



EFFECTIVENESS OF PESTICIDE SPRAYING CAMPAIGNS IN CONTROLLING GREEN SCALE INSECTS: A FIELD-BASED QUANTITATIVE STUDY IN WADI ATBA

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ABSTRACT

The paper will evaluate the effectiveness of pesticide spraying campaigns in controlling the green scale insects (Coccidae) in the real field conditions in Wadi Atba which is a semi-arid agricultural region. Quantitative approach based on structured questionnaires, which were administered to 140 farmers along with observational inputs were used. The findings reveal that the pesticide spraying campaigns have a huge impact of reducing the population of the green scale insects, in particular, when the application coincides with the crawler stage of the pest lifecycle, which is the most vulnerable stage. The statistical analysis demonstrated the great positive correlations between timing and perceived effectiveness which demonstrated the significance of phenological targeting in pest management strategies. However, there were also critical ecological trade-offs with the use of pesticides being associated with an apparent decline in the population of natural predators and parasite like predators. It reduces, contributing to pest re-emergence and undermining long-term biological control processes. The awareness of farmers as far as the use of pesticides is concerned both as regards to the benefits and the ecological impacts of using pesticides was found to be high but the farmers remained dependent on the use of chemicals in the control of pests as it was so effective in the short run. The study is unique by offering field-based empirical data of the relationship between pesticide efficacy, timing of application, and ecological consequences in one analytical construct. It emphasizes the need to promote integrated pest management (IPM) that balances the impacts of the chemicals in terms of their efficiency and environmental sustainability.

Keywords: Pesticide spraying campaigns, integrated pest management (IPM), ecological trade-offs, pest control effectiveness, Wadi Atba

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INTRODUCTION

Among the most economically harmful sap-sucking pests of agricultural systems is scale insects, especially green scale species (Coccidae) due to their high reproduction rate, honeydew production, and ability to promote secondary fungal infections that decrease crop productivity and quality (Kondo and Watson, 2022; Moghaddam and Abdollahipour, 2021). Their cryptic nature, protection by waxy coverings, make them hard to control, particularly at later stages of development, thereby necessitating specific and well-timed control measures (Golan et al., 2023). In regions where semi-arid agroecosystems are common, such as Wadi Atba, the outbreak of pests is usually augmented by environmental hassles, causing a greater reliance on the use of chemical pesticide spraying campaigns as a main control measure.

One of the most popular techniques of rapid control over the population of scale insects due to the immediate and visible effect has been the use of pesticides (Peterson, 2025). However, the recent literature also emphasizes that the effectiveness of the chemical control can largely depend on the time of its application, in particular, at the crawler stage that is the most vulnerable and mobile stage of the insect life cycle (Ebrahim, 2024; Golan et al., 2023). Lack of coordination between pesticide application and this significant step can occasionally result in a reduction in effectiveness, increased application, and development of pesticide resistance that negatively affects the long-term consequences of pest management (Shang et al., 2025).

Despite the fact that the pesticide spraying campaigns have been shown to be of short-term effect, it has serious ecological trade-offs. Numerous studies indicate the negative impact of the broad-spectrum insecticides on non-target organisms, especially natural enemies such as the parasitoids and predators that have a very important role in the regulation of the population of the pests that are targeted by them (Akhtar et al., 2025; Grove, 2022). When such biological control agents are not disrupted, it may result in a cycle of dependence on chemical interventions since it can lead to pest resurgence and secondary outbreaks (Chen & Luo, 2025). This paradox helps to understand the importance of managing to achieve a balance between efficiency and environmental sustainability through the implementation of chemical control and ecological approaches as the part of the framework of the Integrated Pest Management (IPM) (Kumari et al., 2023).

It is against this backdrop that there is a growing pressure to conduct field based quantitative research that would not only evaluate the instantaneous efficacy of pesticide spraying campaigns but would also be in a position to evaluate their time and ecological implication under real farming scenarios. Such studies are essential in the generation of context-specific information that can be used in shaping sustainable pest management practices. In this regard, the present study looks into the effectiveness of pesticide spraying campaigns in the management of green scale insects in Wadi Atba with special reference to the timing of the campaign and the implications that come with it on the population of natural enemies.

