 37.42/bu. on Nov. 14th, close to the federal sample rice grade criteria, so that fumigation was suggested. The effectiveness of fumigation was assumed to be 95%, and it reduced the population of adult insects to 1.99/bu. on Nov. 15th. After the treatment, the LGB developed at a slower rate due to the lower winter temperatures.

At the end of December and March, the number of adult lesser grain borers was 2.99/bu. and 5.65/bu. However, for rice stored until July, the insect population started to grow at a quicker rate due to the warmer weather, and the number of adult insects reached 26.4/bu. on June 8th, indicating that fumigation was needed. With 95% effectiveness, fumigation reduced the adult insect population to 1.43/bu. At the end of storage, the adult insect number was 3.48/bu.

Table III-10 presents the percentage of milling yield loss, loss in weight, broken kernel percentage, total number of adult insects per bushel at the end of storage, extra fumigation cost and IPM discount during the three storage periods under the strategy of sampling-based fumigation. For all three storage periods, the number of adult insect at the end of storage was less than 40/bu., so no further fumigation was needed. But there was 0.02% broken kernels for rice stored until December and rice stored until March, and 0.03% broken kernels for rice stored until July, as shown in figures III-20, III-22 and III-

24. The broken kernel discounts were $0.002/bu. for three storage periods. Sampling-based fumigation is also an IPM method, so the extra value consumers place on IPM was counted as negative IPM discount.

Cost of failing to control – calendar-based fumigation

Table III-11 presents the percentage of grain damaged, loss in weight, total number of adult insects per bushel at the end of storage, extra fumigation cost and economic discount during alternative storage periods under the strategy of calendar-based fumigation. For calendar-based fumigation, it was assumed that the elevator manager fumigated once on Dec. 1 for rice that was stored until December and March, and fumigated on both Dec. 1 and July 1 for rice that was stored until July. For rice that was stored until Dec 31 and March 31, as shown in figures III-25 and III-27, the population of adult insects reached 39.01 per bushel on Nov. 13, the sampling and fumigation date suggested by the insect growth model. However, the elevator using calendar-based fumigation did not fumigate until Dec. 1. By then the adult insect population was 118.42 per bushel. Fumigation that was 95% effective reduced the population to 6.31 per bushel, which then grew to 16.94 adults insects per bushel by December 31 and 35.02 adult insects per bushel by March 31. For rice that was stored until July 31, the elevator fumigated twice, once on Dec. 1 and once on June 1, resulting in an adult insect population at the end of storage of 198.16/bushel, so that a fumigation was needed with an extra cost of $0.016 per bushel. The total losses in milling yield were 0%, 0% and 0.05% while the broken kernels percentages were 0.05%, 0.06%, and 0.16% for three storage periods. The losses in weight for stored rice without any treatment are $0/bu.,

$0/bu., and $0.006/bu. for the three storage periods. And the broken kernel discounts of stored rice without any treatment are $0.004/bu., $0.005/bu., and $0.013/bu. for three storage periods.

Total cost

Table III-12 presents the costs of the simulated insect control strategies over the three storage periods, including the value to consumers of using an IPM strategy. The costs of the no-treatment strategy were $0.037/bu., $0.076/bu., and $1.565/bu. for the three storage periods. The cost of controlled aeration, an IPM strategy, was -$0.69/bu. for all three storage periods. The costs of sampling-based fumigation for the three storage periods were -$0.669, -$0.669, and -$0.655 per bushel. The negative costs were due to the large value that consumers place on rice stored using IPM methods, as determined in the other parts of this study. The implication is that, taking into account treatment costs, failure-to-control costs, and the value to consumers of using IPM methods, costs of IPM methods such as controlled aeration and sampling-based fumigation are negative compared to the cost of conventional non-IPM methods such as calendar-based fumigation. Calendar-based fumigation costs were $ 0.021/bu., $0.022/bu., and $0.061/bu. for the three storage periods. A no-treatment strategy was used as a baseline here: even though it had no treatment cost, it had the highest failure-to-control cost. Aeration and sampling-based fumigation controlled the insects effectively, with no fail-to-control cost. Calendar-based fumigation also reduced the insect growth, but it was not as effective as aeration and sampling-based fumigation: it had higher numbers of insect population at the end of storage, which led to higher percentage of grain damaged for all three storage periods and one extra fumigation for the longest storage period.

Among these insect control methods, aeration was the one with the lowest total cost. Due to the warm temperatures in Texas, sampling results always suggested fumigation, so treatment cost for sampling-based fumigation was more expensive than calendar-based fumigation because of the extra cost of sampling which never gave a "no-fumigation" recommendation. But considering the premium consumers are willing to pay for rice stored using IPM methods, the total cost of sampling-based fumigation was lower than the cost of calendar-based fumigation.

In reality, though, consumers are currently not given information on the methods used to control storage insects in rice products they purchase. They do not currently have an opportunity to express this preference in the market. Given that, table III-13 presents the total costs of alternative insect control methods without considering the extra value consumers place on IPM methods: the costs of controlled aeration for the three storage periods were 0.014$/bu., 0.014$/bu. and 0.015$/bu.; the total costs of sampling-based fumigation for the three storage periods were 0.035$/bu., 0.035$/bu., and 0.049$/bu.; and the total costs of calendar-based fumigation were 0.021$/bu., 0.022$/bu., and 0.034$/bu. Controlled aeration was still the strategy with the lowest cost. Compared to the costs of calendar-based fumigation, the costs of sampling-based fumigation were higher for rice stored for the shorter storage periods, but lower for rice stored under longest period. Also, both aeration and sampling-based fumigation controlled the insects effectively without incurring any fail-to-control cost, while the insects were controlled less effectively using calendar-based fumigation.

Conclusion and Discussion

The objective of this article was to determine the most economic insect control method for rice storage. To achieve the objective, two IPM insect control methods– controlled, aeration and sampling-based fumigation – and one traditional treatment – calendar-based fumigation – were simulated and both treatment costs and failure-to-control costs of these methods were compared. The results suggested that among all insect control methods, aeration is the best strategy: it had the lowest total cost and it controlled the insects effectively. Moreover, aeration does not include any chemical application, which is consistent with consumers' apparent preference for reduced chemical use.

For rice storage facilities that do not have aeration capacity, sampling-based fumigation is a better choice than calendar based fumigation if firms can use it as a promotional tool. Although the cost of sampling-based fumigation is higher than the cost of calendar-based fumigation, it is a method of IPM and consumers are willing to pay a premium for rice stored using IPM methods.

For calendar-based fumigation, it is hard to determine the optimal fumigation date. If the date selected is too early, then after fumigation the insect population may rebound to a damaging level, but if the date selected is too late, the insect population may have already caused damage. Sampling-based fumigation has a similar issue in selecting sampling dates. Moreover, if a potential problem is not detected in the sampling procedures, so that no fumigation is suggested, it can cause great loss.

This study used one year weather data (temperature and humidity) to estimate insect population in stored rice and used that information to compute cost function to determine the optimal insect management strategy, thus, it is a deterministic approach. Weather conditions vary from year to year can influence the insect growth pattern and then affects the costs of alternative insect control methods. In further studies, more yearly weather data will be incorporated to release this limitation.

Our simulation assumed the insect growth model and sampling are perfect: i.e., the suggested sampling date is correct, and sampling detects the actual insect population. By using the publicly available web-based post-harvest management program developed by Yang et al. (2010), rice storage firms can predict the optimal sampling date and insect populations based on their own storage environments and situations. Improving the accuracy of the insect growth model and making it available to more rice storage firms may help more elevators adopt sampling-based fumigation and better meet consumers' demand for good insect control as well as their concerns about food and worker safety, environmental health and pesticide resistance.

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Appendix

Web-based Insect Growth Model Computation

Input weather data:

		Country	State	County	Station	Use Historic Average
Edit	Delete	US	TX	JEFFERSON	BEAUMONT RESEARCH CTR	☐

Add Simu-Weather

Rice Storage Assumption

Grain Depth (ft)	10
Initial Grain Temp(ºF)	84
Initial Grain MC (%w.b.)	13
Date Grain Load	09/01/2009
Date Grain Unload	07/31/2010

Insect Assumption:

Infestation Date(days after storage)	0
Initial Pest Egg/Bu	0
Initial Pest Immature/Bu	0
Initial Pest Adult/Bu	1

Controlled Aeration:

Aeration Strategy	EMCControlled Air	
Highest EMC (%w.b.)	14.5	
Lowest EMC (%w.b.)	12.5	
Control Target	Average Grain Temperature	
	Levels	Interval
Control Target Value(ºF)	60	1

Sampling-based Fumigation:

Type	Fumigant: Phosphine
	Grain Borer
Mortality (%)	95

Table III-1. Total Insect Control Treatment Simulation Scenarios

Scenarios	Insect Control Treatments
Scenario 1	No Treatment
Scenario 2	Aeration, storage until December
Scenario 3	Sampling-based fumigation: sampling on Nov. 13th, storage until December
Scenario 4	Calendar-based fumigation: fumigation on Dec. 1st, storage until December
Scenario 5	Aeration, storage until March
Scenario 6	One sampling-based fumigation: sampling on Nov.13th, storage until March
Scenario 7	One calendar based fumigation: fumigation on Dec. 1st, storage until March
Scenario 8	Aeration, storage until June
Scenario 9	Two sampling-based fumigations: sampling on Nov.13th and June 1st, storage until July
Scenario 10	Two calendar-based fumigations: fumigation on Dec. 1st and June 1st , storage until July

Table III-2. Treatment Cost of Alternative Insect Control Strategies

Cost Components	Description
Aeration	
Initial aeration equipment cost	$4066 amortized at 10% over of 10 years + insurance + maintenance
Electricity cost	Electricity cost per bin *Price of electricity*# of bins
Sampling-based fumigation	
Equipment cost	
Initial sampling equipment cost	($9000 insect sampling equipment cost amortized at 10% over 10 years + insurance + maintenance)+On site insect trap costs
Initial fumigation equipment cost	($3000 fumigation equipment cost + $800 fumigation monitoring device cost) amortized at 10% over 10 years + insurance + maintenance
Fumigation training cost	Training fee + (training hours per employee *# of employees * labor cost)
Labor cost	Fumigation liability Insurance + Trap set up labor cost + sampling labor cost + fumigation labor cost
Chemical cost	Price per tablet*Dosage
Calendar-based fumigation	
Initial fumigation equipment cost	($3000 fumigation equipment cost + $800 fumigation monitoring device cost) amortized at 10% over 10 years + insurance + maintenance
Labor cost	Fumigation liability Insurance + Training fee + (training hours per employee *# of employees * labor cost) +fumigant labor cost
Chemical cost	Price per tablet*Dosage

[a] For cost of two sampling-based fumigation, double the labor cost and chemical cost.
[b] For cost of two calendar-based fumigation, double the labor cost and chemical cost.

