horticulturae

Article

Adoption of Integrated Pest Management for Red Palm Weevil Control among Farmers in Saudi Arabia

Bader Alhafi Alotaibi, Ali Ahmed, Abdullah Awad Al-Zaidi and Hazem S. Kassem *

Department of Agricultural Extension and Rural Society, College of Food and Agriculture Sciences, King Saud University, Riyadh 11451, Saudi Arabia; balhafi@ksu.edu.sa (B.A.A.); alisalihe33@gmail.com (A.A.); azaidi@ksu.edu.sa (A.A.A.-Z.)

* Correspondence: hskassem@ksu.edu.sa; Tel.: +966-581045671

Abstract: The red palm weevil (RPW), *Rhynchophorus ferrugineus*, is widely considered to be highly invasive and the most damaging insect pest affecting palms in the world. Nonetheless, the prevention or significant slowing of the spread of RPW mainly relies on the application of integrated pest management (IPM) programs. This study aimed to evaluate farmers' adoption of RPW IPM practices and examine the differences in adoption according to the farmers' socio-economic attributes and their farm characteristics. The data were collected from 156 farmers through structured questionnaires by the Al-Kharaj governorate, Saudi Arabia. The findings showed that the farmers moderately adopted the categories of legislative control (54.77%) and cultural practices (50.44%), whereas they were showed a low-level adoption regarding the prevention, mechanical control, and chemical control categories. The cluster analysis revealed two variable farmer segments, "low adopters" and "moderate adopters", based on the average level of adoption of the 23 IPM practices examined. The cluster of "moderate adopters" accounted for 57.1% of the samples and had a higher average adoption in terms of all the practices investigated. Significant differences ($p < 0.01$) were found between the two groups of farmers, corresponding to their age, education level, farm size, farming experience, number of date palm trees on the farm, off-farm income, farming activities, source of irrigation, type of irrigation, growing of the 'Khodri' cultivar, growing of the 'Barhi' cultivar, and tree spacing. The results suggest that implementing campaigns to increase public awareness of the consequences resulting from the non-adoption of IPM, enhancing the participation of date palm farmers in the area-wide IPM strategy, and improving recognition behavior by detecting RPW with digital devices are useful actions.

Keywords: red palm weevil; integrated pest management; farmers; adoption; sustainable agriculture; agricultural extension; Saudi Arabia

Citation: Alotaibi, B.A.; Ahmed, A.; Al-Zaidi, A.A.; Kassem, H.S. Adoption of Integrated Pest Management for Red Palm Weevil Control among Farmers in Saudi Arabia. *Horticulturae* **2022**, *8*, 1005. https://doi.org/10.3390/horticulturae8111005

Academic Editor: Laura Warner

Received: 9 October 2022
Accepted: 26 October 2022
Published: 29 October 2022

1. Introduction

Date palm (*Phoenix dactylifera* L.) is the most important crop in Saudi Arabia, where it serves as a significant source of vitamins, minerals, and fiber [1]. In addition to being a very good source of food, dates provide various antioxidants that may help to prevent the development of certain chronic illnesses, such as diabetes, heart disease, cancer, and Alzheimer's [2,3]. According to the Ministry of the Environment, Water, and Agriculture (MEWA) report [4], there are over 31 million date palm trees in the country, covering an area of 107,000 hectares (ha). In 2021, Saudi Arabia ranked second after Egypt in the total production of dates, with an amount of 1.5 million tons. Moreover, dates are the key driver of Saudi Arabia's agricultural exports, since it ranked first in the export of dates in 2021, with an amount of 215,000 tons. Saudi Arabia is not only one of the leading producers of date palm but also one of the centers of diversity of this crop, which comprises 17 cultivars in the arid regions of the world, including the Middle East, North Africa, and the Arabian Peninsula [5]. Despite the significant increase in date palm production in Saudi Arabia, the average yield is low compared with other date-producing countries [6,7], mainly due to insect pests and plant diseases, poor management practices, and the low yield potential of certain cultivars [8,9].

Insect pests are a key factor affecting global food security [10,11] and are one of the main constraints on date palm production in Saudi Arabia [12]. Undoubtedly, The red palm weevil (RPW) *Rhynchophorus ferrugineus Olivier* (Coleoptera: Curculionidae) is among the world's most severe pest species affecting palms that causes considerable crop losses [13,14]. The cryptic life of weevils occurs inside the palm truck, leading to the infested palm's collapse and death by destroying the palm trunk's vascular system [15]. This invasive pest was first reported in South Asia as a pest of coconut (Cocos nucifera) [16], and it has become the major pest of 40 palm species belonging to 23 different genera worldwide [17]. In Saudi Arabia, it was first detected in approximately the mid-1980s in the eastern part of the country [18] and then spread to other date-growing areas, mainly through infested planting materials transported for landscape gardening and farming [19].

Due to the global seriousness of RPW, the FAO has identified it as a 'category-1' insect pest of date palm in the Gulf region [20]. In its 'Rome Declaration' in March 2017, the FAO expressed the urgent need for RPW's eradication by unifying the efforts between date palm farmers and the agricultural organizations in palm-growing countries [21]. The numbers of infested date palm trees by RPW are rising rapidly. According to the MEWA's statistical book of 2020, the number of infested trees in 2020 was 382, 500, compared to 80,000 in 2017 [22], and this is not to mention the overall economic loss due to the management and eradication of RPW in date palm, which is estimated to be more than USD 8.69 million every year [23]. In Saudi Arabia, date palm is a historical fruit that is grown predominately by different categories of farms of various sizes all over the region [24]. Therefore, prompt and serious action with respect to RPW control should be implemented, since, if left unattended, this invasive pest may threaten the livelihood security of palm-farming communities [25].

The control of RPW primarily relies on the use of synthetic pesticides [26]. However, such practices are not sustainable, deteriorate environmental quality, endanger biological diversity, and have negative effects on human health [27,28]. Furthermore, Al-Ayedh et al. [29] argued that synthetic pesticides do not provide adequate control of RPW. These setbacks have led to a growing demand for the implementation of an integrated pest management (IPM) strategy for date palm pests [30,31]. This strategy depends upon the utilization of all possible control strategies, including cultural techniques, ecosystem health techniques, and biological and chemical techniques, in order to encourage the reduction in pesticides while maintaining the crop yield, quality, and profits [32,33]. The current RPW IPM strategy is based on several components, including periodic field surveys for detecting infestations, the removal of severely infested palms, pheromone trapping, maintaining crop and field sanitation, preventive and curative chemical treatments, phyto-sanitation and agro-techniques (treating hidden breeding sites, including neglected and closed gardens, palm and field sanitation, and palm injury prevention), and training and supplementary education [19,34]. Nevertheless, farmers should adopt such components to ensure the effective control of RPW and, in turn, achieve environmental sustainability and a secure livelihood in rural areas [14,25].

Adopting RPW IPM concepts and practices might increase the overall resilience of farms and enhance the natural capital while ensuring the financial capital of palm farmers [35–37]. Despite the fact that, today, many RPW preventive and curative measures are in place, they have not achieved the expected outcomes, and their application is still partial and jeopardized due to several challenges [20,38,39]. The challenges in managing an RPW IPM strategy in most of countries can mainly be addressed by the better involvement of all the stakeholders in awareness and capacity-building activities; enhancing research in the field of biological control and early detection technologies; the evaluation of preventive, curative and eradication treatments; better enforcement of quarantine measures; and the assessment of the role of agricultural practices in RPW control [39–41].

To foster and encourage the application of RPW IPM programs that suit the farming context in developing countries such as Saudi Arabia, an analysis of farmers' patterns in adopting the different components of these strategies is crucial [37,42]. Evidently, determining the adoption gap is vital for enhancing the RPW IPM programs by adapting the RPW management practices to local farming systems [43,44]. Meanwhile, it is also important to develop awareness campaigns and extension programs [45,46]. Limited studies at the local and international levels were available to analyze the adoption rate of RPW IPM among farmers and the ways in which their socio-economic attributes can influence this rate. Only one empirical survey [25] performed in Saudi Arabia on this topic studied the nexus between farmers' adoption of RPW IPM and their knowledge of the symptoms. In light of ongoing justifications, the literature fails to cover this topic. Therefore, this study aims to analyze the actual adoption rates of RPW IPM practices. Moreover, it seeks to determine the differences in adoption based on the farmers' socio-economic attributes and farm characteristics.

2. Materials and Methods

2.1. Description of the Study Area

The present study was carried out in the Al-Kharj governorate (24.1589° N, 47.3279° E), as shown in Figure 1. The Al-Kharj governorate is located in the Riyadh Region in central Saudi Arabia, located around 100 km from the capital, Riyadh. In terms of its administration, the governorate is comprised of 21 districts. Three districts were selected randomly for the data collection in the northern and central parts of the governorate, namely, Al-Rafiaa, Al-Hyathem, and Naajan. The total area of the governorate covers 19,970 km^2, equivalent to 5% of the Riyadh Region's total territory. Out of this area, agricultural lands occupying about 40,000 hectares are distributed over 7112 farms [47]. According to the General Authority of Statistics report [48], the population of the Al-Kharj governorate in 2017 was 332,243, representing approximately 4% of the Riyadh Region's population and 0.97% of the overall population of Saudi Arabia. The climate of the governorate is continental, being dry and cold throughout the winter and hot throughout the summer, with the annual mean temperature ranging between 5°–18° Celsius (C) in winter and 31°–48° in summer. Moreover, the annual rainfall ranges between 95 and 185 mm [49]. Date palm is the most important crop cultivated in the study area. Other crops, including alfalfa and wheat, are cultivated, as well as vegetables in open fields and greenhouses (tomatoes, cucumber, pepper, squash, lettuce, eggplant, watermelon, and cantaloupe) [47]. Groundwater wells are the main source of irrigation in the governorate. Additionally, there are some natural springs used to supply some agricultural lands with water through a set of channels [50].