The statement of Problem

Although pesticide spraying campaigns have been widely used as a main method of scale insect control, there are still significant gaps in knowledge regarding their effectiveness in terms of scale insects control at the field level under real agricultural conditions. Most of the existing literature concentrates on the laboratory effectiveness or controlled trials, but the number of studies quantifying the actual impact of repeated spraying campaigns in a heterogeneous farm setting is relatively limited (Schmidt-Jeffris, 2023; Yarahmadi and Rajabpour, 2024). This difference limits the possibility to extrapolate the results to real-life farming systems such as Wadi Atba where the interactions between the variations in the environment, farming practices, and pest pressure are dynamic.

One of the major shortcomings of existing research is the lack of understanding of the impact of timing of pesticide application especially when it is targeted at the crawler stage on the long term pest suppression in the field. The fact that the vulnerability of the early stages of development is a well-documented issue is also a problem (Bueno et al., 2017; Yarahmadi and Rajabpour, 2024). This often results in the use of routine, or calendar-dependent spraying in lieu of evidence-based timing management, which can be less efficient in control and may increase the use of chemicals.

Besides, there is a large research gap in regards to ecological implications of pesticide spraying campaigns, in particular, their effects on the populations of natural enemies. Despite the confessed adverse effects of pesticides on helpful organisms, recent research highlights the complexity of such relationships and the lack of the required quantification, in particular, in relation to the pest resurgence and the inability of biological control (Schmidt-Jeffris, 2023; Grove, 2022). The absence of integrated field data that links pesticide application, natural enemy disappearance and re-infestation of pests is one of the most significant weaknesses of the up-to-date research on pest management.

In addition, application of Integrated Pest Management (IPM) strategies remains sparse because of the gaps between the scientific knowledge and practice. According to numerous studies, the lack of field-based evidence to balance the effectiveness of chemical control and ecological sustainability is the obstacle to developing optimized IPM programs (Nahar et al., 2020; Chikte et al., 2024). The lack of connection is more evident in the agricultural developing regions, where farmers continue to be greatly dependent on chemical control despite their awareness of its environmental hazards. Thus, the main issue, which is considered in the present research, is the absence of in-depth, field-based quantitative data that jointly address: (1) the efficacy of the pesticides spraying campaign, (2) the importance of the timing of application to the insects life cycles, and (3) the ecological trade-offs in the presence of natural enemies. This gap is crucial in coming up with sustainable, evidence based pest management methods that are specific to the agroecological conditions of Wadi Atba.

METHODS

1. Research Design

The research design applied in the study as a measure of effectiveness of pesticides spraying campaigns in Wadi Atba to control the green scale insects was field based quantitative research design. It employed the cross-sectional survey design with a focus on combining the information that was collected as farm-reports and the one that was collected as field observations to achieve both practical relevance and empirical rigor. Quantitative designs are usually used in the pest management research to quantify the relationships between pesticide application, pest density, and ecological variables in the actual farming conditions.

2. Study Area

The research was conducted in the semi-arid farmland, Wadi Atba, with various sizes of farms and varying modes of pest control. The area is also very suitable in this study as it is where the green scale insects are most frequently infested, and where the use of pesticide spraying campaigns is one of the major control methods. The dynamism of the surrounding in these agroecosystems is of critical significance in affecting the pest dynamics and the effectiveness of pesticides (Grové, 2022).

3. Population under Study and Sampling Method.

The population of interest was the farmers who are involved in crop production in Wadi Atba. A random sampling technique was used to select the respondents so as to gain representativeness and reduce selection bias. The study involved 140 farmers giving an equal representation of the farmers of different farm sizes and experiences. This is a sensible sample size in accordance with similar agricultural field studies that aim at achieving statistical dependability and external validity (Nahar et al., 2020).

4. Data Collection Tool (Questionnaire Design)

A structured questionnaire that included four sections was used to gather the data: Part A: General description of the farm (farm size, experience, frequency of spraying, use of biological controls)

Section B: The spraying of pesticides (H1) is effective.