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Table III-3. Economic-Engineering Costs of Controlled Aeration.

Controlled Aeration Cost Components		Rate	$/bu.
Aeration fan equipment cost		102.77/bin/yr	0.005
Electricity cost	Storage until Dec. 31st	167.4/bin/yr	0.008
	Storage until March 31st	183.6/bin/yr	0.009
	Storage until July 31st	194.4/bin/yr	0.010
Treatment cost	Storage until Dec. 31st	282.77/bin/yr	0.014
	Storage until March 31st	286.37/bin/yr	0.014
	Storage until July 31st	297.17/bin/yr	0.015

Table III-4. Economic-Engineering Costs of One Sampling-Based Fumigation.

Fumigation Cost Components	Rate	$/bu.
Sampling equipment cost	258.52/bin/yr	0.013
Sampling labor cost	57.60/bin/yr	0.003
Fumigation equipment cost	104.84/bin/yr	0.005
Fumigation training cost	19.8/bin/yr	0.001
Fumigation labor cost	116/bin/yr	0.006
Fumigation chemical cost	102.86/bin/yr	0.005
Total cost	659.62/bin/yr	0.033

Table III-5. Economic-Engineering Costs of Two Sampling-Based Fumigations.

Fumigation Cost Components	Rate	$/bu.
Sampling equipment cost	280.57/bin/yr	0.014
Sampling labor cost	115.2/bin/yr	0.006
Fumigation equipment cost	104.84/bin/yr	0.005
Fumigation training cost	19.8/bin/yr	0.001
Fumigation labor cost	212/bin/yr	0.011
Fumigation chemical cost	205.72/bin/yr	0.010
Total cost	938.13/bin/yr	0.047

Table III-6. Economic-Engineering Costs of One Calendar-Based Fumigation.

Fumigation Cost Components	Rate	$/bu.
Fumigation equipment cost	104.84/bin/yr	0.005
Fumigation training cost	19.8/bin/yr	0.001
Fumigation labor cost	116/bin/yr	0.006
Fumigation chemical cost	102.86/bin/yr	0.005
Total cost	343.5/bin/yr	0.017

Table III-7. Economic-Engineering Costs of Two Calendar-Based Fumigations.

Fumigation Cost Components	Rate	$/bu.
Fumigation equipment cost	104.84/bin/yr	0.005
Fumigation training cost	19.8/bin/yr	0.001
Fumigation labor cost	212/bin/yr	0.011
Fumigation chemical cost	205.72/bin/yr	0.010
Total cost	542.36/bin/yr	0.027

Table III-8. Failing-to-Control Cost of Rice Stored under No-Treatment Strategies

	Progeny Population (#/bu.)	Lost in Milling Yield	Loss in Weight ($/bu.)	Broken Kernel Percentage	Broken Kernel Discount	Adult Insect Population (#/bu.)	Extra Fumigation Cost ($/bu.)	IPM Discount ($/bu.)	Total Fail to Control Cost ($/bu.)
Storage until Dec. 31st	1032.56	0.067%	0.009	0.17%	0.013	388.87	0.016	0	0.037
Storage until March 31st	639.02	0.042%	0.005	0.58%	0.045	1270.34	0.026	0	0.076
Storage until July. 31st	56955.98	3.702%	0.435	13.98%	1.094	31828.16	0.036	0	1.565

Table III-9. Failing-to-Control Cost of Rice Stored under Controlled Aeration Insect Control Strategies

	Progeny Population (#/bu.)	Lost in Milling Yield	Loss in Weight ($/bu.)	Broken Kernel Percentage	Broken Kernel Discount	Adult Insect Population (#/bu.)	Extra Fumigation Cost ($/bu.)	IPM Discount ($/bu.)	Total Fail to Control Cost ($/bu.)
Storage until Dec. 31st	3.4	0%	0	0%	0	0.33	0	-0.704	-0.704
Storage until March 31st	0.61	0%	0	0%	0	1.85	0	-0.704	-0.704
Storage until July. 31st	20.17	0%	0	0%	0	3.64	0	-0.704	-0.704

Table III-10. Failing-to-Control Cost of Rice Stored under Sampling-Based Fumigation Insect Control Strategies

	Progeny Population (#/bu.)	Lost in Milling Yield	Loss in Weight ($/bu.)	Broken Kernel Percentage	Broken Kernel Discount	Adult Insect Population (#/bu.)	Extra Fumigation Cost ($/bu.)	IPM Discount ($/bu.)	Total Fail to Control Cost ($/bu.)
Storage until Dec. 31st	5.56	0%	0	0.02%	0.002	2.99	0	-0.704	-0.702
Storage until March 31st	4.45	0%	0	0.02%	0.002	5.65	0	-0.704	-0.702
Storage until July. 31st	21.33	0%	0	0.03%	0.002	3.48	0	-0.704	-0.702

Table III-11. Failing-to-Control Cost of Rice Stored under Calendar-Based Fumigation Insect Control Strategies

	Progeny Population (#/bu.)	Lost in Milling Yield	Loss in Weight ($/bu.)	Broken Kernel Percentage	Broken Kernel Discount	Adult Insect Population (#/bu.)	Extra Fumigation Cost ($/bu.)	IPM Discount ($/bu.)	Total Fail to Control Cost ($/bu.)
Storage until Dec. 31st	35.54	0%	0	0.05%	0.004	16.94	0	0	0.004
Storage until March 31st	18.86	0%	0	0.06%	0.005	35.02	0	0	0.005
Storage until July. 31st	708.75	0.05%	0.006	0.16%	0.013	198.16	0.016	0	0.034

Table III-12. The Total Cost of Alternative Simulated Insect Control Strategies Considering Extra Values Consumers Place on IPM Methods ($/bu.)

	Storage until Dec. 31st	Storage until March 31st	Storage until July 31st
No treatment			
Treatment cost	0	0	0
Failing-to-control cost	0.037	0.076	1.565
Total cost	0.037	0.076	1.565
Controlled aeration			
Treatment cost	0.014	0.014	0.015
Failing-to-control cost	-0.704	-0.704	-0.704
Total cost	-0.69	-0.69	-0.689
Sampling-based fumigation			
Treatment cost	0.033	0.033	0.047
Failing-to-control cost	-0.702	-0.702	-0.702
Total cost	-0.669	-0.669	-0.655
Calendar-based fumigation			
Treatment cost	0.017	0.017	0.027
Failing-to-control cost	0.004	0.005	0.034
Total cost	0.021	0.022	0.061

Table III-13. The Total Cost of Alternative Simulated Insect Control Strategies without Considering Extra Values Consumers Place on IPM Methods ($/bu.)

	Storage until Dec. 31st	Storage until March 31st	Storage until July 31st
No treatment			
Treatment cost	0	0	0
Failing-to-control cost	0.037	0.076	1.565
Total cost	0.037	0.076	1.565
Controlled aeration			
Treatment cost	0.014	0.014	0.015
Failing-to-control cost	0	0	0
Total cost	0.014	0.014	0.015
Sampling-based fumigation			
Treatment cost	0.033	0.033	0.047
Failing-to-control cost	0.002	0.002	0.002
Total cost	0.035	0.035	0.049
Calendar-based fumigation			
Treatment cost	0.017	0.017	0.027
Failing-to-control cost	0.004	0.005	0.034
Total cost	0.021	0.022	0.061

Figure III-1. Daily Grain Temperature for Rice Stored until Dec. 31st under No-Treatment Strategy.

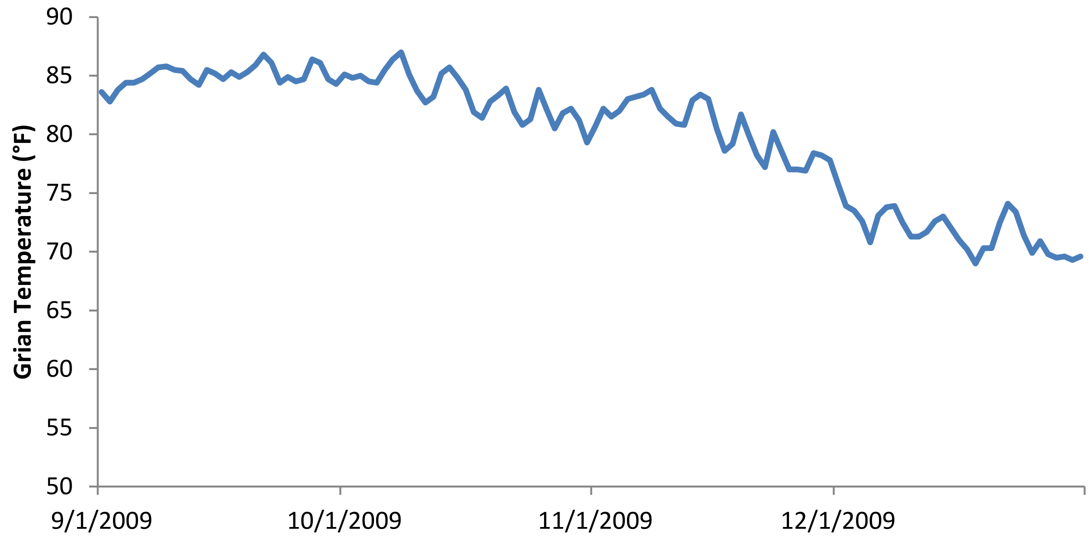


Figure III-2. Accumulated Daily Insect Populations for Rice Stored until Dec. 31st under No-Treatment Strategy.

