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Farmers' Knowledge, Attitudes, and Control Practices of Rodents in an Agricultural Area of Taiwan

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Abstract: Rodents threaten agricultural industries and food security on a global scale. Rodent management practices routinely involve the use of chemical products, mainly anticoagulant rodenticides (ARs). An understanding of farmer rodent control behaviors is crucial in order to implement management changes to more environmentally friendly practices. In this study, we surveyed farmers in an agricultural area of northwestern Taiwan on their knowledge, attitudes, and control practices for rodent pests. From our survey sample of 126 farmers, rodents were perceived to be the most problematic for vegetable crops, followed by rice, and then fruit. Farmers in the oldest age group and those that perceived rodents to cause extensive damage to their crops were found to have the most negative attitudes toward the pests. One-third of the farmers in our survey stated they currently use rodenticides, with crop type, perceived problems caused by rodents, and attitudes toward rodents found to be important explanatory variables. Our results indicate that the use of rodenticides is reactive; farmers are more likely to apply the chemical products if they perceive rodents to cause damage. Additionally, cost–benefit assessments are likely important in governing rodent control behaviors; farmers may be more inclined to use control products that are subsidized by the government, which include ARs, when they observe damage to their crops inflicted by rodents. We also describe how ecologically based rodent management (EBRM) practices could be feasible and sustainable alternatives to rodenticide use.

Keywords: rodents; attitudes; knowledge; control; rodenticides; ecologically based rodent management (EBRM)

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1. Introduction

Rodents are one of the most widespread taxonomic groups of mammals spread throughout every continent except Antarctica. Rodents can fill a variety of niches in their respective communities, including seed dispersal, nutrient cycling, pollination, and prey for predators [1,2]. Their pervasiveness and ability to adapt to highly modified landscape and habitats has had its costs on human health, agricultural industries, and even infrastructure [3–5]. Some species of rodents can be commensals living in close proximity to humans, which can lead to issues for sanitation, food contamination, property damage, and disease risk [6,7]. Human health risks can be attributed to rodents harboring ectoparasites and having high reservoir competence for certain zoonoses, such as Lyme disease, scrub typhus, and hantavirus [4,8–10]. Therefore, it is not surprising that rodents are often perceived negatively and viewed as pests. In a more literal sense, rodents' pest-related activities have had devastating impacts on crop yields throughout Asia and on a global scale [11–14]. Crop yield losses usually range from 5–15% in most countries [12,15]. However, the losses can be more severe; in the Philippines, up to 50% yield losses of rice due to rodents have been reported [12,16].

To combat these pests, agricultural workers often use anticoagulant rodenticides (ARs) [17–19]. The initial ARs commercially available were first-generation anticoagulant rodenticides (FGARs) and included products such as warfarin [20,21]. The subsequent resistance of rodents to FGARs led to the development of second-generation anticoagulant rodenticides (SGARs), which have higher toxicity and potential for adverse environmental effects, such as residues in the soil and poisoning of nontarget wildlife [22,23].

Farmers' pest control practices and subsequent behavior may be governed by their experiences and attitudes throughout their agricultural careers [20,24]. Experiential factors, which can be based on a single or series of events, can predicate emotion and subjectivity. These emotions may then supersede rationality for decision-making [25,26]. For example, a negative experience with wildlife may facilitate strong adverse emotions thereby affecting decisions related to conservation and management [27,28]. Pertaining to agricultural behaviors, Petway et al. [29] determined that the most important factors for organic farming decisions were related to life experience and community patterns based on a survey conducted in western Taiwan. It has been posited that in order to design and implement changes to pest management, namely by reducing the usage of chemical products, the behaviors of farmers need to be understood so effective interventions and planning may be conceived [30].

In Taiwan, smallholder farm crops represent almost half of all agricultural products, and these include fruit (37.4%), vegetables (26.3%), and rice (15.3%) [31]. Rice is a vital food staple in Taiwan and the average annual yield amounts to 1.5 million metric tons [31]. Rice paddies cover around 400 kilohectares, almost half of the arable land in Taiwan [32]. The importance of plant crops toward Taiwan's agricultural industry and GDP as a whole has implications for pest management and the types of products applied. Historically in Taiwan, FGARs have been used since the 1950s to control rodents as pests in agriculture and in urban areas [21]. Efforts to control rodents increased in the 1980s with the launch of an anti-rodent campaign by providing SGARs to farmers free of charge annually in late autumn [33]. Because of wildlife conservation initiatives, the amount of free ARs provided by the government has decreased over the years, but they are still supplied to farmers upon request and can also be acquired by other means [34].