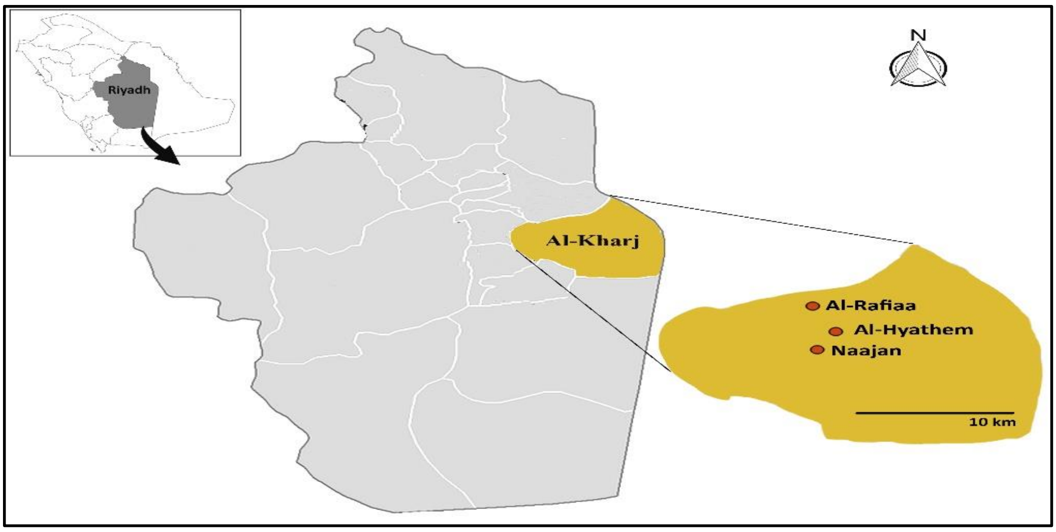

Figure 1. Map of the study area showing the selected districts.

2.2. Sampling Procedures

The population of the study consisted entirely of small-scale date palm farmers (<10 hectares) in the three districts of the governorate in the agricultural season of 2019/2020 (N = 856). Following Yamane's [51] sample size determination formula, systematic random sampling was employed to select a total of 165 respondents from the selected districts, as indicated in the formula below:

$$n = \frac{N}{1 + N(e^2)} \quad (1)$$

where n = sample size, N = the total number of respondents, e = accepted sampling error (5%), and N = 856. Therefore,

$$n = \frac{856}{1 + 856(0.05^2)} = 272 \quad (2)$$

The farmers were listed according to their farm numbers. After determining the sampling fraction (3) by dividing the population by the sample size, we selected every 3rd number to obtain a sample consisting entirely of the respondents. As we needed to select three farmers from every ten on the list, we depended upon the 3rd farmer as the starting point and then selected every 3rd farmer from that point. If a randomly selected respondent was not available during the data collection, the next consecutive farmer on the list was invited for the survey.

2.3. Survey Data Collection

The survey was performed between October and December 2019. Face-to-face interviews were conducted based on the sample identified using structured questionnaires. Of the 272 questionnaires sent to the farmers, 156 questionnaires were returned, representing a response rate of 57.3%. The questionnaire included two sections. The first section focused on collecting information on socio-economic and farm characteristics, while the second section explored the farmers' level of adoption of pest management practices for RPW. The index of the IPM practices consisted of 23 practices grouped into four categories: prevention (five practices), legislative control (five practices), cultural practices (four practices), mechanical control (six practices), and chemical control (three practices). These practices were adopted based on a previous study conducted in Saudi Arabia in the same field. The data collection tool was first prepared in English and then translated into Arabic. To ensure the content validity of the tool, five experts in the plant protection department of King Saud University were selected to revise the contents and assess their suitability in the Saudi context. Moreover, a pilot test was conducted on ten farmers in the study area prior to the data collection. All suggestions and comments were revised and addressed in the final draft of the questionnaire. Using Cronbach's alpha test, the reliability of the IPM scale for RPW was examined (0.88), indicating that the data had relatively high internal consistency.

2.4. Variable Measurement

A five-point Likert scale ranging from 1 = never to 5 = always was used to assess farmers' level of adoption of RPW control. The farmers' level of adoption of each practice was calculated using the relative weight (%), as follows [52]:

$$\frac{\sum Pi \times wi}{\sum n \times Wmax}$$

where Pi = each parameter amount (frequencies in each category); wi = each parameter weight; n = the sample size; and Wmax = the maximum weight of the parameter.

Similarly, the overall adoption score for each category was summed and converted into a percentage. The farmers' adoption was classified into three categories: low adoption if it was less than 50%; moderate if it was between 50 and 75%; and high if it was more than 75%.

2.5. Data Analysis

The statistical techniques in this study were performed using the Statistical Package for Social Sciences (ver. 25.0, IBM Corp, Armonk, NY, USA). Descriptive statistics such as frequency distributions, percentages, and the arithmetic mean were used to analyze and report the responses of the respondents. Agglomerative hierarchical cluster analysis was also used to identify the similarities/differences between the studied practices with respect to the average score of adoption [53]. The Euclidean distance was employed in this paper as a dissimilarity measure, and Ward's method was applied for the hierarchical clustering of the practices. The Mann–Whitney test was then implemented in order to identify statistically significant differences between the two groups identified in the cluster analysis [54]. Furthermore, the chi-squared test of independence was used to examine the differences between clusters regarding the farmers' socio-economic attributes and farm characteristics [55]. A graphical representation of the results of the cluster analysis, including a dendrogram and a heatmap, was created using BioVenci (ver. 2; BioTuning Corp., San Diego, CA, USA).

3. Results

3.1. Profile of the Respondents

The socio-economic profile of the farmers interviewed is presented in Table 1. The results showed that less than half of the respondents (45.7%) were aged between 40 and 60 years, with the mean age of 56.35 years. Most farmers (51.9%) had less than seven years of education, while only 10.9% of them had more than 12 years. The farming experience of the farmers ranged between a minimum of 8 years and a maximum of 65 years, with an average mean of 25.71 years of experience. On average, the farmers managed 2.8 ha of farmland and 628.33 trees on their farms. Most of the farmers interviewed (59%) had off-farm incomes. A minority of the respondents (9%) had had frequent contact with extension services for RPW control in the last three years. Regarding the farm characteristics (Table 2), the findings also revealed that 50% of the farmers cultivated both date palm and vegetables, 23.1% cultivated date palm only, 18.6% cultivated both date palm and field crops, and 8.3% cultivated vegetables, field crops, and vegetables. The farmers mentioned surface water and ground water as the main sources of irrigation in the study area, with the percentages of 34.6% and 65.4%, respectively. Furthermore, more than half of the respondents (57.7%) used drip irrigation on their farms, while 42.3% of them used flood irrigation. Among the five cultivars grown on the date palm farms, the 'Khalas' and 'Khodri' cultivars were the most frequent cultivars, with the percentages of 83.3% and 80.8%, respectively. Finally, a small proportion of farmers (12.2%) followed the recommended spacing between date palm trees (8×8 m^2), according to the documented cultivars in this study and the farming context in the study area.

Table 1. Socio-economic profile of the respondents.

Farmers' Characteristics	Number of Farmers (n = 156)					
	Frequency	**%**	**Min.**	**Max.**	**Mean**	**Standard Deviation**
Age						
Less than 40 years	22	14.1				
40–60 years	71	45.5	28	80	56.35	13.67
More than 60 years	63	40.4				
Education						
Less than 7 years	81	51.9				
7–12 years	58	37.2	0	16	8.11	4.26
More than 12 years	17	10.9				

Table 1. *Cont.*

Farmers' Characteristics	Number of Farmers (n = 156)					
	Frequency	%	Min.	Max.	Mean	Standard Deviation
Farming experience						
Less than 20 years	61	39.1	8	65	25.71	17.78
20–30 years	59	37.8				
More than 30 years	36	23.1				
Farm size						
Less than 3 hectares	92	59.0	1	8	2.80	1.61
3–5 hectares	47	30.1				
More than 5 hectares	17	10.9				
Number of date palm trees on the farm						
Less than 500 trees	92	59.0	200	4000	628.33	364.25
500–1500 trees	33	21.2				
More than 1500 trees	31	19.8				
Off-farm income						
Yes	92	59	0	1	0.58	0.36
No	64	41				
Attending extension activities for RPW in the last three years						
Frequently	14	9.0	1	3	1.37	0.64
Sometimes	30	19.2				
Rarely	112	71.8				

Table 2. Descriptive summary of farm characteristics.

Farm Characteristics	Frequency (n = 156)	%
Crops		
Date palm only	36	23.1
Date palm and vegetables	78	50.0
Date palm and field crops	29	18.6
Date palm, vegetables, and field crops	13	8.3
Source of irrigation		
Surface water	54	34.6
Groundwater	102	65.4
Type of irrigation		
Flood irrigation	66	42.3
Drip irrigation	90	57.7
Cultivars *		
Khodri	130	83.3
Barhi	93	59.6
Shishi	81	51.9
Khalas	126	80.8
Salg	28	17.9
Tree spacing		
4×4 m^2	24	15.4
5×5 m^2	33	21.2
6×6 m^2	44	28.2
7×7 m^2	36	23.0
8×8 m^2	19	12.2

* More than one answer was allowed; percentages of categories do not add up to 100.