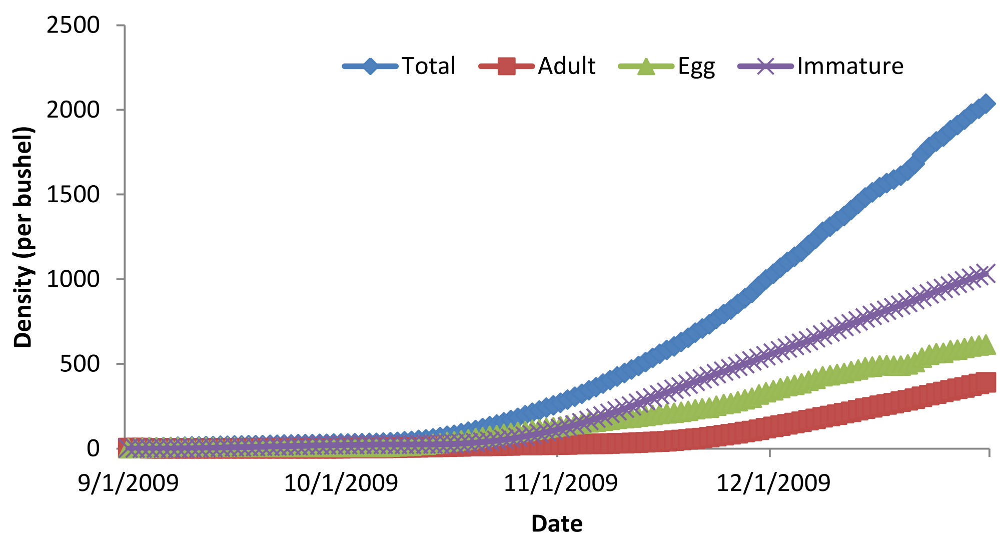


Figure III-3. Accumulated Percentage of Broken Kernels when Stored until Dec. 31st under No-Treatment Strategy.

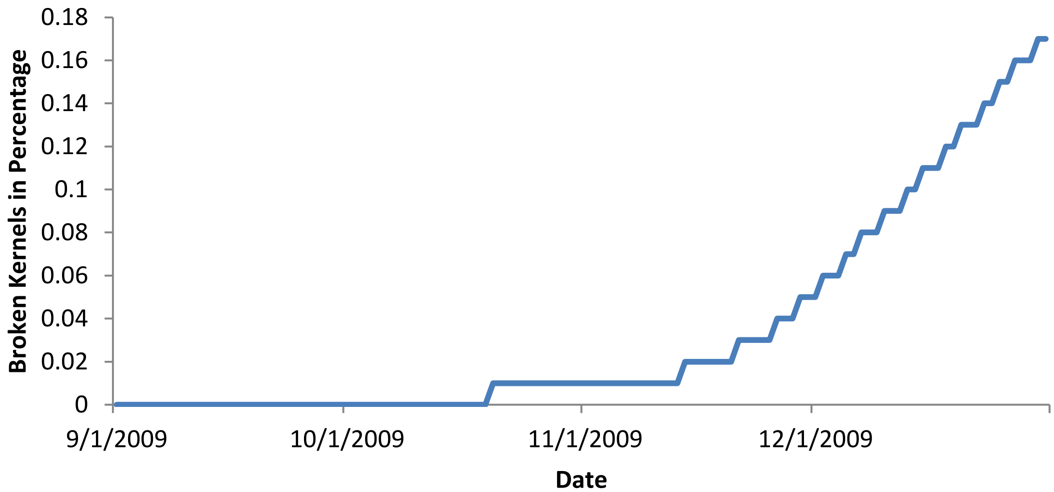


Figure III-4. Daily Rice Temperature when Stored until March 31st under No-Treatment Strategy.

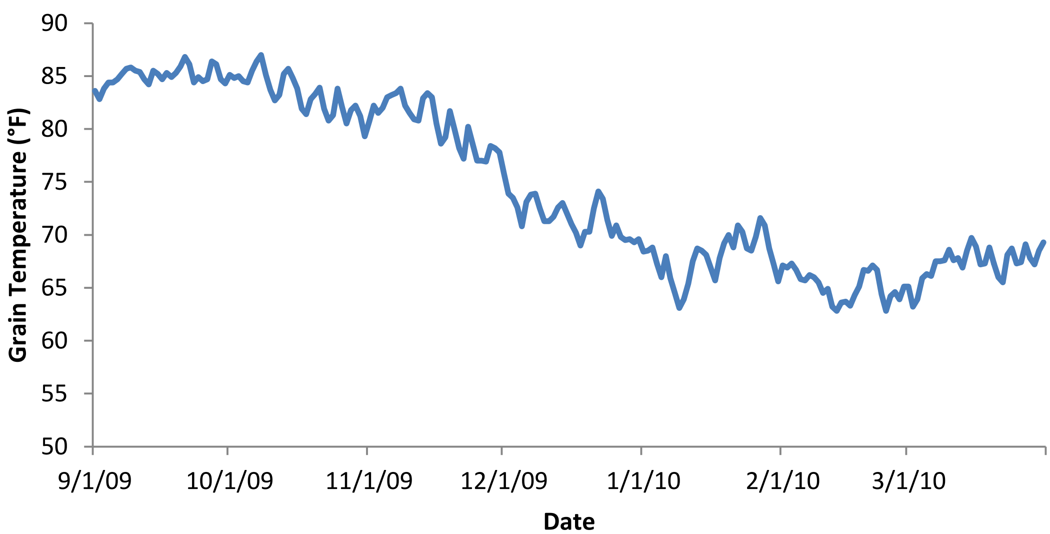


Figure III-5. Accumulated Daily Insect Populations for Rice Stored until March 31st under No-Treatment Strategy.

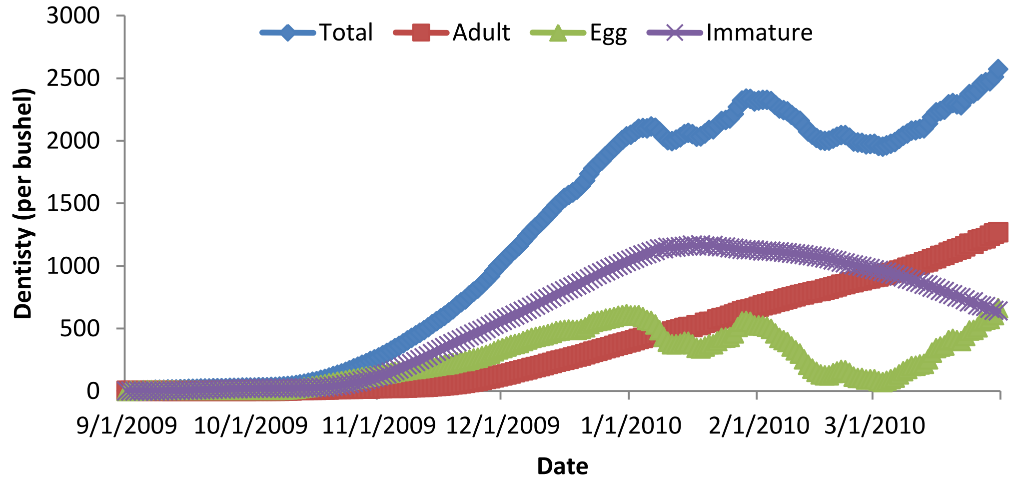


Figure III-6. Accumulated Percentage of Broken Kernels when Stored until March 31st under No-Treatment Strategy.

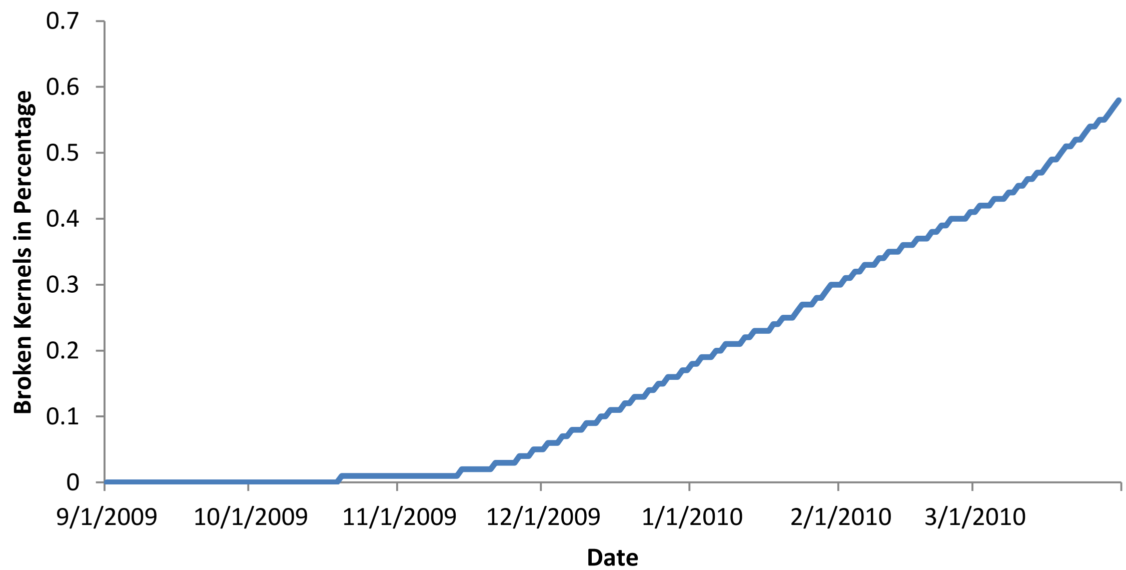


Figure III-7. Daily Grain Temperature for Rice Stored until July 31st under No-Treatment Strategy.