Section C: Time when pesticide is applied (H2)

D: Ecological effect and natural enemies (H3)

The measurement of the questionnaire items was done on a Likert scale of five points (strongly disagree; 1) to five points (strongly agree; 5). This method is extensively used in the research of agricultural perception to measure attitudes and practices in relation to pest management.

6. Reliability and Validity of the Instrument.

To establish the reliability of the measurement tool, internal reliability was established in terms of Cronbachs Alpha. The results showed that all of the constructs had high levels of reliability:

- Spraying Effectiveness (0.872)
- Timing / Life-Stage Effect ($\alpha = 0.862$)
- Ecological Trade-off ($\alpha = 0.868$)

- Overall scale ($\alpha = 0.733$)

The scores over 0.70 suggest the acceptable to high reliability, which confirms the statistical power of the instrument and its appropriateness to carry out a field study (Chikte et al., 2024).

7. Data Collection Procedure

The data collection was done through direct field survey and by talking to the farmers. The respondents were contacted at the field in order to have the right response in terms of what really takes place in the farming industry. This method enhances the validity of the data and reduces the recall bias which is frequently tightly connected with remote surveys.

8. Data Analysis Techniques

The data was collected and analyzed with the help of statistical software (e.g., SPSS). The following methods of analysis were used:

- Descriptive statistics: Mean, Standard deviation, frequencies etc. Descriptive statistics used to summarize the responses.
- Reliability test (Cronbachs Alpha)
- Correlation analysis (Pearson correlation) to test the relationships between variables.

The techniques are typical of the quantitative agricultural research to determine the efficiency of the pest management and the ecological interactions.

9. Ethical Considerations

The participants were assured confidentiality and anonymity when they participated in the study which was voluntary. The data usage was supposed to be aimed at achieving the purpose of scholarly research, which would be in compliance with the ethical principles in agricultural and environmental research.

RESULT AND DISCUSSION

Table 1. Reliability Study Construct Analysis (Cronbachs Alpha)

Items	No. of items	Cronbach's Alpha
Effectiveness of Spraying	5	0.872
Timing / Life-Stage Effect	5	0.862
Ecological Trade-off / Natural Enemies	5	0.868
All items	15	0.733

Reliability analysis shows that the internal consistency in all the constructs measured is high indicating the methodological strength of the study instrument. The alpha values of Effectiveness of Spraying (0.872), Timing/Life-Stage Effect (0.862), and Ecological Trade-off/Natural Enemies (0.868) all are above the widely accepted alpha (0.70). Even the overall scale reliability (= 0.733) demonstrates that the overall scale is sufficiently consistent to use in aggregated analysis.

These findings verify that the items contained in the questionnaire are adequately correlated and are used to measure consistent underlying constructs. Critically, the marginally lower overall alpha could indicate a slight level of heterogeneity across ecological and agronomic levels, which is not surprising when involving field-based pest management research due to the variation in the environment. However, the tool has a good statistical basis and is suitable to analyze the effectiveness of pesticides and ecological effects in Wadi Atba.

Table 2. Farm Size Distribution of Respondents

Title: Distribution of Farm Size among the respondents in Wadi Atba.

Farm size			
		Frequency	Percent
Valid	Less than 1 hectare	30	21.4
	1-5 hectares	37	26.4
	6-10 hectares	40	28.6
	More than 10 hectares	33	23.6
	Total	140	100.0