3.2. Farmers' Adoption of IPM for RPW Control

The results regarding the adoption of preventive measures for RPW control are depicted in Figure 2. The results in Figure 2 show that the preventive measures examined were considered as a low level of adoption. The range of adoption ranged between a maximum relative weight of 47.65% for the practice of "removing offshoots" and a minimum of 35.51% for the practice of "using pheromone traps". The adoption of the legislative control measures investigated ranged between moderate and low levels of adoption (Figure 3). The results in Figure 3 indicated that the practice of "not allowing anyone to transfer infested offshoots from an infested farm" was the highest adopted measure, with a relative weight of 69.11%, while "burning and burying the infested palm" was the measure least adopted by the respondents (41.66%). In the same vein, the farmers' adoption of cultural practices ranged between moderate and low levels (Figure 4). However, the importance of maintaining the recommended distance between trees had a low level of adoption (49.48%). By contrast, the other cultural practices were moderately adopted.

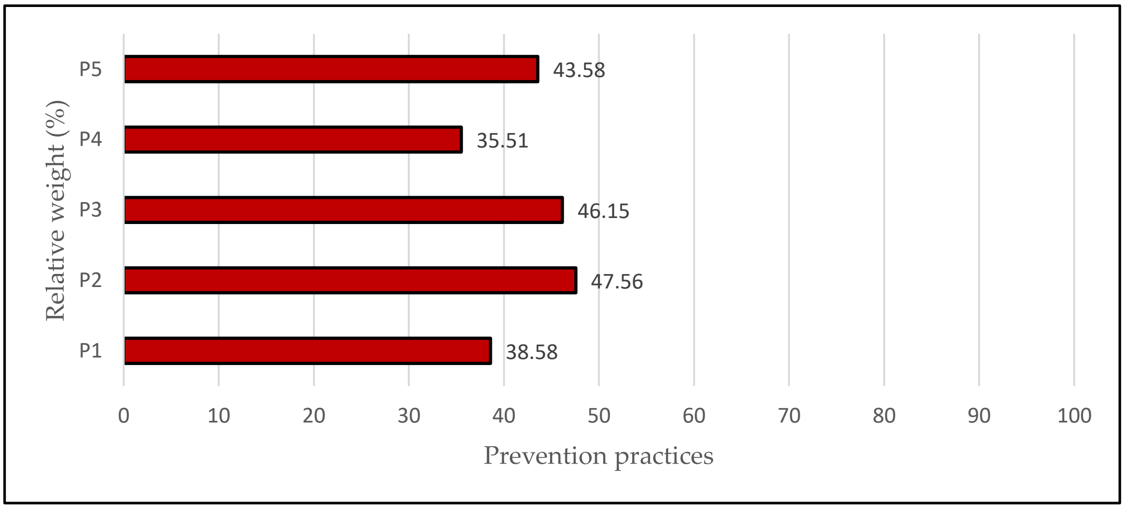

Figure 2. Farmers' adoption of prevention practices for red palm weevil control. (P1 = checking trees at regular intervals to detect early infestation, P2 = removing offshoots as a protective measure, P3 = removing fonds by applying pruning in the winter, P4 = using pheromone traps to detect early infestation, P5 = treating wounds resulted from the removal of frond bases and offshoots using contact pesticides).

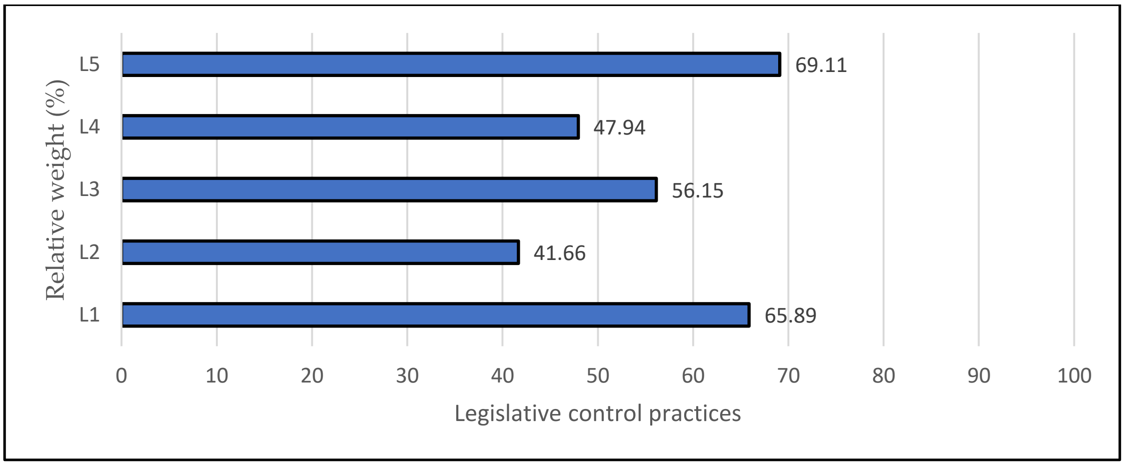

Figure 3. Farmers' adoption of legislative control practices for red palm weevil control. (L1 = adhering to the measure against transferring infested trees or offshoots to non-infested areas, L2 = burning and burying the infested palm far away after cutting it into small portions, L3 = adhering to the measure against transferring infested palm waste to other areas, L4 = surveying RPW-infested palms and informing the authorities when necessary, L5 = not allowing anyone to transfer infested offshoots from an infested farm).

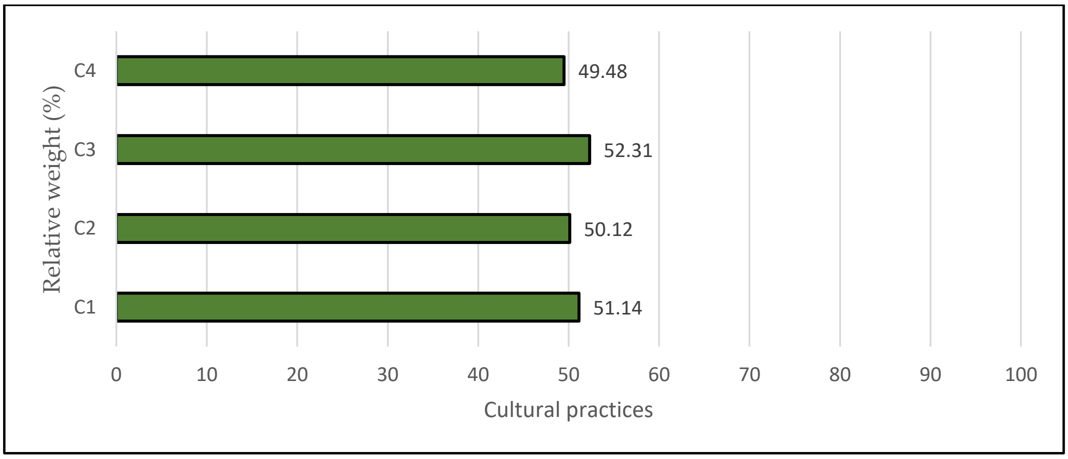

Figure 4. Farmers' adoption of cultural practices for red palm weevil control. (C1 = adhering to the time and depth specified for planting offshoots, C2 = applying moderate irrigation to reduce humidity on farms, C3 = adhering to good plowing before planting, C4 = maintaining the recommended distance between trees).

The findings also revealed that three practices out of the six mechanical control practices examined in this study were moderately adopted by the farmers, while the other practices were considered as having a low level of adoption (Figure 5). The mechanical control practices with the highest relevance rankings in the order of their adoption were eradicating infested palms (61.92%), removing weeds and dry trunks and disposing of them (49.61%), closing all openings on the trunks of palms (44.35%), scraping infested areas until healthy tissue is exposed (42.69%), removing infested or dead trees and the pruning products on neglected farms (40.38%), and covering the roots of small trees with soil to a height of 20 cm (37.69%). However, the assessment of the three statements pertaining to chemical control practices (Figure 6) demonstrates that farmers considered the adoption of chemical control practices (i.e., dusting farms, spraying pesticides of various quantities and qualities within the specified time, and spraying according to the extension recommendations) as being a low-level requirement (relative weight < 50%).