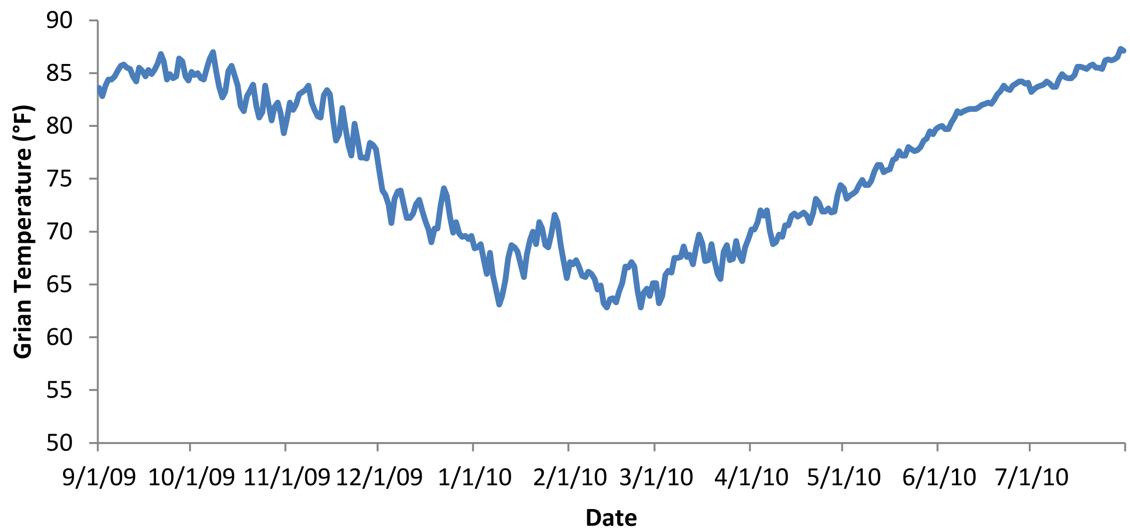


Figure III-8. Accumulated Daily Insect Population in Rice Stored until July 31st under No-Treatment Strategy.

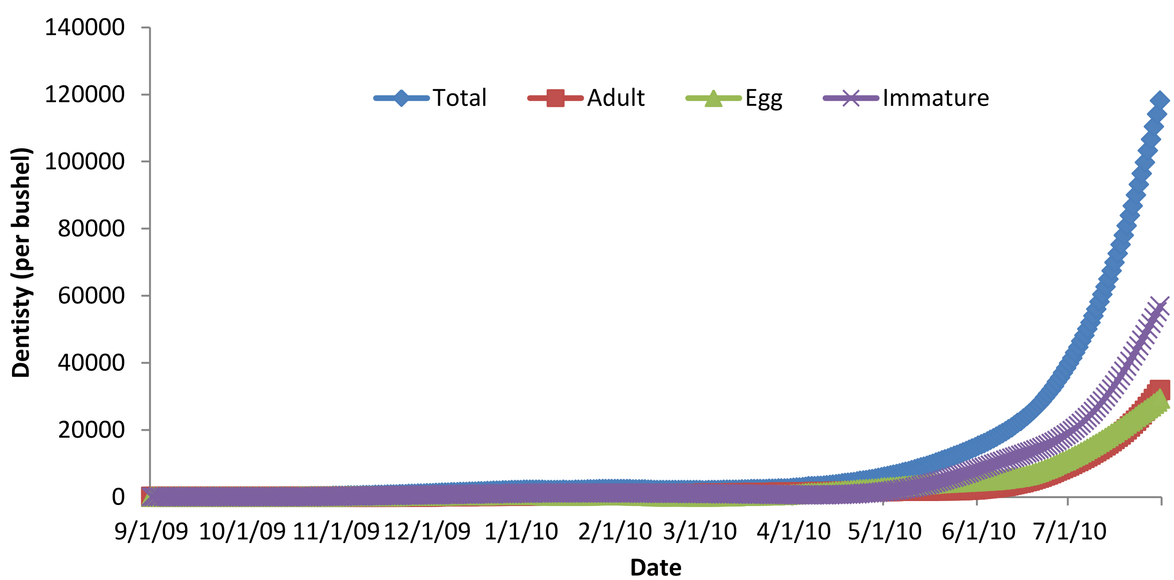


Figure III-9. Accumulated Percentage of Broken Kernels when Stored until July 31st under No-Treatment Strategy.

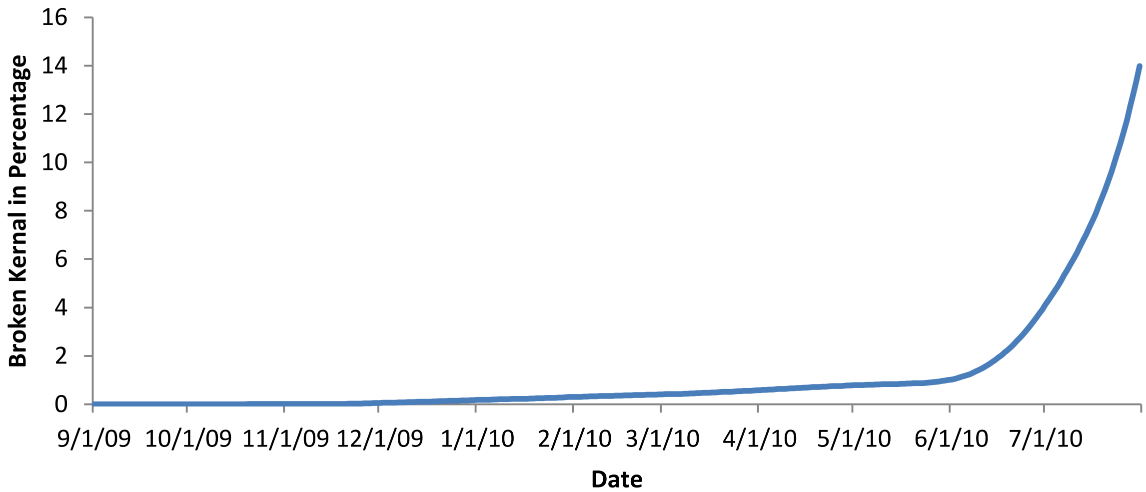


Figure III-10. Daily Grain Temperature for Rice Stored until Dec. 31st under Controlled Aeration Strategy.

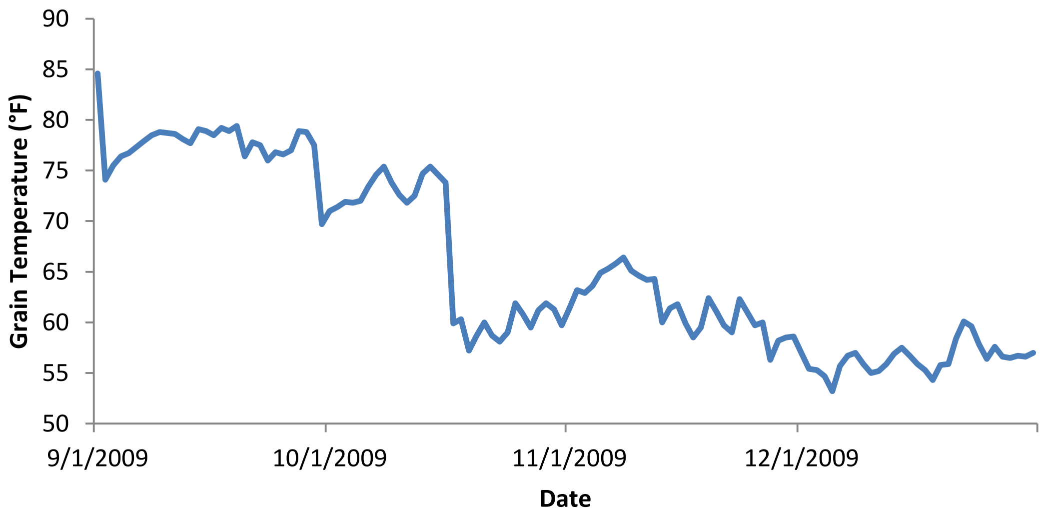


Figure III-11. Accumulated Electricity Usage in Kilowatt hours for Rice Stored until Dec. 31st under Controlled Aeration Strategy.

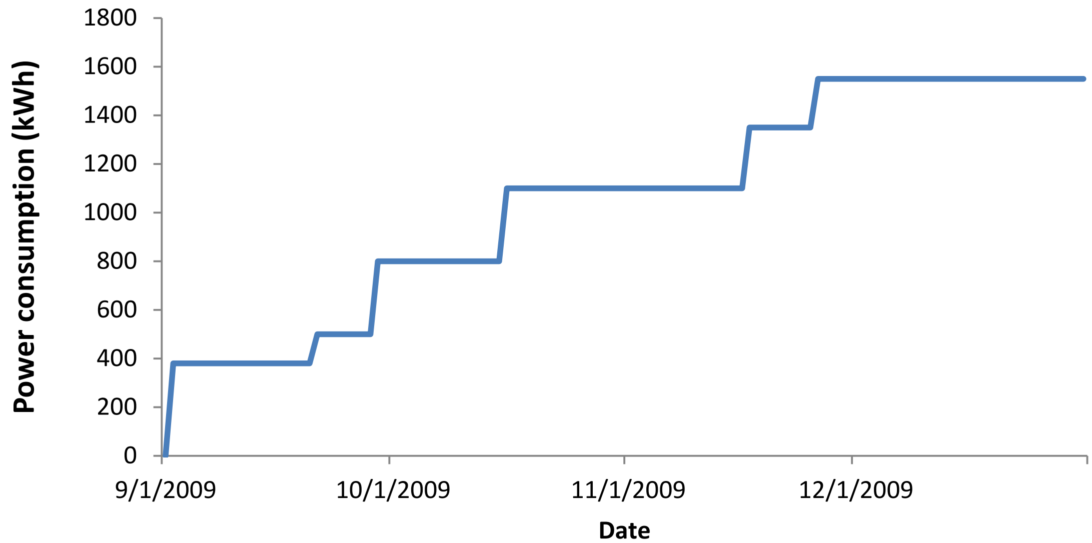


Figure III-12. Accumulated Daily Insect Populations In Rice Stored until Dec. 31st under Controlled Aeration Strategy.