In this study, we surveyed farmers in an agricultural region with the use of a structured questionnaire and adopted the knowledge, attitude, and practices (KAP) framework. We collected information from farmers concerning their perceived knowledge of rodents as pests, their attitudes toward rodents, and their behaviors toward rodent control practices. Additionally, we sought to determine the relationships between sociodemographic factors, farming-related factors, attitudes toward rodents, and behaviors for rodent control (Figure 1). We expected that severity of rodent problem would influence attitudes toward rodents, which would also motivate the use of rodenticides. We also hypothesized that older farmers would have more negative attitudes toward rodents and be more likely to use rodenticides, since they belong to a generation that has been provided with both FGARs and SGARs, and experienced the anti-rodent campaign. This study provided novel information on modified habitat preference of rodents in Taiwan, how they are perceived as pests, and factors that may motivate farmers' rodent control behavior.

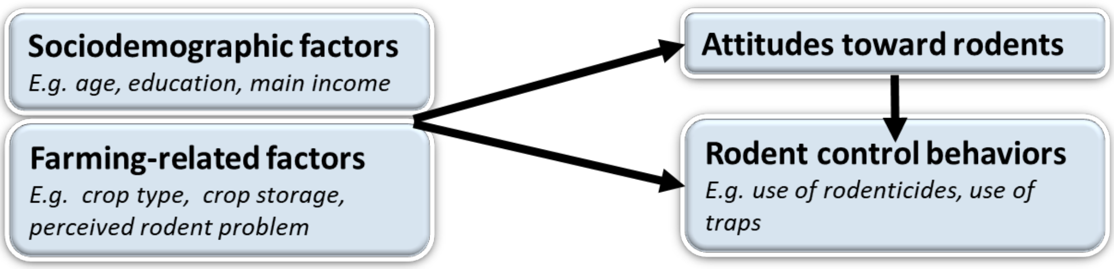

Figure 1. Conceptual framework for associations between different parameters of farmers from the survey (n = 126). Both 'sociodemographic factors' and 'farming-related factors' are delineated as independent variables. Arrows indicate potential explanatory power/influence.

2. Methods and Materials

2.1. Study Area

We conducted our survey in four townships, namely Tongxiao, Yuanli, Sanyi, and Zhuolan, of Miaoli County (24.56° N, 120.82° E), northwestern Taiwan (Figure S1) from June to October 2020. Miaoli County has extensive agricultural activity, which comprises a large component of its economy. The population of Miaoli is 548,863 and roughly 26% are involved in agricultural activities [35]. Additionally, 33% of the land is designated as farmland for agriculture [36]. The average farm size in Miaoli County is 0.79 ha, and designated as smallholder farms for commercial purposes [37]. Rodent species, including *Rattus losea* and *Apodemus agrarius*, known to be crop pests [38], are distributed throughout Miaoli County (I.N. Best, unpublished data).

2.2. Data Collection

A structured questionnaire was employed for this social survey (available from corresponding author upon request). Preliminary tests of the questionnaire were pretested on eight farmers to help identify any issues or lacking content. We collected data on sociodemographic variables of participants, information about their farms and farming practices, knowledge of rodent-related crop damage, attitudes toward rodents, and rodent control practices. Sensitive questions requesting specific chemical or brand names of rodenticides were excluded from the questionnaire since some have been banned. Furthermore, overly sensitive topics may discourage participants from answering questions truthfully or from completing questions altogether [39,40]. The questionnaire was designed to take a participant roughly 15 min to finish and was presented in Mandarin Chinese.

Most questionnaires were distributed with the assistance of the local farmer association centers in each township of the study area. The farmer association provides local services for farmers including technical advice and sale of farming materials. Since the association centers have regular contact with farmers, their aid in distributing the questionnaires helped us sample a large representation of farmers in our study area. We distributed 100 questionnaires each to the association centers in Sanyi, Zhuolan, and Yuanli, and 40 questionnaires in Tongxiao. Questionnaire responses were also collected by employing quasi-random sampling in the agricultural areas of the townships in our study area. Each questionnaire was joined with a cover letter, which made farmers aware of the scope of the project, anonymity and protection of participant identity, consent to participate in the study by completing the questionnaire, and the utilization of participant data strictly for the purposes of academic research. A total of 142 questionnaires were returned, but after data cleaning the responses from 126 completed questionnaires were retained.

2.3. Data Analysis

Farmers were categorized into three groups based on their main crop: rice, vegetables, and fruits. We assessed the perceived severity of problems caused by rodents; whether damage was afflicted to crops during the pre-harvest (growing) stage, post-harvest (storing) stage, or both. Because of the low frequency of post-harvest damage due to rodents (6.3%, $n = 126$), we combined pre-harvest-only and post-harvest-only problems. Therefore, for perceived rodent damage to crops (hereafter *rodent problem*) *singular* problems reflected damage caused during either the growing or storing stage of the crop, and *dual* problems were defined as damage caused during both stages. Cross tabulations were performed with chi-square tests to test for associations between *rodent problem* and the farming-related predictor variables crop type and crop storage. Please refer to Table 1 for a list of predictor variables and their definitions.