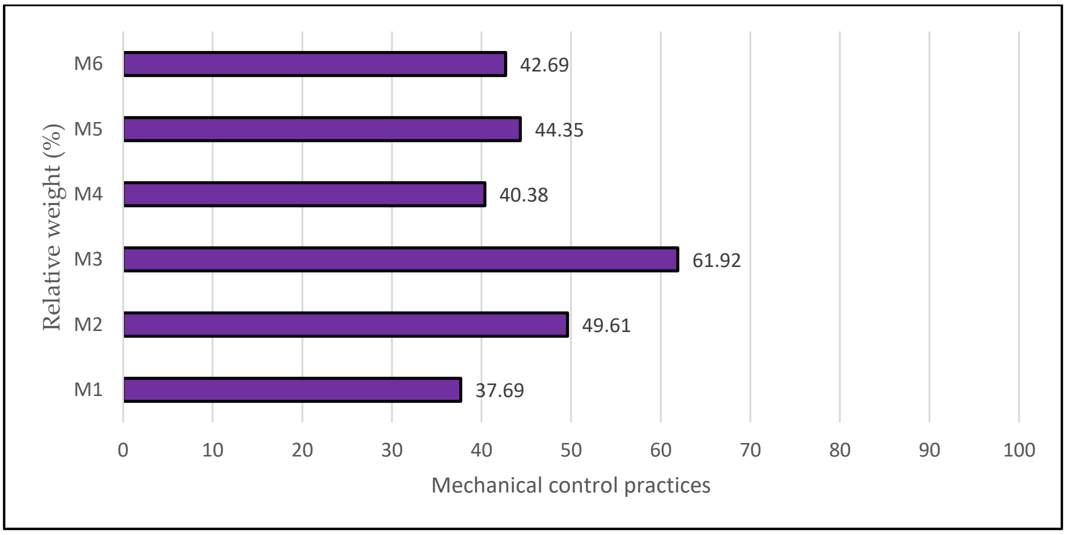

Figure 5. Farmers' adoption of mechanical control practices for red palm weevil control. (M1 = covering roots of small trees with soil to a height of 20 cm to prevent insect attacks, M2 = removing weeds and dry trunks and disposing of them in the recommended way, M3 = eradicating infested palms, M4 = removing infested or dead trees and the pruning products on neglected farms, M5 = closing all openings on the trunks of palms, M6 = scraping infested areas until healthy tissue is exposed).

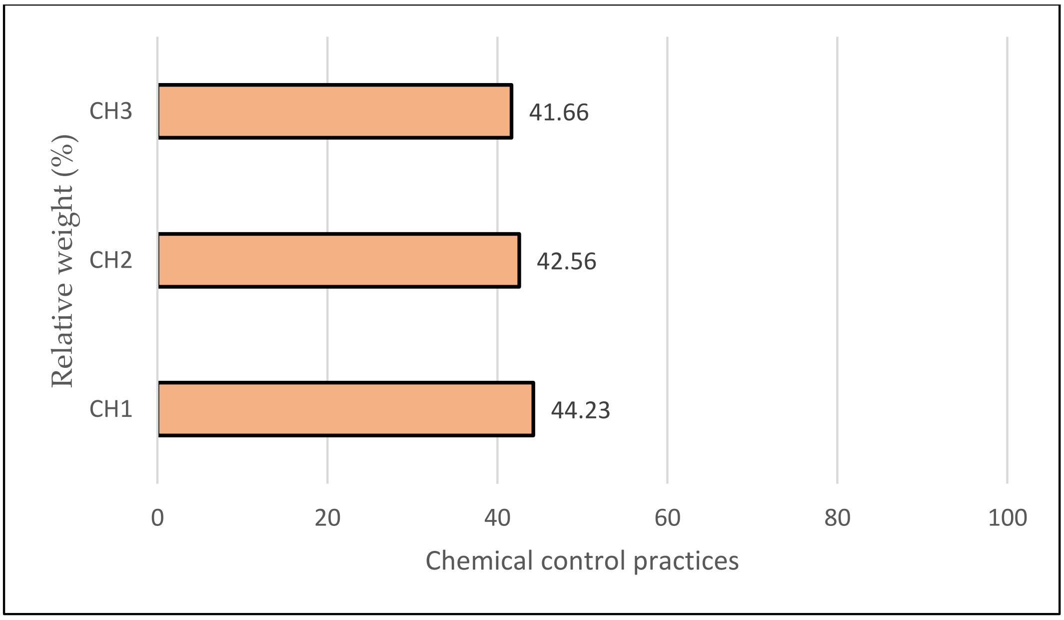

Figure 6. Farmers' adoption of mechanical control practices for red palm weevil control. (CH1 = spraying according to the extension recommendations, CH2 = spraying pesticides of a proper quantity and quality and within the specified time frame, CH3 = dusting farms).

In general, Table 3 shows that farmers moderately adopted the categories of legislative control (54.77%) and cultural practices (50.44%), whereas a low level of adoption was observed regarding the remaining categories. To sum up, the percentage of the overall adoption of RPW IPM practices was 47.65%, indicating a low level of adoption.

Table 3. Overall adoption of integrated pest management categories for red palm weevil control.

Categories of Practices	Adoption Level		Min.	Max.	Rank
	Mean (%)	SD			
Prevention	43.30	14.83	25.00	75.00	5
Legislative control	54.77	12.72	30.00	75.00	1
Cultural practices	50.44	16.53	25.00	75.00	2
Mechanical control	45.75	14.40	25.00	70.83	3
Chemical control	43.96	19.98	25.00	75.00	4
Total	47.64	15.69	25.00	75.00	

3.3. Cluster Analysis

Hierarchical clustering analysis was used, followed by the Mann–Whitney U test, to examine the significant differences between clusters. Two clusters were identified, representing the most significant difference in the adoption of RPW IPM practices. Cluster one consists of the respondents who moderately adopted the examined practices, and this group represents 57.1% of the sample (89 observations). On the other hand, cluster two consists of farmers who were less willing to adopt RPW IPM practices, and this group accounts for 42.9% of the respondents (67 observations). As denoted in Table 4, the means of adoption for cluster one are higher than those of cluster 2 and were significantly different at the probability level of 0.01 for all the practices examined. The differences and similarities between the various practices are visually illustrated in the dendrogram and heat map generated by the hierarchical clustering analysis of adoption data (Figure 7). The visual presentation of the cluster analysis, as shown in the heat map (Figure 7), illustrates significant differences between the two clusters regarding the L4, C1, and C2 practices. This was confirmed by the standardized test statistic (Z-score) values for these practices, which obtained higher mean differences (−10.199, −10.282, −10.856, respectively) between the two clusters compared to the other practices.

Table 4. Differences between clusters according to the adoption of IPM practices for RPW control.

Practices	Cluster I (n = 89)		Cluster II (n = 67)		Mann–Whitney U	Z	*p*-Value
	Mean	SD	Mean	SD			
P1	2.41	0.97	1.51	0.55	1.416.000 **	−6.213	0.00
P2	2.92	0.88	1.69	0.77	1.041.000 **	−7.386	0.00
P3	2.94	1.00	1.54	0.65	881.000 **	−8.025	0.00
P4	2.37	0.98	1.26	0.15	1.072.500 **	−7.929	0.00
P5	2.82	0.87	1.45	0.55	701.000 **	−8.775	0.00
L1	3.44	0.66	2.81	0.66	1.682.000 **	−5.269	0.00
L2	2.62	0.92	1.52	0.52	1.083.000 **	−7.387	0.00
L3	3.35	0.71	1.95	0.79	756.500 **	−8.532	0.00
L4	3.18	0.77	1.39	0.51	303.500 **	−10.199	0.00
L5	3.48	0.69	3.05	0.79	2.142.000 **	−3.594	0.00
C1	3.32	0.65	1.52	0.61	336.000 **	−10.282	0.00
C2	3.04	0.94	1.81	0.76	1.057.000 **	−7.284	0.00
C3	3.00	0.77	2.05	0.91	1.391.500 **	−6.078	0.00
C4	3.34	0.72	1.36	0.35	129.500 **	−10.856	0.00
M1	2.51	0.85	1.31	0.26	680.500 **	−9.195	0.00
M2	3.10	0.75	1.66	0.73	689.000 **	−8.697	0.00
M3	3.55	0.59	2.27	0.57	562.000 **	−9.530	0.00
M4	2.30	0.49	1.34	0.33	722.500 **	−9.309	0.00
M5	2.99	1.04	1.30	0.33	612.500 **	−9.296	0.00
M6	2.82	0.87	1.36	0.42	577.500 **	−9.305	0.00
CH1	3.01	1.01	1.26	0.15	522.500 **	−9.665	0.00
CH2	2.92	0.92	1.28	0.31	496.500 **	−9.706	0.00
CH3	2.81	0.88	1.28	0.21	490.500 **	−9.713	0.00