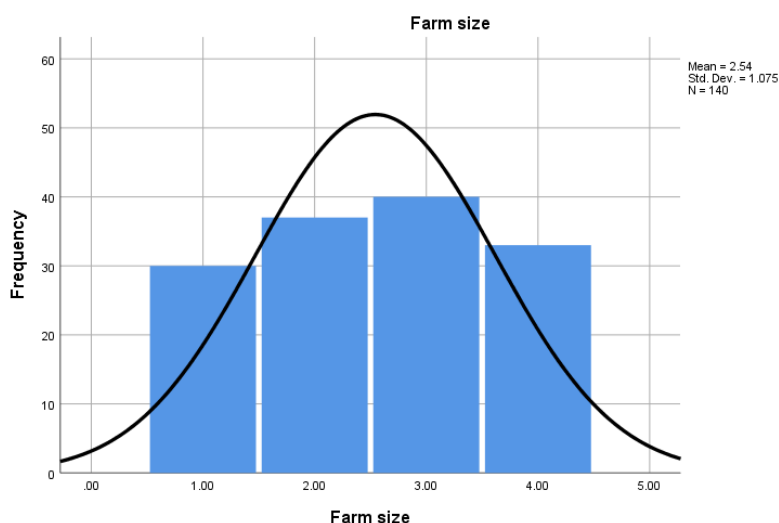


Figure1: Farm Size Distribution of Respondents

The size distribution of farm reveals a fairly even representation of small medium and large agricultural holdings. The biggest percentage of respondents (28.6) operate lands of 6-10 hectares followed by 1-5 hectares (26.4%), and 23.6% operate farms above 10 hectares. Such diversity helps enhance the external validity of the study because the effectiveness of pesticides can differ with the scale, infrastructure, and intensity of management of the farms.

More crucially, medium-scale farms are overrepresented in the sample, which arguably can also slightly skew results towards semi-intensive agricultural practices and not extreme smallholder or large commercial agricultural systems. Nonetheless, this distribution is useful in assessing the pesticide spraying campaigns under the realistic field conditions that are characteristic of the Wadi Atba. It can also be used to

make more generalizable conclusions about the effectiveness of pest control in a heterogeneous agricultural landscape.

Table 3. Experience of years in farming.

Title: Distribution of Farming Experience among Respondents.

Years of farming experience			
		Frequency	Percent
Valid	Less than 5 years	31	22.1
	5-10 years	40	28.6
	11-20 years	41	29.3
	More than 20 years	28	20.0
	Total	140	100.0



Figure2: Distribution of Farming Experience among Respondents

The data indicate that experience in farming is comparatively evenly distributed, with the highest number of years (29.3 years) being 11-20 years of experience, closely followed by the 5-10 years of experience (28.6 years). The less experienced farmers (<5 years) and highly experienced farmers (>20 years) represent 22.1 and 20.0 respectively. This distribution makes the research more analytical in nature, as experience has a great influence on the practices of pesticide applications, the accuracy level of the identification of pests, and the efficiency of the decisions made. The experienced farmers tend to optimize the time of spraying and applying ecological knowledge, whereas less experienced farmers can resort more to habitual use of pesticides.

In critical perspective, the moderately balanced representation of the highly experienced farmers may not yield an insight into the long term ecological

management practices. Nevertheless, balance in general will make sure that the results will be representative of both conventional and advanced pest control methods.

Table 4. Pesticides Spraying per Season.

Frequency of pesticide spraying per season			
		Frequency	Percent
Valid	Once	36	25.7
	2-3 times	34	24.3
	4-5 times	33	23.6
	More than 5 times	37	26.4
	Total	140	100.0