Table 1. Definitions for predictor variables associated with sociodemographic factors and farming practices of participants.

Predictor	Definition	Type of Variable and Subgroups
Age	Age of participant	Ordinal. 1 = 18–35, 2 = 36–55, 3 = 55+
Gender	Gender of participant	Nominal (binary). 1 = Male, 2 = Female
Education	Highest level of education participant has completed	Ordinal. 1 = Elementary school, 2 = High school, 3 = University/College, 4 = Graduate studies
Main income	The main income of the participant	Nominal (binary). 1 = Farming, 2 = Other
Own farm	Whether a farmer owns their farmland or not	Nominal (binary). 0 = No, 1 = Yes
Years farming [a]	The number of years a participant has been farming	Ordinal. 1 = 1–10, 2 = 11–20, 3 = 21–30, 4 = 30+
Pets	Whether a participant has pets (dogs and/or cats)	Nominal (binary). 0 = No, 1 = Yes
Farm animals	Whether a participant has farm animals	Nominal (binary). 0 = No, 1 = Yes
Crop type	The main crop grown by farmers grouped into categories	Nominal. 1 = Rice, 2 = Vegetables, 3 = Fruit
Crop storage	Whether a farmer stores their crops before distribution/sale	Nominal (binary). 0 = No, 1 = Yes
Rodent problem	The extent of problems caused by rodents	Ordinal. 0 = None, 1 = Singular (only problematic during growing or storing, not both), 2 = Dual (Problematic during both growing and storing)
Use of traps [a]	Whether farmers use any sort of trap for rodents, e.g., live or lethal	Nominal (binary). 0 = No, 1 = Yes

Note: [a] predictor variable not included in model construction for *rodent attitude (RA) score.*

Likert scale scores were used for the statements associated with attitudes toward rodents (Table 2), ranging from 1 (strongly agree) to 5 (strongly disagree). A sixth option (uncertain) was available on the questionnaire; however, these responses were omitted from the analysis.

Table 2. Principal component analysis (PCA) loading *rodent attitude (RA) score* component, mean Likert score, and distribution (%) of agreement of farmers for statements related to attitudes toward rodents.

Original Statement	*Rodent Attitude* Loading Score	Mean Likert Score (1–5) [a]	% of Farmers		
			Agree	Neutral	Disagree
Rodents are a major pest for my house	0.777	2.62	43.6	42.6	13.9
Rodents are a major pest for farming in my community	0.915	2.57	45.5	43.6	10.9
Rodents are a risk to people	0.795	2.29	64.4	29.7	5.9

Notes: [a] Likert scale has been reversed (1 = strongly agree 5 = strongly disagree) for lower scores to indicate negative attitudes; n = 101; 69.1% of variance explained by component (*RA score*).

The direction of the Likert scores was due to the wording of the statements—indicating agreement would suggest negative attitudes toward rodents. Therefore, a lower Likert score represented negative attitudes. In order to evaluate the distribution of agreement (in percentage of participants), the Likert scores were condensed into three categories: agree, neutral, and disagree. To measure participant internal consistency for these statements, an estimate of Cronbach's alpha [41] was determined ($\alpha = 0.735$). A principal component analysis (PCA) was performed to reduce the number of variables (statements with full Likert scale). We incorporated a varimax rotation in the PCA and only retained the components that explained most of the variance with eigenvalues greater than 1 (following the Kaiser–Guttman criterion [42]). One component was generated from the PCA and explained 69.1% of the variance (Table 2). The component reflected farmers' attitudes toward rodents (*RA score* hereafter), with lower values indicating negative attitudes and higher values positive. A main objective in this study was to determine important explanatory variables for farmers' attitudes toward rodents. We examined the relationships between predictor variables using Spearman rank correlation. We excluded predictor variables based on expert opinion and highly significant correlation with other variables to avoid redundancy and multicollinearity [43]. We performed model construction utilizing generalized linear models (GLM) with a Gaussian identity link function to determine what predictor variables best explained *RA score* [44]. Predictor variables that contributed the least to the model were sequentially removed and we evaluated changes in goodness-of-fit (refer to Table 3 for the initial model).

Table 3. Model outcomes of generalized linear models (GLM with linear function) by testing predictor variables (sociodemographic and farming-related variables) on *rodent attitude (RA) score*. The final model is indicated in bold.