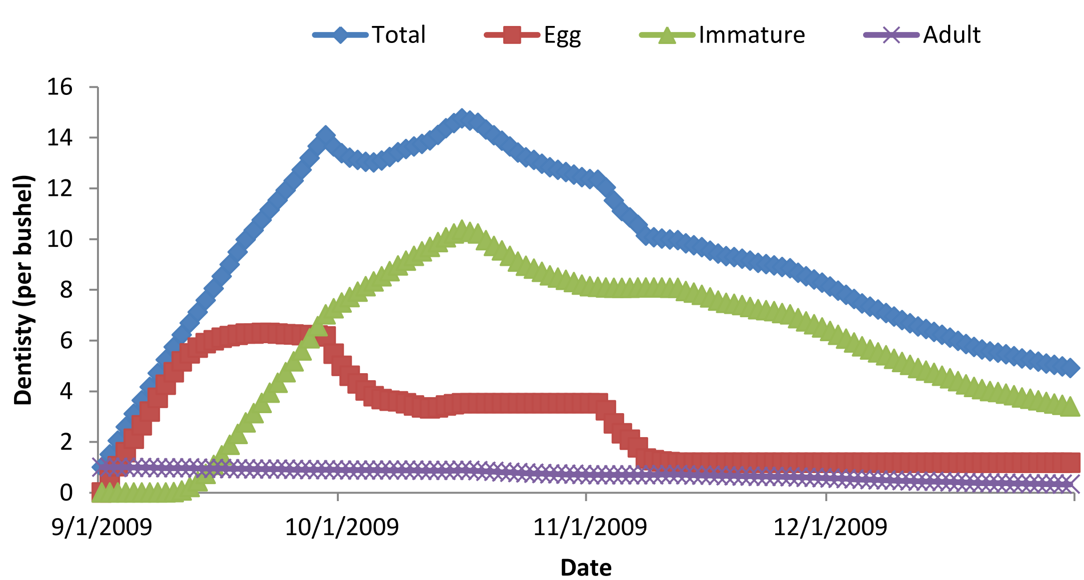


Figure III-13. Daily Grain Temperature for Rice Stored until March 31st under Controlled Aeration Strategy.

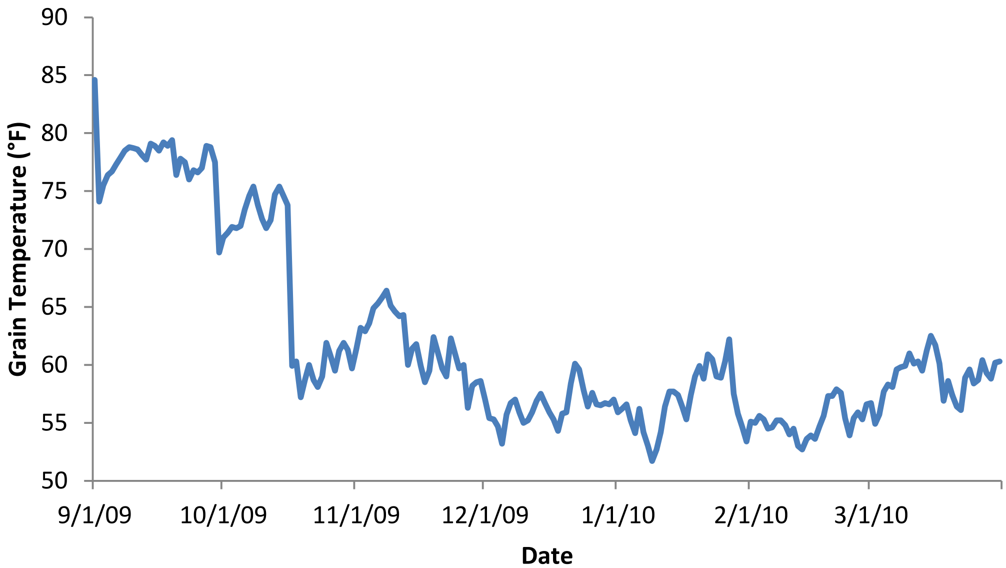


Figure III-14. Accumulated Electricity Usage in Kilowatt hours for Rice Stored until March 31st under Controlled Aeration Strategy.

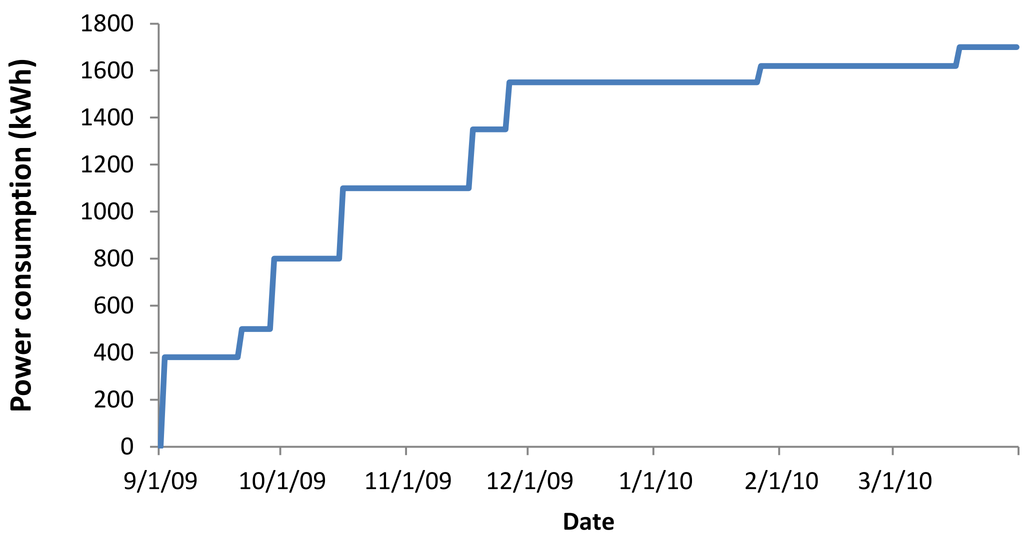


Figure III-15. Accumulated Daily Insect Population in Rice Stored until March 31st under Controlled Aeration Strategy.

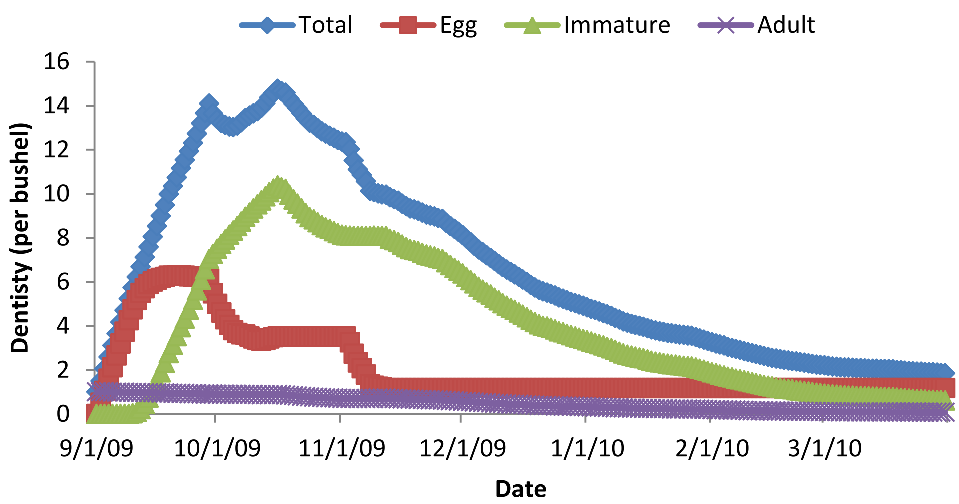


Figure III-16. Daily Grain Temperature for Rice Stored until July 31st under Controlled Aeration Strategy.

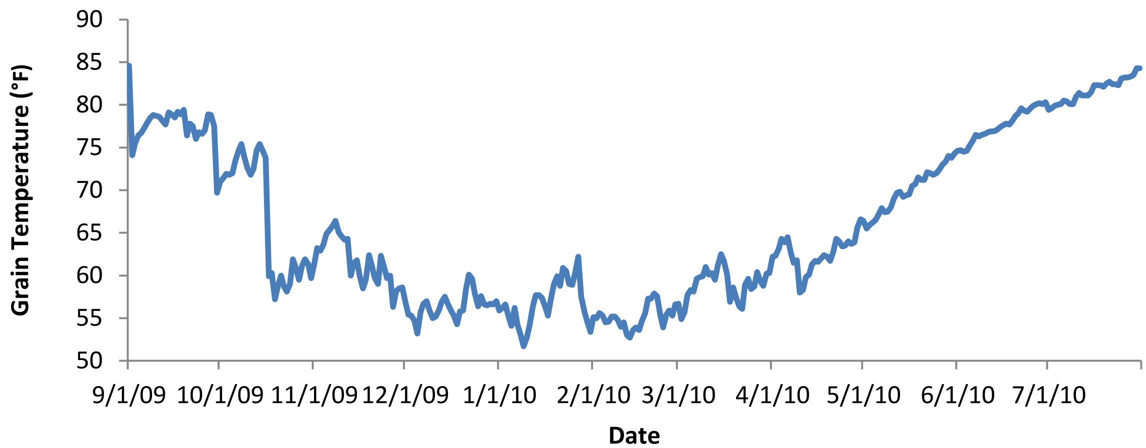


Figure III-17. . Accumulated Electricity Usage in Kilowatt hours for Rice Stored until July 31st under Controlled Aeration Strategy.