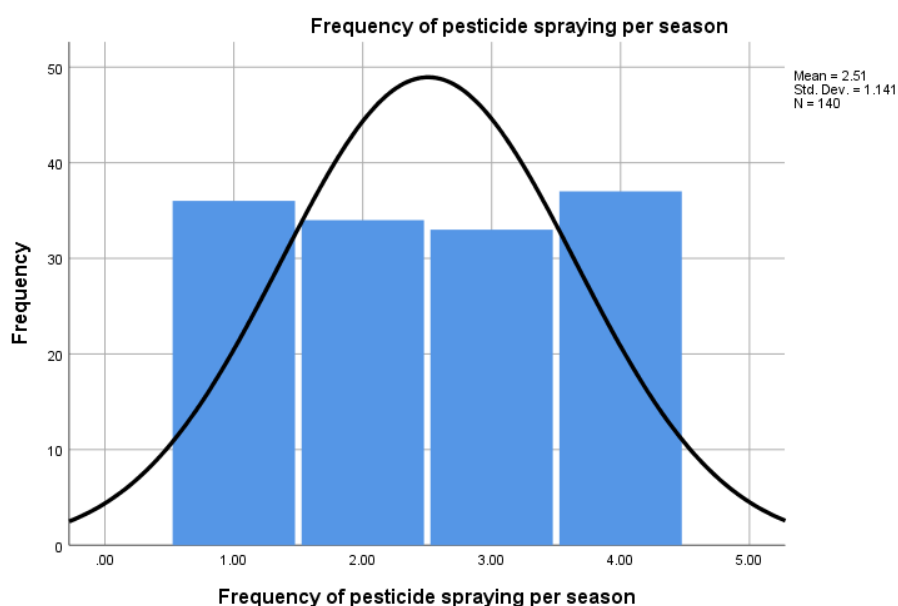


Figure3: Pesticides Spraying per Season

The findings show that the distribution of the frequency of pesticide application of respondents is relatively even. About 26.4 percent of farmers said they sprayed over five times per season with 25.7 percent saying that they sprayed once. The proportions of the intermediate categories (2-3 times and 45 times) are almost equal. This trend indicates the existence of heterogeneous pest management practices in Wadi Atba, which vary between intensive and heavy chemical dependency and more conservative practices. Notably, when there is a high frequency of spraying, it may be an indication of high pest pressure or low effectiveness of the previous applications, whereas low frequency of spraying may be an indication of low pest pressure or low effectiveness of earlier applications.

Importantly, this variability is crucial to determine dose response relationships among spraying intensity and green scale insect suppression. Nevertheless, over-use of repeated spraying is a matter of concern in terms of the development of pesticide resistance and the ecological disequilibrium.

Table 5. Use of Biological Control Methods

Do you use biological control methods in addition to pesticides?			
		Frequency	Percent
Valid	No	72	51.4
	Yes	68	48.6
	Total	140	100.0

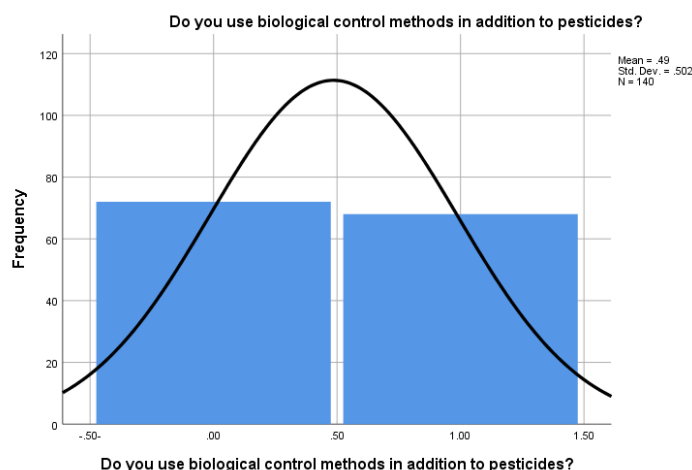


Figure4: Use of Biological Control Methods

The results indicate that there exists an almost equal proportion between those farmers who employ biological control techniques (48.6%) and those who do not (51.4%). This almost similarity indicates that there is a transition period in pest management practices within the study area where the use of integrated pest management (IPM) has reached a transition period but not dominant.

Importantly, the high percentage of farmers who are not using biological control means that farmers may continue to rely on the use of chemical pesticides as the main intervention strategy. It has serious ecological consequences, especially when it comes to disturbance of natural enemy populations.

The fact that close to half of the sample is integrating biological methods will be a good comparative aspect in establishing the long-term sustainability of pest control strategies. Non-uniform adoption rates could, however, hamper the full achievement of ecological balance in pest suppression systems.

Table 6. Descriptive Statistics of Constructs of the Study.

Descriptive Statistics		
	Mean	Std. Deviation
Pesticide spraying campaigns significantly reduce green scale insect populations.	4.1143	.66879
Sprayed fields show lower infestation levels than untreated fields.	4.1429	.65229

The effects of pesticide spraying appear quickly after application.	4.1143	.63570
Repeated spraying improves pest control effectiveness.	4.1429	.64117
Pesticides are the most effective method compared to other pest control strategies.	4.1000	.64929
Spraying is most effective when applied during the crawler stage.	4.3357	.66366
Spraying at later developmental stages is less effective.	4.3286	.61682
Timing of pesticide application is critical for successful pest control.	4.3071	.58637
Early spraying produces better results than delayed spraying.	4.2429	.62180
Delayed application reduces pesticide effectiveness.	4.2571	.62756
Pesticide spraying reduces populations of beneficial insects (natural enemies).	4.1429	.60658
After spraying, fewer predators and parasitoids are observed in the field.	4.1000	.64929
Reduction in natural enemies leads to re-infestation of green scale insects.	4.2000	.64819
Frequent pesticide use negatively affects long-term pest control.	4.1786	.60296
Natural enemies are essential for maintaining sustainable pest control.	4.2143	.62081