Model	Predictor Variables	K	Log-Like	AICc	ΔAICc	w_i
9	**RA score ~ Age * + Rodent problem ****	**6**	**−93.95**	**201.09**	**0.00**	**0.60**
8	RA score ~ Age * + Crop type + Rodent problem *	8	−92.36	202.80	1.71	0.25
7	RA score ~ Age ** + Education + Crop type + Rodent problem *	11	−89.61	205.21	4.12	0.076
6	RA score ~ Age ** + Education + Own farm + Crop type + Rodent problem *	12	−88.71	206.21	5.12	0.046
5	RA score ~ Age ** + Education + Own farm + Crop type + Crop storage + Rodent problem *	13	−88.27	208.22	7.13	0.017
4	RA score ~ Age ** + Education + Own farm + Farm animal + Crop type + Crop storage + Rodent problem *	14	−87.72	210.10	9.01	0.0066
3	RA score ~ Age ** + Education + Own farm + Pets + Farm animal + Crop type + Crop storage + Rodent problem *	15	−87.30	212.35	11.26	0.0021
2	RA score ~ Age ** + Education + Main income + Own farm + Pets + Farm animal + Crop type + Crop storage + Rodent problem *	16	−87.30	215.51	14.42	0.00044
1	RA score ~ Age ** + Education + Gender + Main income + Own farm + Pets + Farm animals + Crop type + Crop storage + Rodent problem *	17	−87.30	218.79	17.70	0.000086

Notes: Model selection was based on Akaike's information criterion corrected for finite sample size (AICc). Model 1 represents the initial model considered. *K* = number of parameters included in model; Log-like = the maximized value of the log-likelihood function; ΔAICc = the difference in AICc values between a given model and the best candidate model (model with the lowest AICc value); w_i = Akaike weight. Significance is based on Wald chi-square tests: * $p < 0.05$, ** $p < 0.01$.

The Akaike information criterion corrected for small sample size (AICc) was used to rank the models, and the model with the lowest AICc score was selected as the candidate model. AICc ranking is commonly used for regression model selection and differences of 2 or more units between models represent significant improvement [45]. Post hoc analysis of main effects in the candidate model was performed with pairwise comparisons of estimated marginal means incorporating least significant difference (LSD).

To determine what factors contributed to whether farmers used rodenticides (hereafter referred to as *rodenticide use*), cross tabulations and chi-square tests were performed. *Rodenticide use* was dichotomous with 'yes' or 'no' as the possible responses. Because all the farmers that reported no perceived rodent problems for their crops also did not use rodenticides, we further analyzed a subset of our sample (i.e., only farmers that reported singular or dual problems due to rodents). We performed cross-tabulations and chi square tests between all predictor variables and *rodenticide use* for this subset of data (Table S3).

To address whether farmers' attitudes toward rodents influenced pest control behaviors, GLMs were used with a binomial logit link function for the variables *rodenticide use* and *use traps*. *RA score* was incorporated as a covariate in each model. The reference category for the models was set to the lowest value, which was 'no' for using the control products.

For all cross tabulations, when necessary, Fisher's exact tests were used for quality control of the data [46]. Normality of the GLMs performed was determined based on the residual of the models, with no assumptions violated. For each statistical analysis performed, significance was considered at $\alpha = 0.05$. All statistical analyses were completed with SPSS *v.27.0* (IBM, Armonk, NY, USA).

3. Results

3.1. Farmer Background Information

The majority of participants in our survey were male (67.3%, $n = 107$; Table S1). Most of the farmers stated their main income was from farming (74.6%, $n = 126$; Table S1). Over half of the farmers' main crop type was fruit (53.2%), followed by rice (27.8%), and then vegetables (19.0%, $n = 126$; Table S1). Most of the farmers stated they store their crops (79.4%, $n = 126$; Table S1).

3.2. Rodent Problems and Severity on Crops

More than half of the farmers (55.5%, $n = 126$) indicated rodents caused damage to their crops. About half of the farmers (49.2%, $n = 126$) indicated rodents caused damage to their crops during the pre-harvest, or growing, stage. Only 28.6% of participants stated that rodents caused damage during the post-harvest, or storage, stage for their crops. More specifically, 27.0% of farmers reported only pre-harvest problems, 6.3% reported only post-harvest problems, and 22.2% perceived rodents to cause damage during both stages ($n = 126$). *Rodent problem* was significantly associated with crop type ($\chi^2_4 = 12.88$, $p < 0.05$) and crop storage ($\chi^2_2 = 9.37$, $p < 0.01$). Farmers who grow vegetables reported the highest proportion of dual problems caused by rodents, followed very closely by rice, and then fruit (Figure 2A). Farmers who did not store their crops were more likely to have no crop damage from rodents (Figure S2).