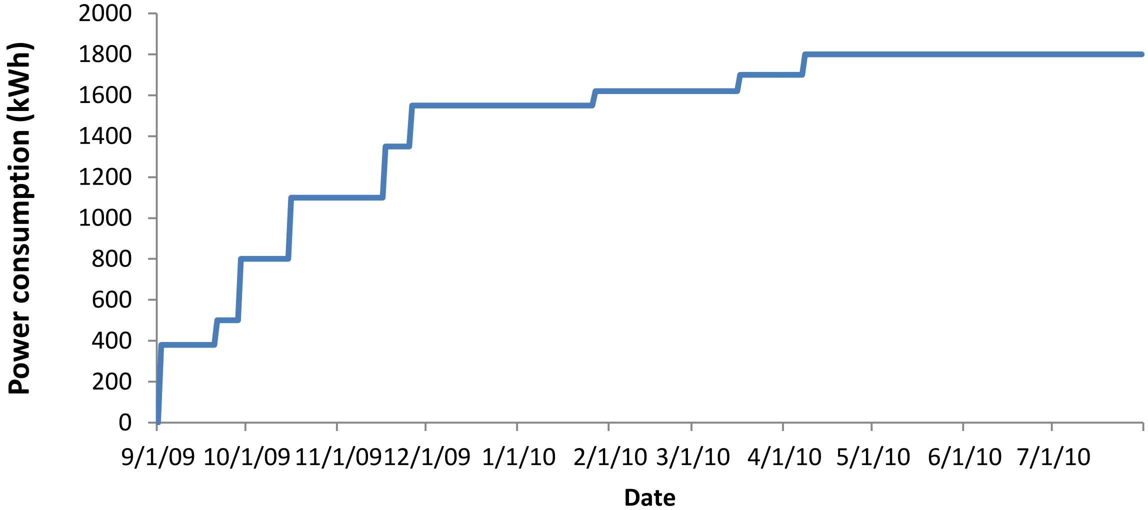


Figure III-18. Accumulated Daily Insect Population in Rice Stored until July 31st under Controlled Aeration Strategy.

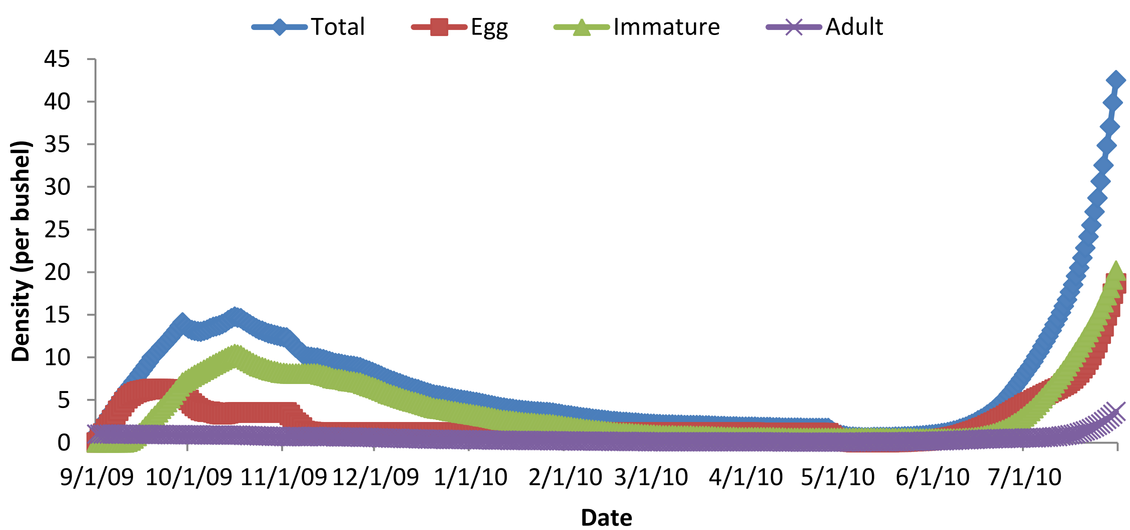


Figure III-19. Accumulated Daily Insect Population in Rice Stored until Dec. 31st under Sampling-Based Fumigation Strategy.

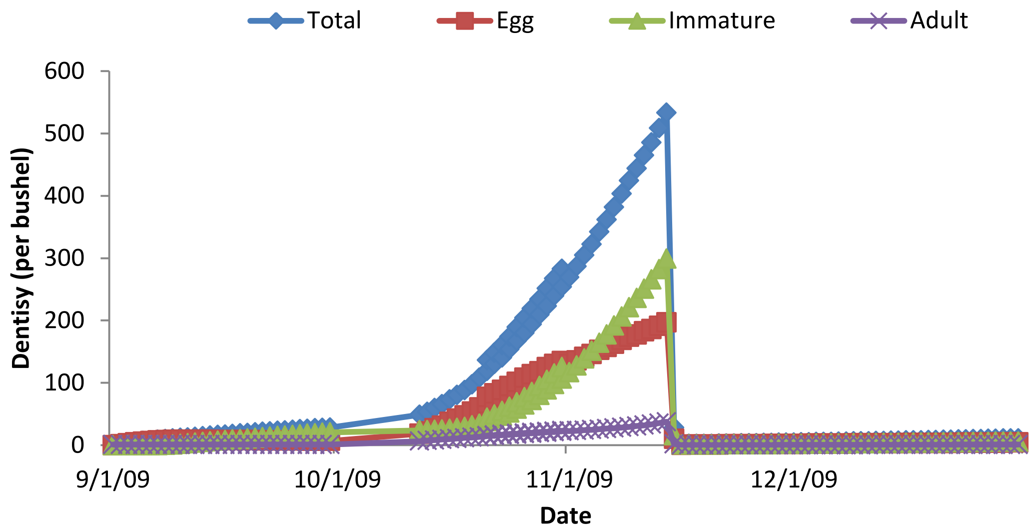


Figure III-20. Accumulated Percentage of Broken Kernels when Stored until Dec. 31st under a Sampling-Based Fumigation Strategy.

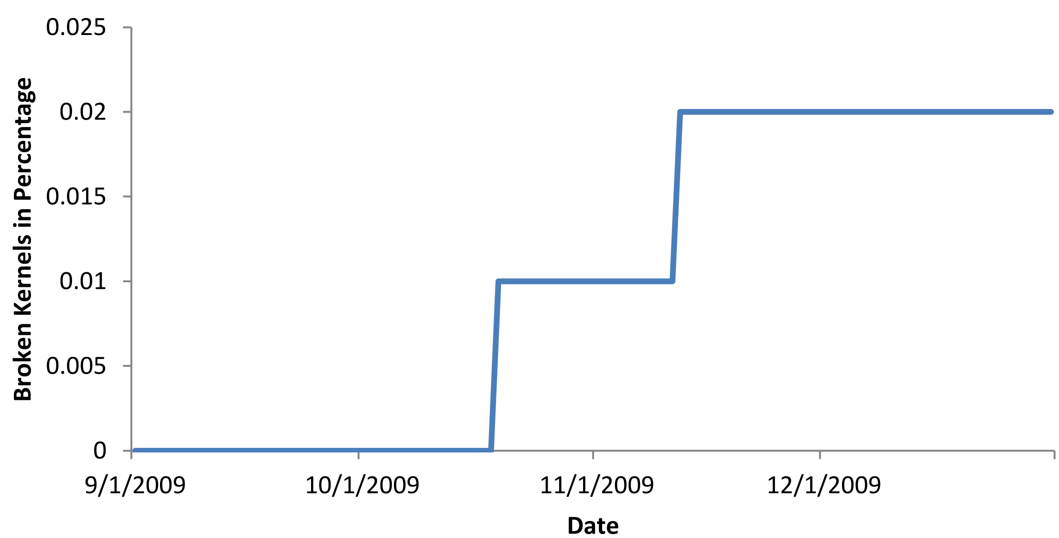


Figure III-21. Accumulated Daily Insect Population in Rice Stored until March 31st under a Sampling-Based Fumigation Strategy.

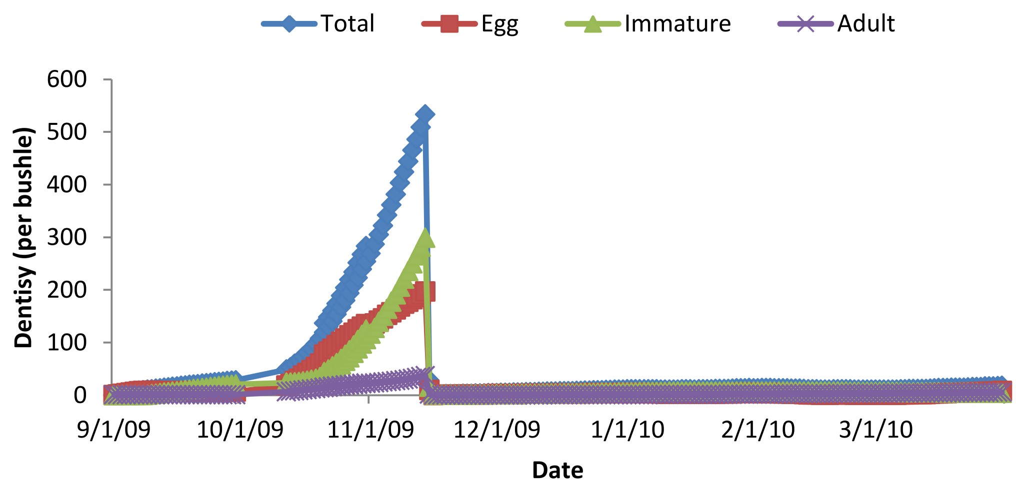


Figure III-22. Accumulated Percentage of Broken Kernels when Stored until March 31st under a Sampling-Based Fumigation Strategy.