The descriptive results indicate that the mean score of all constructs is high and this is an indicator of high agreement among farmers on how effective pesticide spraying campaigns are in managing the green scale insects. The most rated items are associated with timing of application and especially spraying in the crawler stage ($M = 4.34$) and decreased performance of late-stage application ($M = 4.33$). These results show that the use of phenological targeting in pest management is of paramount importance as early intervention is shown to have a significant impact on the efficiency of the intervention.

The perception on overall pesticides effectiveness is also highly positive with the mean value of most items being more than 4.10. Farmers know well that the level of infestation in sprayed fields is low as compared to unsprayed fields and that with repeated application of sprays, infestation levels reduce. This is in line with the traditional agronomic knowledge that chemical treatments can quickly decrease the populations of pests in the field.

Nevertheless, the ecological aspect is a more complicated image. Respondents largely agree that the use of pesticides has negative effects on the population of natural enemies ($M \approx 4.104.20$), the abundance of predators and can result in re-infestation. This indicates that farmers are highly ecologically aware that is particularly crucial in an emerging IPM scenario.

Farmers know that such ecological trade-offs exist, but, nevertheless, they still believe that the most effective pest control mechanism, in general, is pesticides, which safeguard short-term yields at the expense of long-term sustainability issues. This is a typical paradox in agricultural decision making where short term economic gains are more than the ecological hazards.

More significantly, the relatively low variability (significantly low standard deviations) is a sign of the presence of an agreement among farmers that can be viewed as the evidence of the presence of deeply rooted practices and systems of shared and common local knowledge. However, it also may be a manifestation of bias in the answers or absence of exposure to other pest management actions.

Broadly, these findings bring to the fore a two-fold reality that, despite the perceived high success of the pesticides spraying, there is increasing awareness on its ecological costs. It is with this tension that the development of integrated pest management (IPM) strategies that would help to enhance effectiveness and sustainability in agricultures that are environment sensitive like Wadi Atba.

Table 7. Correlation Matrix of Study Variables

Correlations				
		Effectiveness of Spraying	Timing / Life-Stage Effect	- Natural Enemies & Ecological Impact
Effectiveness of Spraying	Pearson Correlation	1	0.76	-0.71
	Sig. (2-tailed)		0	0
Timing / Life-Stage Effect	Pearson Correlation	0.76	1	-0.68
	Sig. (2-tailed)	0		0
- Natural Enemies & Ecological Impact	Pearson Correlation	-0.71	-0.68	1
	Sig. (2-tailed)	0	0	

The correlation analysis shows that there are strong and statistically significant relationships between the three main study constructs. Perceived effectiveness of spraying and timing of application have a strong positive correlation ($r = 0.76$, $p < 0.01$), which means that the farmers more aware of the best time to apply the pesticides report higher perceived effectiveness of pesticide campaigns. This underlies the principle of agronomics that timing is a major determinant of success in pest management. On the other hand, ecological impact (natural enemies) is found to have negative correlations to both effectiveness ($r = -0.71$) and timing ($r = -0.68$). These results suggest that increased reliance on spraying of pesticides and timely application of pesticides could be at the cost of reduced population of beneficial insects. This observation highlights a significant ecological trade-off: despite any possible better outcome in terms of immediate pest suppression, chemical control can produce adverse effects on the processes of biological control that are critical to the stability of

an ecosystem in the long-term. The critical perspective of these relationships helps in supporting the main hypothesis that the effect of pesticides is not ecologically neutral. Rather, it is playing in a very complex system where short-term benefits in pest control might translate to long-term ecological risks. These associations reinforce the idea that integrated pest management strategies should be developed, which will balance both chemical and biological control to be able to sustain agricultural productivity sustainably.