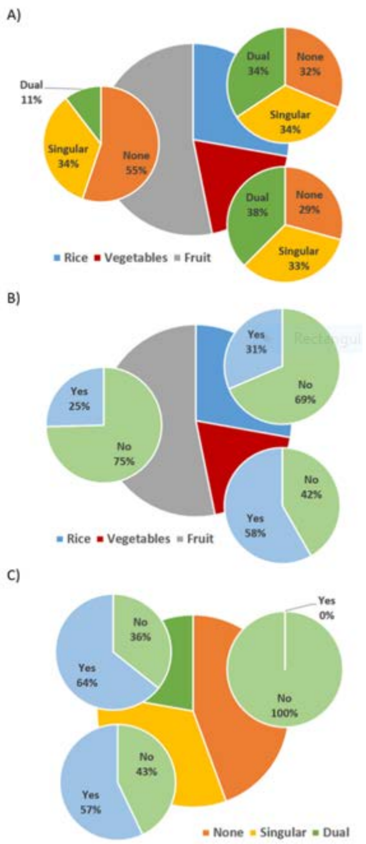

Figure 2. Comparisons of (**A**) crop type and perceived rodent problem, (**B**) crop type and rodenticide use, and (**C**) perceived rodent problem and rodenticide use. Percentages based on farmers' responses.

Smaller pie charts indicate distribution (%) for the subgroup it is overlapped with. Results based on cross-tabulations and chi square tests (Table 4).

Table 4. Chi-square test statistics determining associations between independent variables and 'rodenticide use'. Significance is indicated in bold.

Variable	*n*	χ^2	*df*	*p*
Age	120 [a]	3.79	2	0.151
Gender	107 [a]	0.15	1	0.696
Education	123 [a]	2.82	3	0.429
Main income	126	1.34	1	0.247
Ownership	124 [a]	0.40	1	0.528
Years farming	117 [a]	4.83	3	0.184
Pets	125 [a]	0.15	1	0.701
Farm animals	124 [a]	0.00	1	0.989
Crop type	126	8.72	2	**<0.05**
Crop storage	126	1.55	1	0.213
Use of traps	117 [a]	3.17	1	0.075
Rodent problem	126	50.79	2	**<0.001**

Notes: [a] indicates lower total *n* value due to missing data, participants left these questions blank.

3.3. Attitudes toward Rodents

Overall, participant attitudes toward rodents were negative based on the three statements included in the questionnaire (Table 2). The average Likert score (range = 1 to 5) for the three statements was 2.5 ± 0.1 (median = 2.7, IQR = 1.0, $n = 101$). The component *RA score* from the PCA was highly associated with all three statements (Table 2).

Based on our model selection for *RA score*, the delta AICc value between model 8 and model 9 was less than 2, however, we selected model 9 as the best-fitted candidate model since all predictor variables were significant (Table 3). Model 9 included the predictor variables age (Wald $\chi^2_2 = 7.04$, $p < 0.05$) and rodent problem (Wald $\chi^2_2 = 10.10$, $p < 0.01$; Table 3). Farmers in the age group 'above 55' and who perceived rodents to cause dual problems for their crops were found to have the most negative RA scores (Figure 3).

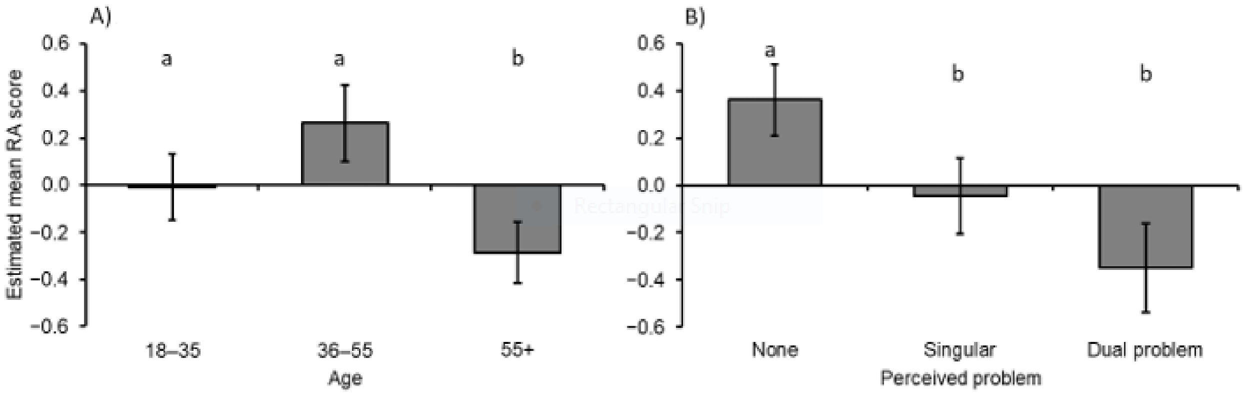

Figure 3. Estimated marginal mean rodent attitude (RA) scores of participants compared between (**A**) age groups and (**B**) perceived rodent problem. Negative values indicate negative attitudes, and values from 0 to positive reflect neutral/indifferent to positive attitudes. Error bars represent standard error of the mean. Differences in letters indicate significant differences based on post hoc analysis from best candidate model, $p < 0.05$ (Table 3).