** Denotes statistical significance at the 0.01 level.

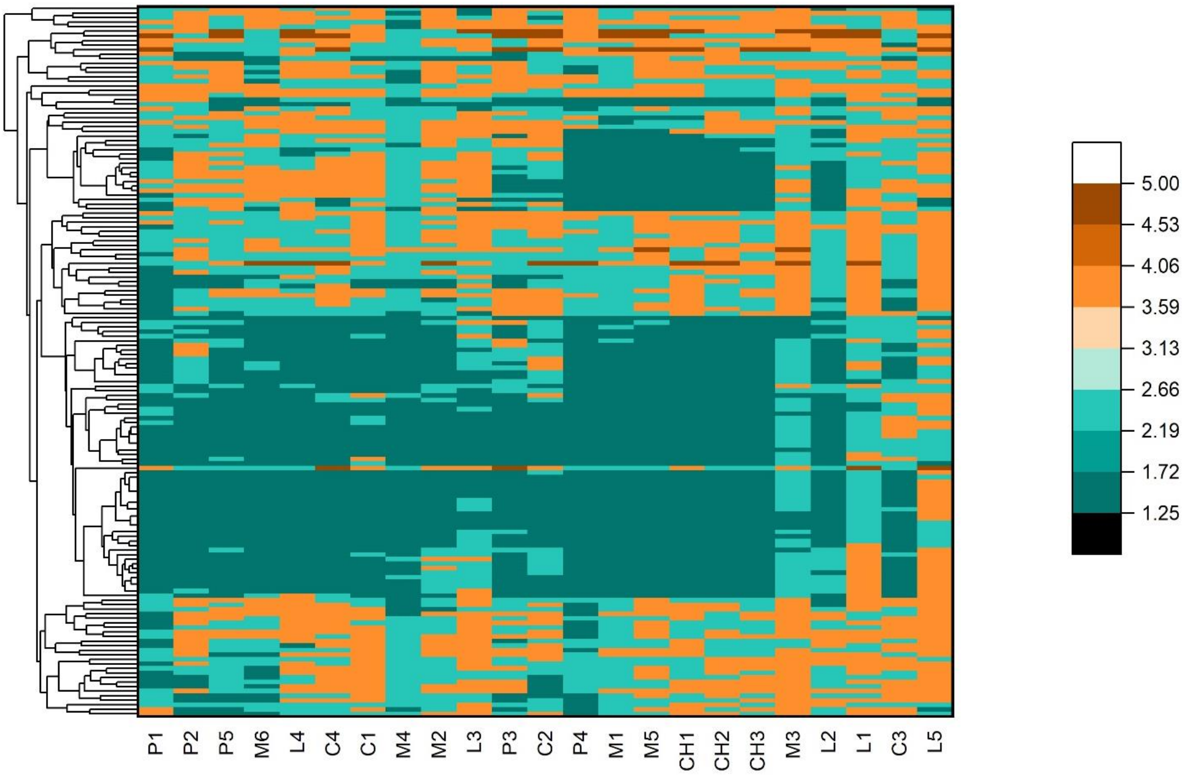

Figure 7. Dendrogram and heat map of the hierarchical cluster analysis of the 23 IPM RPW practices under investigation based on the average scores of the farmers' adoption.

3.4. Differences between Clusters of Adoption According to Farmers' Socio-Economic Attributes and Farm Characteristics

Table 5 indicates the differences between clusters depending on the farmers' socio-economic profiles and their farm characteristics. The chi-squared test results revealed a significant difference at the 0.05 probability level between the two clusters according to age, education level, farm size, farming experience, the number of date palm trees on the farm, off-farm income, farming activities, source of irrigation, type of irrigation, the growing of the 'Khodri' cultivar, growing of the 'Barhi' cultivar, and tree spacing. However, no significant difference ($p > 0.05$) existed between the two clusters for the performance of extension activities related to RPW in the last three years, the growing of the 'Shishi' cultivar, growing of the 'Khalas' cultivar, and growing of the 'Salg' cultivar. These results indicate that the variables studied are useful for distinguishing between the two clusters.

Table 5. Differences between the farmer clusters according to their socio-economic attributes and farm characteristics.

Variable	Category	Cluster 1 (%)	Cluster 2 (%)	χ2	*p*-Value
Age	<40 40–60 >60	21.3 48.3 30.4	4.5 41.8 53.8	13.25 **	0.001
Education	Less than 7 years 7–12 years More than 12 years	30.3 51.7 18.0	80.6 10.4 9.0	39.85 **	0.00
Farm size	<3 3–5 >5	68.5 23.6 7.9	46.3 38.8 14.9	7.89 *	0.02
Farming experience	<20 20–30 >30	51.7 37.1 11.2	22.4 38.8 38.8	21.1 **	0.00
Number of date palm trees on the farm	<500 500–1500 >1500	74.2 14.6 11.2	38.8 29.9 31.3	20.7 **	0.00
Off-farm income	Yes No	27.0 73.0	56.7 43.3	14.12 **	0.00
Performing extension activities related to RPW in the last three years	Frequently Sometimes Rarely	10.1 22.5 67.4	7.5 14.9 77.6	1.86	0.14
Main activity	Date palm only Date palm and vegetables Date palm and field crops Date palm, vegetables, and field crops	30.4 49.4 13.5 6.7	13.4 50.7 25.4 10.5	7.22 *	0.03
Source of irrigation	Surface water Groundwater	47.2 52.8	17.9 82.1	14.48 **	0.00
Type of irrigation	Flood irrigation Drip irrigation	33.7 66.3	53.7 46.3	6.27 **	0.01
Growing 'Khodri' cultivar	Yes No	76.4 23.6	92.5 7.5	7.16 **	0.006
Growing 'Barhi' cultivar	Yes No	46.1 53.9	77.6 22.4	15.79 **	0.00
Growing 'Shishi' cultivar	Yes No	57.3 42.7	44.8 55.2	2.4	0.082

Table 5. *Cont.*

Variable	Category	Cluster 1 (%)	Cluster 2 (%)	χ2	*p*-Value
Growing 'Khalas' cultivar	Yes No	79.8 20.2	82.1 17.9	0.13	0.83
Growing 'Salg' cultivar	Yes No	22.5 77.5	11.9 88.1	2.87	0.09
Tree spacing	4×4 m^2 5×5 m^2 6×6 m^2 7×7 m^2 8×8 m^2	7.9 12.4 35.9 28.1 15.7	25.4 32.8 17.9 16.4 7.5	9.98 **	0.01

* Denotes statistical significance at the 0.05 level; ** denotes statistical significance at the 0.01 level.

The "moderate adopters" in the first cluster were usually younger than the "lower adopters" in the second. The ratio of farmers with more than 12 years of education in the "moderate adopters" cluster (18%) was 9% higher than the "low adopters" (9%). On the contrary, the "lower adopters" cluster had higher farm size than the "moderate adopters". The percentage of farmers with more than five ha was 14.9% among the "low adopters," while the value was 7.9% among the "moderate adopters", and by extension, the "lower adopters" cluster had a higher number of date palm trees than the "moderate adopters". Likewise, the "lower adopters" cluster had more farming experience than the "moderate adopters". The percentage of farmers with more than 30 years of experience was 38.8 among the "low adopters," while the value was 11.2% among the "moderate adopters". Similarly, more than half of the "low adopters" (56.7%) possessed off-farm incomes, compared to the "moderate adopters" (27%).

The findings also showed that a high proportion of "low adopters" (77.6%) and "moderate adopters" (67.4%) rarely joined in the extension activities for RPW in the last three years. Concerning the farming activities, the results in Table 5 show that "moderate adopters" were more concise in cultivating only date palm on their farms (30.4%) compared to the "low adopters" (13.4%). In the same context, both clusters showed similarities in the cultivation of date palm and vegetables on their farms. Less than half of the "moderate adopters" (47.2%) used surface water for irrigation, while the vast majority of "moderate adopters" (82.1%) used ground water. Furthermore, the percentage of farmers who used drip irrigation was 66.3% among the "moderate adopters," while the value was 46.3% among the "low adopters". Significant differences were also observed for the "low adopters" cluster concerning the growing of the 'Khodri' and 'Barhi' cultivars, while both clusters showed similarities as to the remaining cultivars. Lastly, the percentage of farmers who followed the recommended tree spacing (8×8 m^2, according to the cultivar) was 15.7% among the "moderate adopters," while the value was 7.5% among the "low adopters" group.

4. Discussion

The results of this study reaffirmed the importance of adopting the best management practices for RPW eradication, as a major source of sustainable livelihoods for date palm farmers in Saudi Arabia. These results are consistent with the country's 2030 vision, which views the RPW invasion as a national security issue. This strategy aims to develop the palm sector by adopting effective risk management strategies for RPW eradication in cooperation with all stakeholders [20]. The findings of this study allow us to discuss three important aspects: the actual adoption rate of the respondents, the differences between the two clusters according to the adoption of the 23 practices examined, and how socio-economic attributes and farm characteristics distinguish the two clusters of adoption.

4.1. Adoption Rate of IPM for RPW Control

Calculating the relative weight of each IPM practice for RPW control shows that most of the farmers surveyed are considered to show a low level of adoption. Similar results have been presented in the studies of Kassem, Alotaibi, Ahmed, and Aldosri [25], who reported that farmers' uptake of RPW IPM practices in Saudi Arabia ranged between low and moderate levels. This result may be attributed to the farmers' lack of knowledge of IPM principles. On the one hand, Aristizábal et al. [56] argued that IPM is a knowledge-intensive process that requires knowledge of the ecology, biology, and behavior of the pest in order to select the most appropriate management measures based on intensive field observation and data mining. On the other hand, practicing IPM on the farm scale is difficult due to the inability to rely upon an individual practice in isolation and the need to use inter-related strategies [57]. Parsa et al. [58], in their analysis of the barriers to IPM adoption in developing countries, found that the lack of knowledge, lower literacy levels, inadequate IPM training, and lack of supportive policies are the most frequently cited obstacles resulting in non-adoption. Another viewpoint on this matter is voiced by Timprasert et al. [59], who reported that farmers often assume that IPM is challenging and complicated and must be adopted on a large scale. Consequently, farmers rely on traditional practices and an over-dependence on pesticides to manage crop pests [60].

Specifically, in terms of RPW control, the low adoption rate may be attributed to the application challenges of IPM strategies. In this regard, several studies [61–66] confirmed the urgent need to enhance biological control research, develop efficient early detection methods, and solve problems facing management practices (e.g., the lack of farmer and stakeholder cooperation, insufficient human and financial resources, labor-intensive control, and high cost). Among these challenges, early detection is crucial, as it is considered the first step of an overall IPM strategy against RPW [66]. In fact, visual inspection for damage is difficult in the early stage of the infestation, since the evidence of infection appears on the palm in a medium or an advanced stage of the infestation [34,67]. Kassem et al. [24] confirmed this challenge empirically in Saudi Arabia, conducting an in-depth examination of the relationships between farmers' IPM adoption and their knowledge of RPW symptoms. The findings of this study demonstrated the interplay between the two components, where farmers experienced in diagnosing RPW symptoms were more likely to adopt IPM.