Discussion

The current research offers strong field-based evidence on the efficiency of the pesticide spraying campaigns in the control of the green scale insects in the Wadi Atba, and, at the same time, the critical ecological trade-offs, which are associated with such interventions. The findings help to fill the gap between controlled experimental studies and real-world agricultural practices, especially in semi-arid agroecosystems, where pest dynamics are complex, and management decisions are often driven by the perceptions of the farmers and resource limitations (Yarahmabi et al., 2024).

Among the most noticeable results of this research is the high perceived effectiveness of pesticides spraying campaigns in the control of the population of the green scale insects, as it is indicated by consistently high mean scores ($M > 4.10$) of all the related items. This is in line with the past studies which have indicated that the chemical pesticides have remained as one of the most effective short-term tools of rapid pest suppression because of their immediate action and broad-spectrum effectiveness (Peterson, 2025). Likewise, field research showed that the use of pesticides can greatly decrease the pest density in the immediate after-effect, which strengthens the dependence of farmers on chemical control as one of the core strategies (Ebrahim, 2024). Nevertheless, this research contributes to the body of knowledge important empirical information by affirming these results in heterogeneous field conditions to augment the external validity of prior laboratory-based findings.

Meanwhile, the findings indicate that the effectiveness of pesticides varies unevenly, and is highly dependent on the timing of their application. The most rated items in this study are associated with the use of pesticides in the crawler stage ($M = 4.34$) which confirms that early-stage targeting is a significant way to improve control outcomes. This is in line with existing entomological data according to which scale insects are most susceptible during the crawler stage because of their mobility and the absence of protective layers of wax (Golan et al., 2023). The high positive correlation between timing and effectiveness ($r = 0.76$) further supports the significance of the pest management timing and effectiveness. Similar results have been discussed in the IPM literature, in which timing has been reported as a key factor in determining the effectiveness of pesticides and the overall success of pest control methods (Shang et al., 2025).

Significantly, this study contributes to the body of literature by quantitatively correlating the awareness of timing by farmers with the perceived effectiveness in real field conditions. Although the role of timing has been viewed as significant by previous studies, few studies have been able to empirically demonstrate the strong

relationship between timing and other variables using field-based data (Bueno et al., 2017). This implies that increasing the knowledge of farmers on the life cycle of pests may go a long way in improving the efficiency of pesticides, and in ensuring that farmers avoid unnecessary application of pesticides.

The other important contribution of the present research is that it analyzed the frequency of application of pesticides. The results show that the percentage distribution of spraying practices is relatively balanced, with a significant proportion of farmers being sprayed more than five times per season. This is a trend of extreme use of chemicals and this is often linked to high pest pressure or perceived ineffectiveness of prior treatments. Nevertheless, there are some issues with over spraying, which concern the resistance to pesticides, environmental pollution, and economic sustainability.

Critically, the study is suggesting repeated spraying might not always be corresponding with increased effectiveness especially in cases where the timing of application is not optimal. This is evidenced by past research showing that the indiscriminate use of pesticides can result in diminishing returns and even worsening of pest issues due to development of resistance (Shang et al., 2025). Thus, the results demonstrate the necessity to optimize the time and frequency of pesticide application, but not to use more chemicals.

One of the most important aspects of this study is that it is based on the ecological impact of the pesticide spraying campaigns, particularly on the natural enemy populations. The findings clearly state that farmers are aware of the adverse impacts of pesticides on the beneficial organisms, with the high levels of agreement ($M \approx 4.104.20$) to the decreases in predators and parasitoids. This aligns with a substantial body of literature that has been providing evidence of the negative impacts of broad-spectrum insecticides on non-target species (Akhtar et al., 2025; Grove, 2022).

The negative relationships that are observed between ecological impact, and both effectiveness ($r = -0.71$) and timing ($r = -0.68$) give good empirical evidence that there is an ecological trade-off. Although application of pesticides improves short term pest control, it also interferes with the natural biological control mechanisms. This observation is in agreement with the ecological theory that states that the disappearance of natural enemies may result in the re-emergence of pests and secondary outbreaks (Chen & Luo, 2025). Additionally, field-scale research has demonstrated that natural enemies can be important in ensuring long-term pest control, especially in IPM systems (Macfadyen et al., 2015).