3.4. Rodent Management Behavior

One-third of the farmers in the survey currently use rodenticides (33.3%, $n = 126$). Reasons provided by the farmers who currently do not use rodenticides include: products perceived as ineffective, not being necessary, environmentally friendly farming practices, and the belief that biological factors (e.g., predators) would control rodent populations

(Table S4). Around one-third of the farmers stated they use rodent traps, including both lethal and live traps (35.0%, n = 117). Only 15.4% of farmers reported using both traps and rodenticides to control for rodents.

When queried about how rodenticides are obtained (Table S5), the most common response from the farmers was requesting them from the government to be supplied for free (59.3%, n = 54). The most common consideration for which rodenticides to use (Table S5) was availability (26.3%, n = 76), followed by effectiveness (19.7%) and environmental friendliness (13.2%). On average, farmers spent NT$2111 (US$75) per year on rodenticides (n = 36). Moreover, 44.4% of these farmers spent nothing due to government subsidies for rodenticides.

Rodenticide use was significantly associated with crop type and rodent problem (Table 4). Farmers who grow vegetables, and reported dual rodent problems for their crops were more likely to use rodenticides (Figure 2B,C).

Moreover, all farmers that did not perceive rodents to cause any crop damage did not use rodenticides (Figure 2C).

For the subset of participants only including those who perceived rodents to cause damage to their crops, age and education were significant explanatory variables for *rodenticide use* (both $p < 0.05$, Table S3). Farmers in the oldest age group and with high school education were more likely to use rodenticides, whereas younger farmers and those with university-level education had the highest proportions for not using rodenticides (Figure S3).

Attitude toward rodents (*RA score*) was found to be a significant predictor for use of rodenticides. Farmers with negative attitudes were more likely to use rodenticides in their farming practices ($B = -0.79$, Wald $\chi^2 = 9.85$, $p < 0.005$, $EXP(B) = 0.45$; Figure 4). However, farmers' attitudes did not contribute to whether they use traps ($B = -0.20$, Wald $\chi^2 = 0.90$, $p = 0.34$, $EXP(B) = 0.82$).

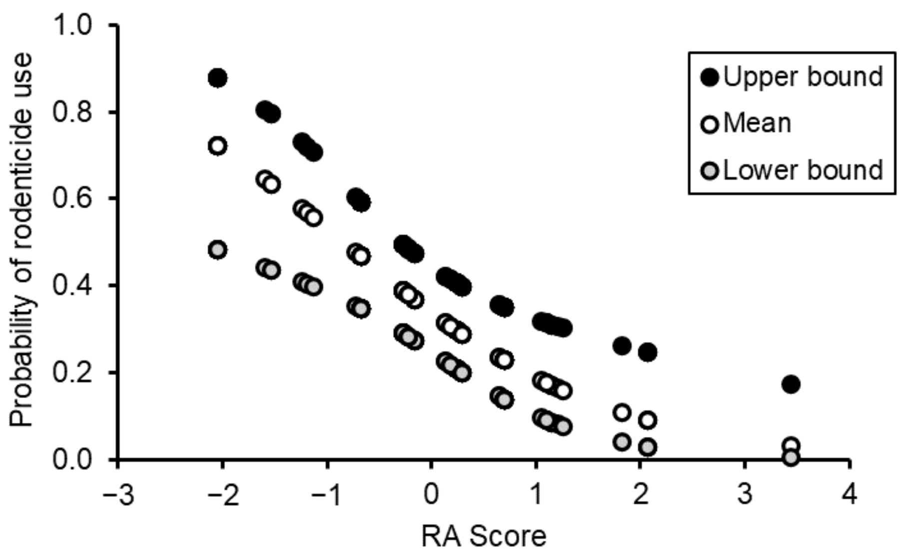

Figure 4. Probability of rodenticide use depending on rodent attitude (RA) scores of farmers. Mean refers to predicted value of mean response, lower bound refers to lower bound of 95% CI of mean, and upper bound refers to upper bound of 95% CI of mean; these values were determined from a GLM with binomial logit link function with *RA score* included as a covariate.

4. Discussion

4.1. Rodent Problems

More than half of the farmers indicated rodents caused damage to their crops. The crop type vegetables and rice were more likely to be afflicted by rodent pests compared to fruit. This survey has brought to attention agricultural systems and locales that are most at risk—vegetable crop fields and rice paddies. This finding is consistent with other studies that surveyed farmers in parts of Asia, where rodents were reported to be important pests for vegetable and rice production [16,47–51]. In this study, more farmers perceived rodents to cause damage during the growing stage, which is consistent with the review by John [11], who found that pre-harvest losses due to rodents can comprise a significant proportion of the overall yield losses. Because most of the farmers in this agricultural area are considered smallholder for commercial purposes, damage to their crops can affect their livelihoods.