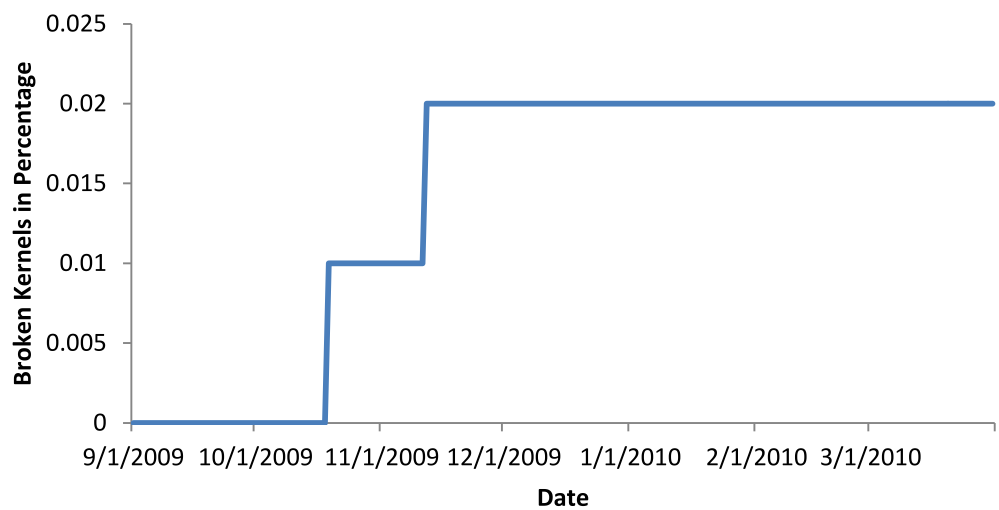


Figure III-23. Accumulated Daily Insect Population in Rice Stored until July 31st under a Sampling-Based Fumigation Strategy.

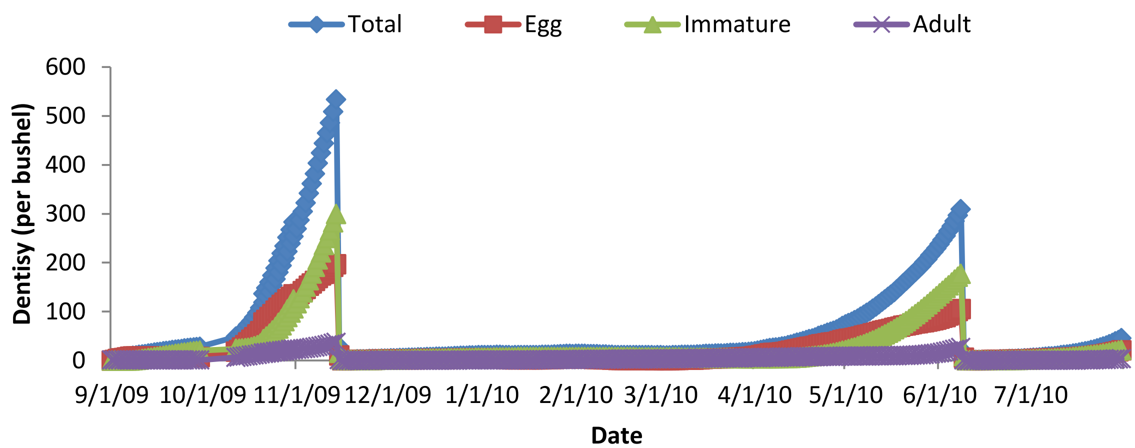


Figure III-24. Accumulated Percentage of Broken Kernels when Stored until July 31st under a Sampling-Based Fumigation Strategy.

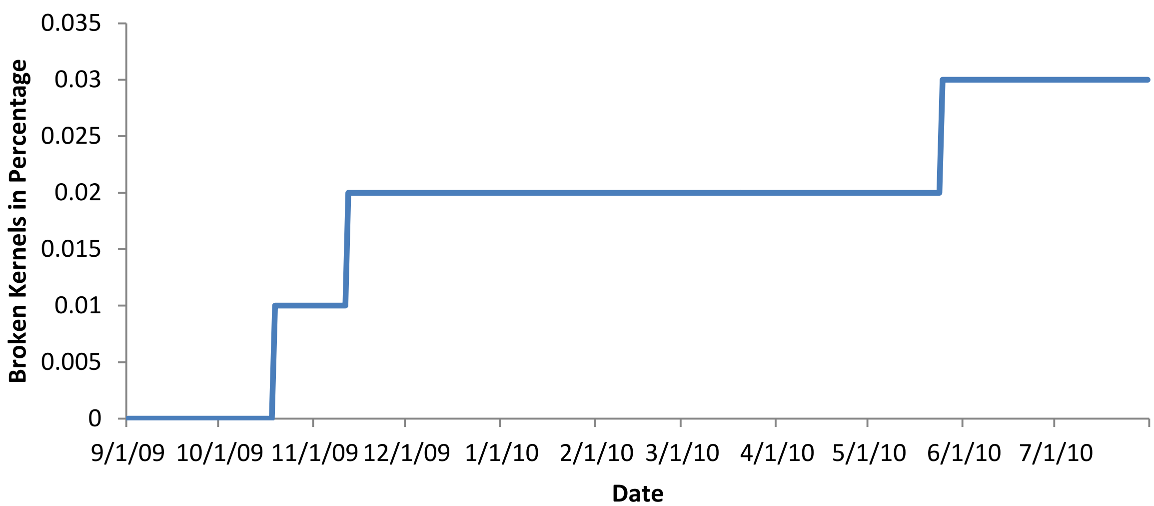


Figure III-25. Accumulated Daily Insect Population in Rice Stored until Dec. 31st under a Calendar-Based Fumigation Strategy.

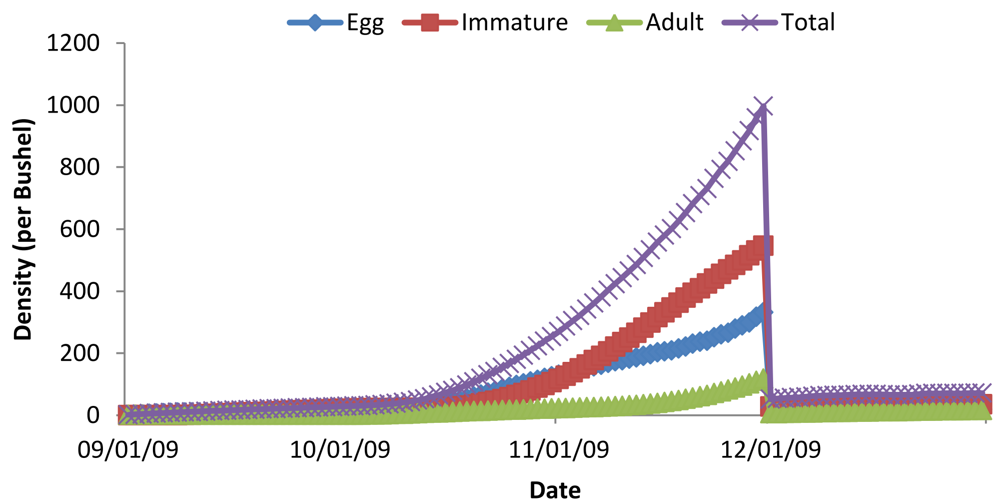


Figure III-26. Accumulated Percentage of Broken Kernels when Stored until Dec. 31st under a Calendar-Based Fumigation Strategy.

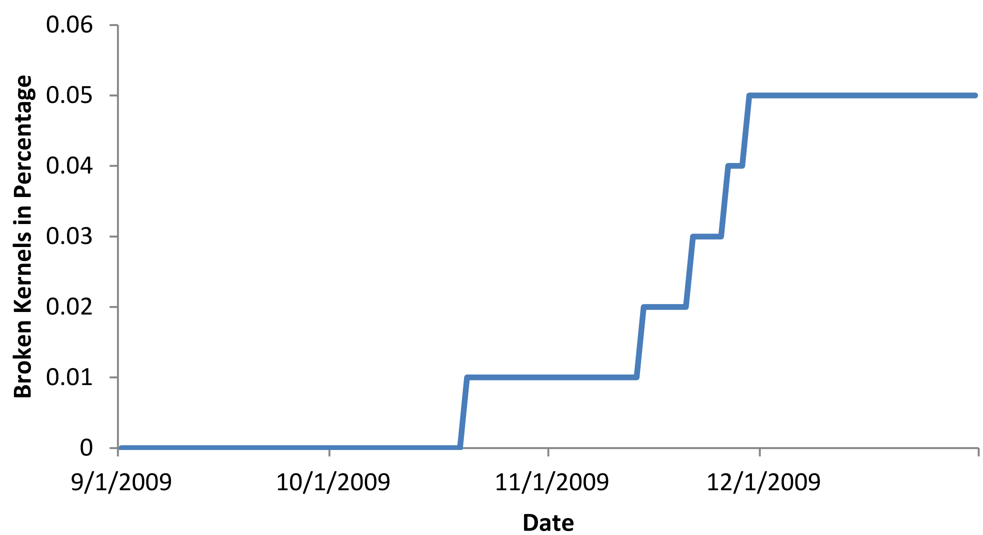


Figure III-27. Accumulated Daily Insect Population in Rice Stored until March 31st under a Calendar-Based Fumigation Strategy.