4.2. Differences between the Clusters According to the Adoption of RPW IPM Practices

The findings highlight that, among the categories of RPW IPM, the level of the adoption of legislative control was average and occupied the first rank. A possible explanation for this can be found in the farmers' commitment to strict quarantine regimes applied by the country in terms of preventing the transfer of infested trees or offshoots. The outcomes of this strategy can clearly be viewed in the Algerian quarantine system, as the pest has been reported in many neighboring North African countries, excluding Algeria. This achievement is due to the application of very strict quarantine regimes that do not allow planting material transportation in order to control the RPW infestation [68]. Saudi Arabia also developed quarantine measures against RPW in 2018 by establishing standard tissue culture laboratories and preparing phytosanitary legislation in terms of the palm nurseries' certification according to the IPPC standards (ISPM 36), infested palm removal, palm tree checkups, and the palms' movement and treatment protocols [69].

Cultural pest management practices were also moderately adopted by the respondents. This might be due to the fact that the respondents perform these practices when establishing their palm farms or at the beginning of the season. These results are in line with the results of Kassem, Alotaibi, Ahmed, and Aldosri [25], who found that Saudi farmers moderately adopt cultural practices, with a percentage of 63.58%.

The results also highlighted the existence of significant differences between farmers with respect to the practice of "applying moderate irrigation to reduce humidity on farms". This result might be due to the fact that 42.3% of the farmers still use flood irrigation (Table 2) as a source of irrigation. This system is not as efficient as drip irrigation in controlling the irrigation water using lighter amounts in order to reduce humidity on the farms. To deepen our view concerning this point, the study results may provide an important example in this matter. More than half of the "low adopter" cluster had adopted flood irrigation, while two-thirds of the "moderate adopters" had adopted drip irrigation. Dewidar [69] suggested that flood irrigation assists in the infestation of RPW entry into the date palm trunk relative to another irrigation system. Hence, this category could be considered the most crucial constituent of IPM in reducing the level of RPW infestation [70] and, consequently, farmers should be supported in these practices by the extension services. In the same vein, "surveying RPW-infested palms and informing the authorities when necessary" was among the practices adopted differently between farmers. A possible explanation for this can be found in farmers' unwillingness to inform the authorities of infested trees so as to avoid burning the severely infested trees or receiving penalties for negligence in RPW control. Some farmers still believe that palm trees form part of their national heritage that governmental bodies should not control.

4.3. Differences between the Clusters According to Socio-Economic Attributes and Farm Characteristics

The results showed that the "moderate adopters" segment profile differed from the "low adopters" segment concerning their socio-economic attributes and farm characteristics. These results reflect the importance of the studied variables as critical determinants of adoption. The findings suggested that younger farmers adopted RPW IPM practices at a higher rate than older farmers. This may be attributed to the fact that IPM practices require physical labor, making it easier for younger date palm farmers to adopt them. Similar findings were found for the distinction between early and late adopters relative to the non-adopters of IPM in Kenya [71]. With regard to education, the findings indicated that farmers with higher education levels adopted IPM practices at a higher rate than less educated farmers. Undoubtedly, education assists farmers in understanding the benefits of IPM and how to apply it professionally. These findings are in line with those of previous studies in the field of IPM [72–75]. The specialization of the production level plays a precarious role in adoption. Thus, in the current study, the "moderate adopters" focused on date palm production only relative to "low adopters." A probable explanation for this result is that focusing on monocropping motivates date farmers to acquire new knowledge and adopt innovations to avoid crop loss. In contrast, farmers who cultivate vegetables or field crops besides date palm are profit-oriented, according to which they place their focus on the net seasonal return from these crops. Therefore, they may ignore the best practices for date palm production. Although the main goal of palm spacing is to enhance the productivity and quality of the dates, interestingly, the farmers who followed the recommendations of palm spacing tended to adopt RPW IPM practices relative to the others, who did not. This may be attributed to the fact that tree spacing facilitates the implementation of cultural practices on the farm, which is one of the strategies of RPW IPM. As Giblin-Davis et al. [76] noted, taking up cultural practices is the practical implementation of the concept of avoidance. In other words, cultural pest management practices have long been identified as a preventive measure and an effective solution that can be used to avoid pest infestations at the farm level.

Surprisingly, the "low adopter" segment had a greater farm size and managed a higher number of palm trees on the farm. According to the results of the present study, there is a two-fold picture representing this issue that may be considered for interpretation. First, we can consider the purpose of farming activities. Most of the "low adopters" segment managed various activities (vegetables and field crops) in addition to date palms. Consequently, those farmers paid more attention to these activities so as to avoid higher economic losses if the crops are damaged, coercing them to conform to the best management practices rather than those for date palm. Secondly, managing RPW IPM strategies on a large scale requires great costs, labor, and expertise. Such requirements may result in a negative attitude that demotivates farmers with respect to adoption. In the same vein, extension contact was not a significant factor in discriminating between the adoption clusters. This result implied that farmers do not depend upon extension services when making decisions with regard to IPM adoption. This result is confirmed by the results of the present study, where the surveyed farmers in the study area had very limited access to extension services. In this sense, the literature provides successful examples of the implementation of participatory extension approaches in the field of IPM, such as farmer field schools (FFSs). FFS have made a significant contribution in promoting IPM in many international contexts based on a "learning by doing" methodology to allow farmers to understand the behavior of pests and practice IPM solutions. More specifically, in this field of study, member farmers participating in FFSs used the FAO's global RPW management platform in recent years to collect and transmit palm inspection data by their mobile phones [34].

5. Conclusions

This article illuminated the actual adoption of RPW IPM among Saudi date palm farmers. It also investigated how this adoption differs between farmer clusters according to demographic and farm variables. The findings highlighted that the adoption rate ranges between 40% and 50%, which strongly suggests that most farmers do not practice RPW IPM extensively. Legislative control practices were among the principles that the respondents, on average, adopted the most. Conversely, prevention measures and chemical control were the least adopted measures. Depending on the average score of the RPW IPM, two farmer segments, the "moderate adopters" and "low adopters", were contrasted. The measurement of RPW IPM adoption in this study has implications in theory and practice. Most previous studies have examined the biological and ecological aspects of the RPW, or the technological side of early detection. Nonetheless, very few studies have methodically documented the IPM practices for RPW control and the factors influencing the adoption. Accordingly, this study contributes to the literature on this topic. Furthermore, the index of RPW IPM offers a valuable source, with a tested and reliable rating scale, that can assist other researchers wishing to conduct comparable studies in different countries. Undoubtedly, our examination of how the adoption clusters can be discriminated based on socio-economic attributes and farm characteristics enrich the theoretical aspect of this issue.

The research provides insights into the gaps that need to be filled by policy makers in order to assist farmers in increasing the adoption of RPW IPM practices. This paper concludes that in order to accelerate the adoption of RPW IPM practices, practices need to be addressed in conjunction with others and, therefore, holistic training programs are required. These programs should develop farmers' skills in using prevention measures (preventive insecticide treatments based on infestation foci and trap capture data, early detection devices or techniques for RPW infestation, and the application of follow-up plans), implementing good agronomic practices that limit the RPW attack, and adopting both visual observation and pheromone traps. A second important conclusion in this matter is that the focus should not only be placed on innovation but also on the farming context and the demographic profiles of farmers. This information is vital for identifying farmers' typologies and developing regional programs and measures. Additionally, this study concludes that harvesting the outcomes of RPW IPM requires significant collaboration between the neighboring farmers. In this regard, developing participatory approaches, such as FFS, would be invaluable and offer a greater insight into the adoption of RPW IPM practices. However, two limitations of this study require acknowledgment. Firstly, this study was conducted in one governorate; therefore, we cannot generalize the results to include other governorates within Saudi Arabia or other countries. Secondly, the assessment of farmers' adoption depends upon their self-reports, implying that this method relies on what the famers believe to be accurate, biasing the adoption results. Measuring the adoption of RPW IPM practices in other countries with varied cultural milieus is recommended. Furthermore, future studies should explore the barriers to, and drivers of, increased adoption.