4.2. Predictors of Attitudes toward Rodents

In the present study, almost two-thirds of the farmers agreed that rodents are a risk to people. This negative perception could arise from the potential of rodents transmitting zoonotic diseases [4,5,52]. If animals have the ability to cause harm, they may be stigmatized and perceived negatively [28,53,54]. However, further specific questioning in future surveys will be required to confirm this conclusion.

Farmer age had a significant effect on the variable *RA score*. In accordance with our hypothesis, the oldest age group (above 55) had the most negative attitudes toward rodents, which is a consistent finding in studies examining relationships between sociodemographic factors (e.g., age) and attitudes toward wildlife [28,55–57], especially when the wildlife in question are perceived as problematic [58,59]. Furthermore, the older farmers in our study may be more prejudiced toward rodents due to an increased likelihood of experiencing rodent population irruptions accompanied with devastating crop losses during their farming career [11], particularly since centralized anti-rodent campaigns were introduced and popularized in Taiwan starting in the 1980s [33]. As expected, farmers that reported dual problems due to rodents also had the most negative attitudes toward the pest. When wildlife are perceived as problematic or even threatening to one's livelihood, attitudes toward said wildlife are often prejudiced [56,60,61]. Personal experiences, such as crop loss due to rodent pests, can be powerful drivers for emotions and perceptions toward wildlife [26,28].

4.3. Determinants of Rodent Management

The results of this study indicate that cost–benefit assessments are largely important in the decision making of farmers' rodent control practices. For instance, the most common response for acquisition of rodenticides was requesting from the government and being supplied the product for free. Almost half of the farmers who stated they currently use rodenticides reported that they spend nothing on the products per year. Additionally, the most common consideration for which product of rodenticide to use was availability, which suggests that rodenticides used by farmers, such as specific products, may be influenced by what the government agencies are providing for free and the recommendations from the agencies. This would imply that many of the rodenticides in use would be SGARs, as those are commonly provided by the government presently [34]. Farmers who currently use rodenticides were not just as likely to use traps. Trapping rodents can be labor intensive and, thus, not cost effective [62]. If farmers are personally required to cover the expenses of traps, and deploy them, they may be less motivated to adopt this management practice. In accordance with our hypothesis, the farming-related factors, crop type and rodent problem, were important explanatory variables for *rodenticide use*. Farmers whose main crop is vegetables, which were also the most afflicted by rodent pests (highest proportion of dual problems), were more likely to use the chemical control products. Contrarily, all farmers that reported no perceived crop damage due to rodents do not currently use rodenticides. The significant association between *rodent problem* and *rodenticide use* likely indicates reactive and rationale responses for rodent management—application of rodenticides after crop damage has become visible. Similarly, other KAP studies have found farmers based their rodent control practices on observed crop damage [12,16,51,63]. The implications of 'reactive' rodent control coupled with the government-endorsed rodenticide programs in Taiwan (i.e., providing ARs for free), even if operating on a more limited capacity [34], could be continual use and application of these control products. The most cost-effective management practices are likely to be favorable among farmers, especially when they suffer economic losses to pests [64].

Among the farmers that do not currently use rodenticides, many based this decision on their perception that rodenticides are not very effective, as indicated from our results (Table S4). There is mounting evidence that supports this opinion [14]. For example, studies have found that rodents have developed resistance to certain FGARs and SGARs [20,65–67]. In Taiwan, the species *R. losea* and *A. agrarius* have shown variation in susceptibility to the FGARs warfarin and bromadiolone [68]. Additionally, in an experiment in Taiwan that tested the mortality of *R. losea* to the SGAR brodifacoum, it was found that the latency to mortality increased over the course of several years [69]. Concomitantly, individuals or even species of rodents may exhibit neophobia toward rodenticides, specifically via 'bait shyness' for novel foods or objects [14,17,70,71]. Therefore, according to the results of this study, if farmers perceive rodenticides to be ineffective or do not perceive rodents to cause damage to their crops, they are likely not to use rodenticides, which reaffirms that rodenticide use in this agricultural area is reactive.

Based on the subset of participants who perceived rodents to cause damage to their crops, age was significantly associated with rodenticide use. Farmers in the oldest age group (above 55) were more likely to apply rodenticides in their management schemes. Despite the lack of significance between years farming and rodenticide use, the farmers in the oldest age group in our study also had the most farming experience and, therefore, a higher likelihood of encounters with rodent population outbreaks during their farming careers. Other studies have also reported that the more years of experience a farmer has, the more likely they were to face pest outbreaks [63,72]. Additionally, in the present study, this group of farmers was likely active in agriculture during the anti-rodent campaigns initiated in the 1980s and predicated on the distribution and application of ARs [34]. Therefore, their current management programs may be based on these earlier control schemes, which were popularized by the government during that decade.