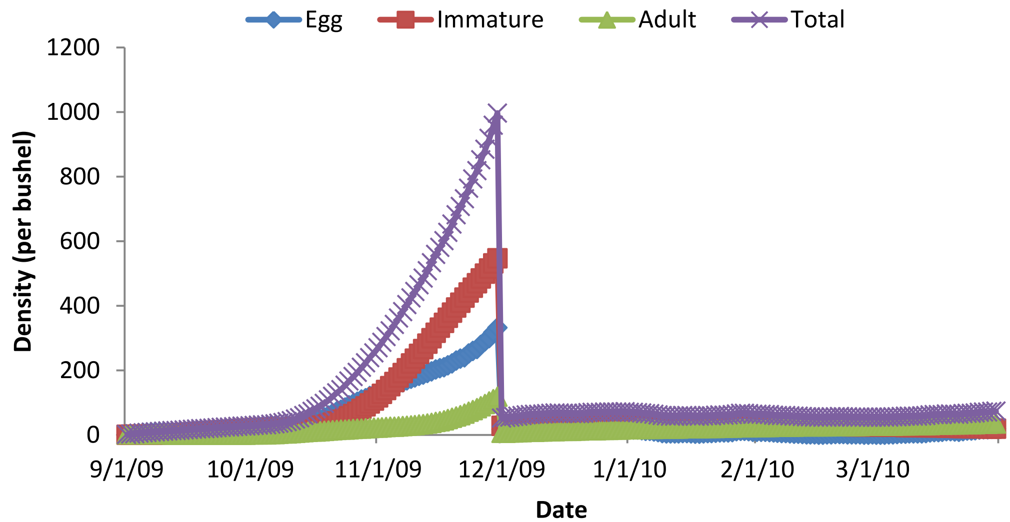


Figure III-28. Accumulated Percentage of Broken Kernels when Stored until March 31st under a Calendar-Based Fumigation Strategy.

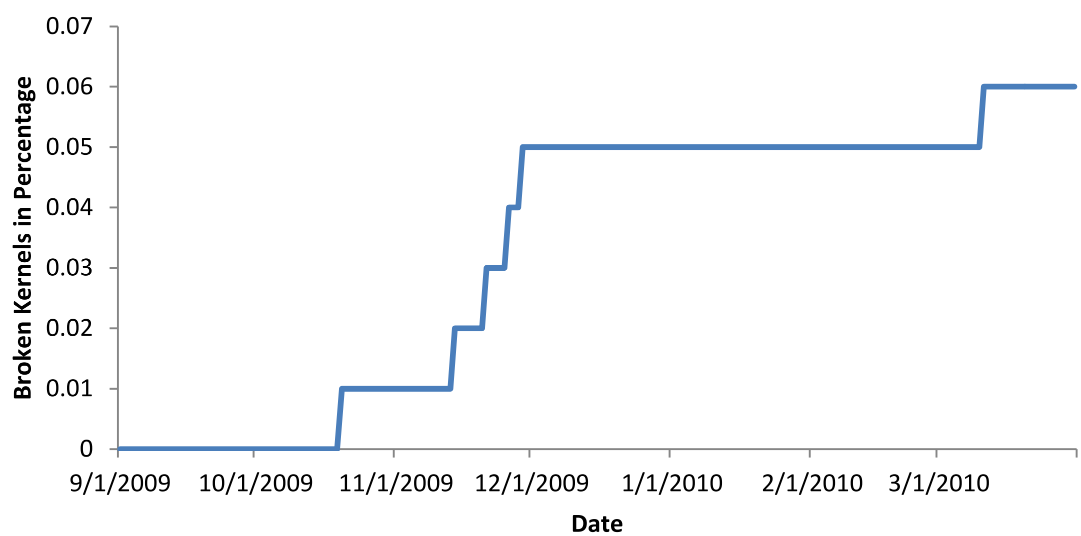


Figure III-29. Accumulated Daily Insect Population in Rice Stored until July 31st under a Calendar-Based Fumigation Strategy.

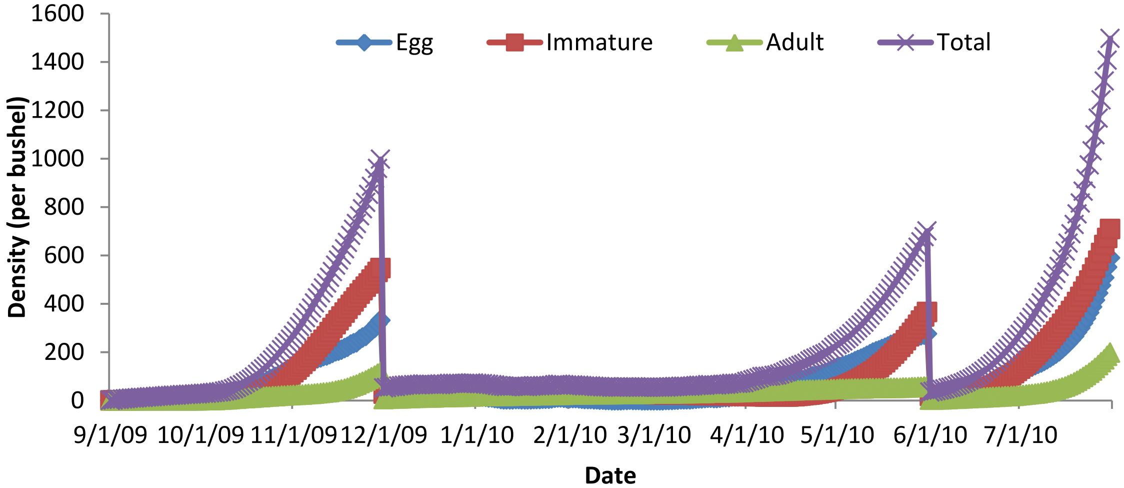
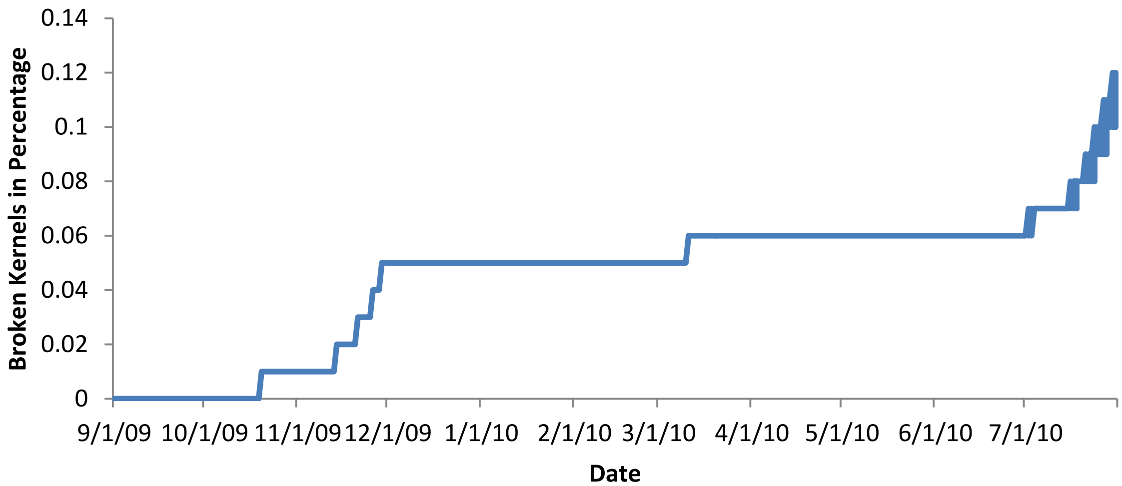


Figure III-30. Accumulated Percentage of Broken Kernels when Stored until July 31st under a Calendar-Based fumigation Strategy



VITA

Lianfan Su

Candidate for the Degree of

Doctor of Philosophy

Thesis: COSTS AND BENEFITS OF STORED RICE INSECT MANAGEMENT METHODS

Major Field: Agricultural Economics

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in December, 2011.

Completed the requirements for the Master of Science in International Studies at Oklahoma State University, Stillwater, Oklahoma in December, 2006.

Completed the requirements for the Bachelor of Science in International Trade and Economics at Nanjing Agricultural University, Nanjing, Jiangsu, China in 2004.

Experience:

Employed as a graduate assistant at Oklahoma State University; School of International Studies, 2005-2006.

Employed as a research assistant at Oklahoma State University; Department of Agricultural Economics, 2008-2011

Name: Lianfan Su Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: COSTS AND BENEFITS OF STORED RICE INSECT MANAGEMENT METHODS

Pages in Study: 145 Candidate for the Degree of Doctor of Philosophy

Major Field: Agricultural Economics

Rice quality is important to rice consumers. Insect infestation can significantly reduce the quality, and thus the economic value, of rice. It can also cause quantity losses. Traditional chemical-based pest management uses pesticides to control pests. However the public is increasingly concerned about potential adverse effects of pesticide use on humans and the environment. This challenges rice storage firms to adopt insect control methods which use fewer chemicals, such as integrated pest management (IPM) approaches.

The general objective of this study is to determine optimal insect control methods for rice storage firms. To achieve this objective, costs and benefits of IPM and non-IPM methods are compared. The non-IPM method considered is calendar-based fumigation, and IPM methods considered are controlled aeration and sampling-based fumigation. To measure benefits of each approach, a 2^{nd} -price auction and a choice experiment are conducted to elicit the value consumers place on rice stored using these storage management alternatives and the value they place on more effective insect control. Empirical results of the auction and choice experiment are compared and two potential reasons – anchoring and amount of information provided – are examined to explain possible discrepancies between the two methods. To measure costs of each approach, economic-engineering models are used to calculate expected treatment costs and insect growth models are applied to predict the costs of failing to control insects under the alternative insect control strategies.

Results indicate that even for fairly high insect infestation levels, participants, on average, were not able to distinguish among rice samples that had previously incurred alternative levels of insect infestation. However, after providing them with objective rice quality information, they were willing to pay a premium for rice with better insect control(less insect infestation). Also, they preferred rice stored with IPM methods. Participants' willingness to pay (WTP) for use of IPM methods was higher than costs of using IPM methods, estimated using economic engineering methods. Automatically-controlled aeration is less costly than other treatment methods when considering both costs of treatment and costs of failing to control insects. The cost of sampling-based fumigation is higher than calendar-based fumigation at this point. To capture benefits to consumers of adopting IPM methods, rice storage firms may need to contract with an independent agency to verify their storage management practices.

ADVISER'S APPROVAL: Dr. Brian D. Adam