Author Contributions: Conceptualization, A.A. and H.S.K.; methodology, H.S.K., B.A.A. and A.A.; software, A.A. and B.A.A.; validation, A.A. and A.A.A.-Z.; formal analysis, H.S.K.; investigation, B.A.A. and A.A.A.-Z.; resources, B.A.A. and H.S.K.; data curation, A.A.; writing—original draft preparation, A.A. and H.S.K.; writing—review and editing, A.A.A.-Z. and B.A.A.; project administration, H.S.K.; funding acquisition, B.A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Researchers Supporting Project (No. RSP2022R443), King Saud University, Riyadh, Saudi Arabia.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical reasons.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hussain, M.I.; Farooq, M.; Syed, Q.A. Nutritional and biological characteristics of the date palm fruit (*Phoenix dactylifera* L.)—A review. *Food Biosci.* **2020**, *34*, 100509. [CrossRef]
2. Al-Mssallem, M.Q.; Alqurashi, R.M.; Al-Khayri, J.M. Bioactive Compounds of Date Palm (*Phoenix dactylifera* L.). In *Bioactive Compounds in Underutilized Fruits and Nuts*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 91–105. [CrossRef]
3. Al-Dashti, Y.A.; Holt, R.R.; Keen, C.L.; Hackman, R.M. Date Palm Fruit (*Phoenix dactylifera*): Effects on Vascular Health and Future Research Directions. *Int. J. Mol. Sci.* **2021**, *22*, 4665. [CrossRef] [PubMed]
4. MEWA. *Achievement of the Date Palm Sector in 2021*; Ministry of Environment, Water, and Agriculture: Riyadh, Saudi Arabia, 2021.
5. Flowers, J.M.; Hazzouri, K.M.; Gros-Balthazard, M.; Mo, Z.; Koutroumpa, K.; Perrakis, A.; Ferrand, S.; Khierallah, H.S.M.; Fuller, D.Q.; Aberlenc, F.; et al. Cross-species hybridization and the origin of North African date palms. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 1651–1658. [CrossRef] [PubMed]
6. Salomón-Torres, R.; Krueger, R.; García-Vázquez, J.; Villa-Angulo, R.; Villa-Angulo, C.; Ortiz-Uribe, N.; Sol-Uribe, J.; Samaniego-Sandoval, L. Date Palm Pollen: Features, Production, Extraction and Pollination Methods. *Agronomy* **2021**, *11*, 504. [CrossRef]
7. FAOSTAT. *Crop Statistics*; FAO: Rome, Italy, 2019.
8. Jonoobi, M.; Shafie, M.; Shirmohammadli, Y.; Ashori, A.; Hosseinabadi, H.Z.; Mekonnen, T. A review on date palm tree: Properties, characterization and its potential applications. *J. Renew. Mater.* **2019**, *7*, 1055–1075. [CrossRef]
9. Krueger, R.R. Date Palm (*Phoenix dactylifera* L.) Biology and Utilization. In *The Date Palm Genome*; Springer: Berlin/Heidelberg, Germany, 2021; Volume 1, pp. 3–28.
10. Verneau, F.; Amato, M.; La Barbera, F. Edible Insects and Global Food Security. *Insects* **2021**, *12*, 472. [CrossRef]
11. Liliane, T.N.; Charles, M.S. Factors Affecting Yield of Crops. In *Agronomy-Climate Change & Food Security*; IntechOpen: London, UK, 2020. [CrossRef]
12. Al-Khayri, J.M.; Naik, P.M.; Jain, S.M.; Johnson, D.V. Advances in Date Palm (*Phoenix dactylifera* L.) Breeding. In *Advances in Plant Breeding Strategies: Fruits*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 727–771.
13. Abdel-Baky, N.F.; Aldeghairi, M.A.; Motawei, M.I.; Al-Shuraym, L.A.M.; Al-Nujiban, A.A.S.; Alharbi, M.T.M.; Rehan, M. Genetic Diversity of Palm Weevils, *Rhynchophorus* Species (Coleoptera: Curculionidae) by Mitochondrial COI Gene Sequences Declares a New Species, *R. bilineatus* in Qassim, Saudi Arabia. *Arab. J. Sci. Eng.* **2022**. [CrossRef]
14. FAO. *Red Palm Weevil: Guidelines on Management Practices*; FAO: Rome, Italy, 2020.
15. Al-Khateeb, S.; Hussain, A.; Lange, S.; Almutari, M.; Schneider, F. Battling Food Losses and Waste in Saudi Arabia: Mobilizing Regional Efforts and Blending Indigenous Knowledge to Address Global Food Security Challenges. *Sustainability* **2021**, *13*, 8402. [CrossRef]
16. Mohammed, M.E.; El-Shafie, H.A.; Alhajhoj, M.R. Recent trends in the early detection of the invasive red palm weevil, *Rhynchophorus ferrugineus* (olivier). In *Invasive Species-Introduction Pathways, Economic Impact, and Possible Management Options*; IntechOpen: London, UK, 2020.
17. Rehman, G.; Mamoon-Ur-Rashid, M. Evaluation of Entomopathogenic Nematodes against Red Palm Weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). *Insects* **2022**, *13*, 733. [CrossRef]
18. Kurdi, H.; Al-Aldawsari, A.; Al-Turaiki, I.; Aldawood, A.S. Early Detection of Red Palm Weevil, *Rhynchophorus ferrugineus* (Olivier), Infestation Using Data Mining. *Plants* **2021**, *10*, 95. [CrossRef]
19. Aldosary, N.M.N.; AlDobai, S.; Faleiro, J.R. Review on the management of red palm weevil *Rhynchophorus ferrugineus* olivier in date palm *Phoenix dactylifera* L. *Emir. J. Food Agric.* **2016**, *28*, 34–44. [CrossRef]
20. Ali-Bob, M. Management of the Red Palm Weevil *Rhynchophorus ferrugineus* (Olivier) using sustainable options in Saudi Arabia. *Arab J. Plant Prot.* **2019**, *37*, 163–169. [CrossRef]
21. FAO. Framework Strategy for Eradication of Red Palm Weevil. In *Scientific Consultation and High-level Meeting on Red Palm Weevil management*; FAO: Rome, Italy, 2017; p. 30.
22. MEWA. *Statistical Book 2020*; Ministry of Environment, Water, and Agriculture: Riyadh, Saudi Arabia, 2020.
23. FAO. *Food Chain Crisis. Red Palm Weevil*; FAO: Rome, Italy, 2017.

24. Aleid, S.M.; Al-Khayri, J.M.; Al-Bahrany, A.M. Date palm status and perspective in Saudi Arabia. In *Date Palm Genetic Resources and Utilization*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 49–95.
25. Kassem, H.S.; Alotaibi, B.A.; Ahmed, A.; Aldosri, F.O. Sustainable Management of the Red Palm Weevil: The Nexus between Farmers' Adoption of Integrated Pest Management and Their Knowledge of Symptoms. *Sustainability* **2020**, *12*, 9647. [CrossRef]
26. Hussain, A.; Rizwan-Ul-Haq, M.; Al-Jabr, A.; Al-Ayied, H. Managing invasive populations of red palm weevil: A worldwide perspective. *J. Food Agric. Environ.* **2013**, *11*, 456–463.
27. Rani, L.; Thapa, K.; Kanojia, N.; Sharma, N.; Singh, S.; Grewal, A.S.; Srivastav, A.L.; Kaushal, J. An extensive review on the consequences of chemical pesticides on human health and environment. *J. Clean. Prod.* **2021**, *283*, 124657. [CrossRef]
28. Ali, S.; Ullah, M.I.; Sajjad, A.; Shakeel, Q.; Hussain, A. Environmental and health effects of pesticide residues. In *Sustainable Agriculture Reviews 48*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 311–336.
29. Al-Ayedh, H.; Hussain, A.; Rizwan-Ul-Haq, M.; AlJabr, A.M. Status of Insecticide Resistance in Field-collected Populations of *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). *Int. J. Agric. Biol.* **2016**, *18*, 103–110. [CrossRef]
30. Ahmad, I. Integrated Pest Management of *Rhynchophorus ferrugineus* Olivier: An Efficient Approach to Reduce Infestation in Date Palm Trees. *Pakistan J. Zool.* **2021**, *54*, 927–936. [CrossRef]
31. El-Shafie, H.A.F. Integrated insect pest management. In *Pests Control and Acarology*; IntechOpen: London, UK, 2018; pp. 1–18. [CrossRef]
32. Dara, S.K. The New Integrated Pest Management Paradigm for the Modern Age. *J. Integr. Pest Manag.* **2019**, *10*, 12. [CrossRef]
33. Deguine, J.-P.; Aubertot, J.-N.; Flor, R.J.; Lescourret, F.; Wyckhuys, K.A.; Ratnadass, A. Integrated pest management: Good intentions, hard realities. A review. *Agron. Sustain. Dev.* **2021**, *41*, 1–35. [CrossRef]
34. Faleiro, J.R.; Ferry, M.; Yaseen, T.; Al-Dobai, S. Overview of the gaps, challenges and prospects of red palm weevil management. *Arab Soc. Plant Prot.* **2018**, *37*, 170–177. [CrossRef]
35. Midingoyi, S.G.; Kassie, M.; Muriithi, B.; Diiro, G.; Ekesi, S. Do Farmers and the Environment Benefit from Adopting Integrated Pest Management Practices? Evidence from Kenya. *J. Agric. Econ.* **2018**, *70*, 452–470. [CrossRef]
36. Grasswitz, T.R. Integrated Pest Management (IPM) for Small-Scale Farms in Developed Economies: Challenges and Opportunities. *Insects* **2019**, *10*, 179. [CrossRef] [PubMed]
37. Rezaei, R.; Safa, L.; Ganjkhanloo, M.M. Understanding farmers' ecological conservation behavior regarding the use of integrated pest management- an application of the technology acceptance model. *Glob. Ecol. Conserv.* **2020**, *22*, e00941. [CrossRef]
38. Ansari, M.; Harding, S. Management of Date Palm Pests: Lack of Commercial Input. *Outlooks Pest Manag.* **2022**, *33*, 5–7. [CrossRef]
39. Dembilio, Ó.; Jaques, J.A. Biology and management of red palm weevil. In *Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 13–36.
40. Wakil, W.; Faleiro, J.R.; Miller, T.A. *Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges*; Springer: Berlin/Heidelberg, Germany, 2015.
41. Fajardo, M.; Rodríguez, X.; Hernández, C.; Barroso, L.; Morales, M.; González, A.; MartíN, R. The eradication of the invasive red palm weevil in the Canary Islands. In *Area-Wide Integrated Pest Management*; CRC Press: Boca Raton, FL, USA, 2021; pp. 539–550.
42. Islam, A.H.M.S.; Schreinemachers, P.; Kumar, S. Farmers' knowledge, perceptions and management of chili pepper anthracnose disease in Bangladesh. *Crop Prot.* **2020**, *133*, 105139. [CrossRef]
43. Bueno, A.F.; Panizzi, A.R.; E Hunt, T.; Dourado, P.M.; Pitta, R.M.; Gonçalves, J. Challenges for Adoption of Integrated Pest Management (IPM): The Soybean Example. *Neotrop. Entomol.* **2021**, *50*, 5–20. [CrossRef]
44. Steiro, L.; Kvakkestad, V.; Breland, T.A.; Vatn, A. Integrated Pest Management adoption by grain farmers in Norway: A novel index method. *Crop Prot.* **2020**, *135*, 105201. [CrossRef]
45. Rezaei, R.; Safa, L.; Damalas, C.A.; Ganjkhanloo, M.M. Drivers of farmers' intention to use integrated pest management: Integrating theory of planned behavior and norm activation model. *J. Environ. Manag.* **2019**, *236*, 328–339. [CrossRef]
46. Mendesil, E.; Shumeta, Z.; Anderson, P.; Rämert, B. Smallholder farmers' knowledge, perceptions and management of pea weevil in north and north-western Ethiopia. *Crop Prot.* **2016**, *81*, 30–37. [CrossRef]
47. GAS. *Detailed Results of Agricultural Census*; General Authority for Statistics: Riyadh, Saudi Arabia, 2018.
48. GAS. *Demographics of Saudi Arabia*; General Authority for Statistics: Riyadh, Saudi Arabia, 2020.
49. PME. *The Meteorology of Al-Kharj*; Presidency of Meteorology and Environment: Riyadh, Saudi Arabia, 2020.
50. Faridi, M.R.; Sulphey, M.M. Food security as a prelude to sustainability: A case study in the agricultural sector, its impacts on the Al Kharj community in The Kingdom of Saudi Arabia. *Entrep. Sustain. Issues* **2019**, *6*, 1536–1545. [CrossRef]
51. Adam, A.M. A Study on Sample Size Determination in Survey Research. *New Ideas Concern. Sci. Technol.* **2021**, *4*, 125–134.
52. Kassem, H.S.; Bello, A.R.S.; Alotaibi, B.M.; Aldosri, F.O.; Straquadine, G.S. Climate Change Adaptation in the Delta Nile Region of Egypt: Implications for Agricultural Extension. *Sustainability* **2019**, *11*, 685. [CrossRef]
53. Köhn, H.F.; Hubert, L.J. Hierarchical cluster analysis. *Wiley StatsRef: Stat. Ref. Online* **2014**, 1–13. [CrossRef]
54. MacFarland, T.W.; Yates, J.M. Mann–Whitney u test. In *Introduction to Nonparametric Statistics for the Biological Sciences Using R*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 103–132.
55. Zibran, M.F. Chi-squared test of independence. *Dep. Comput. Sci. Univ. Calg. Alta. Can.* **2007**, *1*, 1–7.
56. Aristizábal, L.F.; Bustillo, A.E.; Arthurs, S.P. Integrated Pest Management of Coffee Berry Borer: Strategies from Latin America that Could Be Useful for Coffee Farmers in Hawaii. *Insects* **2016**, *7*, 6. [CrossRef]