Attitudes toward rodents were linked to rodenticide use. Participants with negative attitudes toward rodents were more likely to apply rodenticides for management. It is well established that human behavior is associated with attitudes, and this can be heightened in wildlife management contexts [20,73,74]. In this study, there is evidence of a causal network between farming-related factors, attitudes, and rodent control behaviors (hypothesized in Figure 1). As mentioned above, many rodent management responses have been identified as reactive in Asia [11,12,75], which could help affirm that experiential factors motivate attitudes and directly or indirectly facilitate rodent control practices. These experiential factors would be derived from conflictive scenarios of rodents damaging crops resulting in crop loss and posing a risk to human health. Therefore, successful campaigns for shifts in rodent management to more environmentally friendly practices would need to provide favorable incentives, support, and informative suggestions for the stakeholders.

4.4. Alternatives for Rodent Management

Rodenticides, specifically ARs, can be extremely problematic for nontarget wildlife due to direct exposure through consumption of the poisonous baits or secondary exposure through the consumption of poisoned animals [76–78]. Therefore, alternative methods for rodent control are being proposed and developed [79]. Ecologically based rodent management (EBRM) aims to design and implement pest management strategies that reflect the ecology and biology of rodents and considers socioeconomic factors [79–81]. EBRM practices can also encourage farmers to work together at specific times during the year and to use nonchemical products, such as traps and organic lures [50,80]. Therefore, if the government-funded resources and support networks for farmers in Taiwan were to introduce platforms for the integration of EBRM, the reliance on chemical rodenticides could be reduced. The government-funded resources could provide educational guides on the ecology of rodent pests, strategic rodent control methods (e.g., time of year, areas of concentration), and subsidies for traps. The targeted placement of traps and/or lures in microhabitat type where there is expected to be more rodent activity could be an effective measure [75]. For example, Jones et al. [82] found that in an agricultural area of the Philippines *Rattus tanezumi* was more likely to visit baits and traps placed in the center of rice fields with more dense vegetation compared to the perimeter. In a rodent foraging behavior experiment, also conducted in Miaoli County, the rodent species *Rattus losea* and *Apodemus agrarius* concentrated their foraging activity under covered vegetation compared to exposed microhabitat (I.N. Best, unpublished data). Additionally, creating obstacles in the landscape surrounding cropland could be a deterrent; in a survey conducted by Brown and Khamphoukeo [50] farmers reported that they perceived digging ditches and burrows surrounding their rice crops to be an effective control strategy for rodents. The recruitment of actual predators of rodents to facilitate biological control could also be a beneficial tool for both pest management and biodiversity conservation. For instance, developing artificial perches for raptor species could be a cost-effective and straightforward approach for recruiting avian predators and increasing the risk for rodent pests and inducing spatial avoidance [75,83–85]. Additionally, further educating local communities in the agricultural areas of Miaoli on the relative importance of predators, including raptors and small carnivores, for regulating populations of rodents (providing biological control) could also be advantageous.

5. Conclusions

Our study has brought to attention that experiential factors, including perceived damage caused by rodents and farmers' attitudes toward the pest, likely facilitate their pest control practices. Moreover, the use of rodenticides may be a reactive measure, indicated by the severity of problems and damage inflicted by rodents, and also influenced by cost–benefit considerations, i.e., whether control products are subsidized and available at no charge. However, there is mounting evidence that the most effective rodent management involves a holistic approach with an understanding of the ecology of the pest. Therefore, the integration of EBRM could be a sustainable alternative. EBRM has been found to be effective in mitigating crop damage in other parts of Asia [50,86–88], and with proper training and support, it could be in Taiwan as well.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12051169/s1. Table S1: Sociodemographic factors of farmers and background information about participants' agricultural practices in four townships of Miaoli County. Table S2: Spearman rank correlation matrix of relationships between predictor variables. Two-tailed p values are displayed below coefficients. Table S3: Chi-square test statistics determining associations between independent variables and 'rodenticide use' of participants who perceived rodents to be problematic. Table S4: Reasons provided by farmers for not currently using rodenticides. Table S5: Methods of acquisition and considerations for which products of anticoagulant rodenticides to use reported by farmers. Figure S1: Map of townships Zhuolan, Sanyi, Yuanli, and Tongxiao in Miaoli County, Taiwan, where sampling for the survey was conducted. Figure S2: Comparison of crop storage and rodent problem. Figure S3: Rodenticide use of farmers compared between (A) age and (B) education. Subset of sample (n = 70): farmers who perceived rodents to cause damage to their crops

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Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to privacy restrictions.

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Abbreviations

FGAR	First-generation anticoagulant rodenticide
SGAR	Second-generation anticoagulant rodenticide
KAP	Knowledge, attitude, and practice
PCA	Principal component analysis
GLM	Generalized linear model
RA score	Rodent attitude score
AICc	Akaike information criterion corrected
LSD	Least significant difference
IQR	Interquartile range
EBRM	Ecologically based rodent management

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