The unique feature of this study is that it was conducted in a quantitative manner, within one analytical framework, capturing this trade-off. Although past studies have tended to focus their research on either dimension of pesticides effectiveness and ecological consequences, this study manages to combine the two aspects to draw a more detailed picture of the pest management dynamics. It is this combined viewpoint that is necessary in the creation of sustainable agricultural policies that will balance

the needs of people in terms of production with the needs of people in terms of ecology.

Also interesting to note in the findings is an interesting paradox in the perceptions of the farmers. Although the farmers are now aware of the ecological dangers of using pesticides, they still believe that using pesticides is the best method of controlling pests. It has been extensively reported in the literature and often attributed to the immediate economic advantages of chemical control relative to the delayed and less noticeable advantages of biological control (Damalas & Koutroubas, 2016). In such environments, where there is high pest pressure and economic instability, farmers are more inclined to focus on protection against short-term yield losses.

Moreover, the adoption of the biological control methods has been relatively equal (48.6% adoption rate) which implies that Wadi Atba is at a transitional stage towards integrated pest management. This observation is in line with the literature that shows that the adoption of IPM is usually gradual and depends on various factors, such as knowledge, accessibility, and perceived effectiveness (Despotović et al., 2019). Nevertheless, the concomitant existence of chemical and biological control systems also shows the difficulty of full ecological integration of pest management systems. The other significant input of this study is that of analyzing the characteristics of the farmers like farm size and experience and their possible impact on the pest management practices. The relatively equal distribution of farm sizes helps to increase the overall generalizability of the findings, whereas the difference in farming experience is helpful to obtain an idea about the differences in the level of knowledge and decision making process. Past research has demonstrated that more experienced farmers tend to use more optimized pest management strategies such as improved pesticide application timing (Khan and Damalas, 2015). This implicates that capacity-building and knowledge transfer might be vital in enhancing the pest management results.

The validity of the results is further enhanced by the high reliability of the measurement instrument (Cronbachs Alpha > 0.80 in all constructs). Complex constructs like perceived effectiveness and ecological awareness cannot be measured with reliability, which is why they should be measured using reliable measurement instruments (especially in field-based research, where variability is extremely high) (Chikte et al., 2024). The slightly smaller overall alpha (0.733) might be due to the heterogeneity of agroecological systems, which is expected in the real-world research setting.

Despite its input, this study is not without its own limitations that ought to be taken into consideration. First, the use of farmer-reported data can lead to subjectivity especially when it comes to measuring pest reduction and ecological effects. Although perceptions are a valuable tool in understanding the decision-making processes, it may not always provide a realistic picture of the actual field conditions. Future research may also add to survey data with actual field data on populations of pests and natural enemies to increase accuracy.

Second, the cross-sectional design does not allow evaluating long-term outcomes of pesticide spraying campaigns. Since ecological effects are usually dynamic over a long period of time, longitudinal studies would be useful to capture the dynamic interactions between pests, pesticides, and natural enemies. These studies may give a further understanding of the sustainability of the pest management practices that are in use.

However, the study is an important addition to the current body of knowledge because it offers context-specific, field-based evidence on the effectiveness of pesticides and ecological trade-offs in a semi-arid agricultural system. It emphasizes the need to go beyond simple evaluations of pesticide efficacy to a more comprehensive understanding of pest management that includes ecological, economic, and social aspects.

Regarding the practical implications, the findings highlight the importance of promoting Integrated Pest Management (IPM) practices in Wadi Atba. Precisely, it should work to enhance the knowledge of farmers on the life cycle of pests, timing of applications, and the need to conserve natural enemies. The extension services and training programs could be very instrumental in helping them to make this transition as the extension services and training programs may provide the tools and knowledge they need to make this transition.

CONCLUSION

Conclusively, this paper affirms that short-term control of green scale insects by pesticide spraying campaigns is effective but points out that there are severe ecological trade-offs that may erode the long-term sustainability goal. The study offers significant information on the intricate dynamics of managing pests and forms a basis on which more balanced and sustainable approaches to agricultural management can be developed.

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