57. Creissen, H.E.; Jones, P.; Tranter, R.B.; Girling, R.D.; Jess, S.; Burnett, F.; Gaffney, M.; Thorne, F.S.; Kildea, S. Measuring the unmeasurable? A method to quantify adoption of integrated pest management practices in temperate arable farming systems. *Pest Manag. Sci.* **2019**, *75*, 3144–3152. [CrossRef]
58. Parsa, S.; Morse, S.; Bonifacio, A.; Chancellor, T.C.B.; Condori, B.; Crespo-Pérez, V.; Hobbs, S.L.A.; Kroschel, J.; Ba, M.N.; Rebaudo, F.; et al. Obstacles to integrated pest management adoption in developing countries. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 3889–3894. [CrossRef]
59. Timprasert, S.; Datta, A.; Ranamukhaarachchi, S. Factors determining adoption of integrated pest management by vegetable growers in Nakhon Ratchasima Province, Thailand. *Crop Prot.* **2014**, *62*, 32–39. [CrossRef]
60. Khan, F.Z.A.; Manzoor, S.A.; Gul, H.T.; Ali, M.; Bashir, M.A.; Akmal, M.; Haseeb, M.; Imran, M.U.; Taqi, M.; Lukac, M.; et al. Drivers of farmers' intention to adopt integrated pest management: A case study of vegetable farmers in Pakistan. *Ecosphere* **2021**, *12*, e03812. [CrossRef]
61. FAO. *Proceedings of the Scientific Consultation and High-Level Meeting on Red Palm Weevil Management*; FAO: Rome, Italy, 2017; p. 200.
62. Azmi, W.A.; Lian, C.J.; Zakeri, H.A.; Yusuf, N.; Omar, W.B.W.; Wai, Y.K.; Husasin, M. The red palm weevil, *Rhynchophorus ferrugineus*: Current issues and challenges in Malaysia. *Oil Palm Bull.* **2017**, *74*, 17–24.
63. Soroker, V.; Suma, P.; Pergola, A.l.; Cohen, Y.; Alchanatis, V.; Golomb, O.; Goldshtein, E.; Hetzroni, A.; Galazan, L.; Kontodimas, D. Early detection and monitoring of red palm weevil: Approaches and challenges. In Proceedings of the Colloque Méditerranéen Sur les Ravageurs des Palmiers, Nice, France, 16–18 January 2013.
64. Hetzroni, A.; Soroker, V.; Cohen, Y. Toward practical acoustic red palm weevil detection. *Comput. Electron. Agric.* **2016**, *124*, 100–106. [CrossRef]
65. Eldin, H.A.; Waleed, K.; Samir, M.; Tarek, M.; Sobeah, H.; Salam, M.A. A Survey on Detection of Red Palm Weevil Inside Palm Trees: Challenges and Applications. In Proceedings of the 2020 9th International Conference on Software and Information Engineering (ICSIE), Cairo, Egypt, 11–13 November 2020; pp. 119–125.
66. Koubaa, A.; Aldawood, A.; Saeed, B.; Hadid, A.; Ahmed, M.; Saad, A.; Alkhouja, H.; Ammar, A.; Alkanhal, M. Smart Palm: An IoT Framework for Red Palm Weevil Early Detection. *Agronomy* **2020**, *10*, 987. [CrossRef]
67. Rach, M.M.; Gomis, H.M.; Granado, O.L.; Malumbres, M.P.; Campoy, A.M.; Martín, J.J.S. On the Design of a Bioacoustic Sensor for the Early Detection of the Red Palm Weevil. *Sensors* **2013**, *13*, 1706–1729. [CrossRef] [PubMed]
68. Balijepalli, S.; Faleiro, J. Is policy paralysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil, *Rhynchophorus ferrugineus*? *Arab J. Plant Prot.* **2019**, *37*, 89–100. [CrossRef]
69. Dewidar, A. Water saving in arid regions: A comparison of surface and subsurface drip irrigation systems for irrigation of date palms. *Amer. J. Innov. Res. Appl. Sci.* **2016**, *2*, 289–296.
70. Salah, M. Importance of field operations for reducing red palm weevil (RPW) infestation on date palm. *Arab J. Plant Prot.* **2019**, *37*, 159–162. [CrossRef]
71. Muriithi, B.; Gathogo, N.; Diiro, G.; Mohamed, S.; Ekesi, S. Potential Adoption of Integrated Pest Management Strategy for Suppression of Mango Fruit Flies in East Africa: An Ex Ante and Ex Post Analysis in Ethiopia and Kenya. *Agriculture* **2020**, *10*, 278. [CrossRef]
72. Rahman, S. Farmers' perceptions of integrated pest management (IPM) and determinants of adoption in vegetable production in Bangladesh. *Int. J. Pest Manag.* **2022**, *68*, 158–166. [CrossRef]
73. Rahman, M.S.; Norton, G.W. Adoption and impacts of integrated pest management in Bangladesh: Evidence from smallholder bitter gourd growers. *Horticulturae* **2019**, *5*, 32. [CrossRef]
74. Owusu, V.; Abdulai, A. Examining the economic impacts of integrated pest management among vegetable farmers in Southern Ghana. *J. Environ. Plan. Manag.* **2019**, *62*, 1886–1907. [CrossRef]
75. Loko, Y.L.E.; Akohonwe, J.; Toffa, J.; Orobiyi, A.; Assogba, P.; Dansi, A.; Tamò, M. Farmers knowledge, perceptions and management of Kersting's groundnut (Macrotyloma geocarpum Harms) insect pests in Benin. *J.Basic Appl. Zool.* **2019**, *80*, 41. [CrossRef]
76. Giblin-Davis, R.M.; Faleiro, J.R.; Jacas, J.A.; Peña, J.E.; Vidyasagar, P. Biology and management of the red palm weevil, *Rhynchophorus ferrugineus*. *Poten. Invas. Pests of Agric. Crops* **2013**, *3*, 1.