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Evaluation of Insect Control Programs Using Time-Series Data

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Abstract: This research was intended to determine the usefulness of insect control programs in the form of time-series data in analyzing the insect density and abundance changes in subsequent time intervals. The experiment was held in various locations that differed in terms of the environment (agricultural, urban, and semi-natural) and the environmental features of each of the locations were documented. The experiment focused on the most widespread and the most significant insect species, such as flies, mosquitoes, aphids, and locusts. Different control programs were used such as chemical control, biological control, and integrated pest management (IPM) and insect data was collected systematically through light and sticky traps and periodic manual sampling. The outcome showed the substantial decline of insect population after the use of control programs with a percentage change between 41.7% - 60% being the relative change of the insects based on the species and the period of follow-up, where flies recorded the highest percent change. The statistical results (t-test and ANOVA) demonstrated the existence of the significance between the pre- and post-control periods. Correlation applied to the different environmental variables and the abundance of insects were found to be affected by the humidity factor the most in terms of its positive effect on the increase in the insect populations, high temperatures and wind speed affected the factor negatively thus showing the significance of combining the environmental factors in the development of control programs. These results indicate that integrated pest management programs are effective in decreasing the level of insects and maintaining performance in both short-term and medium-term, and additional performance increases can be reached by using accurate environmental monitoring and the right time of intervention.

Keywords: Insect control, time-series data, integrated pest management, time-series analysis, environmental factors.

INTRODUCTION

The insects are also an essential part of the ecosystems and they assist in pollination, organic compounds decay, and food chain (Verma, R. C. *et al.*, 2023). Nevertheless, they may also become dangerous pests that have adverse effects on farming and human health. A number of insect species, including flies, mosquitoes, aphid and locusts, act as vectors of diseases or direct damage of crops and a program to control them should be implemented to protect the health and food security of the people (Ali, M. A. *et al.*, 2023). The rise of population, land use, and climatic changes have resulted in the expansion of the range of some species of insects causing pest control to be a constant problem by scientists and practitioners (Ma, C. S. *et al.*, 2025).

In this regard, conventional control programs that use chemical insecticides only, cannot be effective in the long run with most of them experiencing problems of insect resistance, environmental risks as well as exposures to non-target organisms (Tiwari, A. K. 2024). Hence there has been increased focus on the Integrated Pest Management (IPM) programs where several strategies such as chemical and biological control are integrated with environmental and behavioral interventions (Tiwari, A. K. 2024). The strategy minimizes the use of the chemical insecticides and increases sustainability of the control results (Abbasi, E. 2025).

To determine the effectiveness of these programs, it is necessary to carefully track the temporal changes in the density and abundance of insects, which is possible by using time-series design (Wauchope, H. S. *et al.*, 2021). This design will facilitate the comparison of the insect populations prior to the use of the control programs, during and after the use of such programs (Rowen, E. K. *et al.*, 2022). The environmental conditions, including temperature, humidity, wind and rainfall are very important in the identification of insect activity and distribution and inclusion of these variables in the assessment enables one to conceive a better idea of the insect community dynamics and the performance of the control programs in different natural conditions (Brown, J. J. *et al.*, 2023).

The current research is expected to determine the effectiveness of various insect control programs at various sites which represent the agricultural, urban and semi-natural ecosystems with emphasis on temporal dynamics of the target species of flies, mosquitoes, aphids and locusts. Besides, the analysis examines the correlation between environmental factors and the density of insects to offer evidence-based measures in the future to enhance control measures, lessen the use of chemical insecticides, and enhance environmental sustainability.

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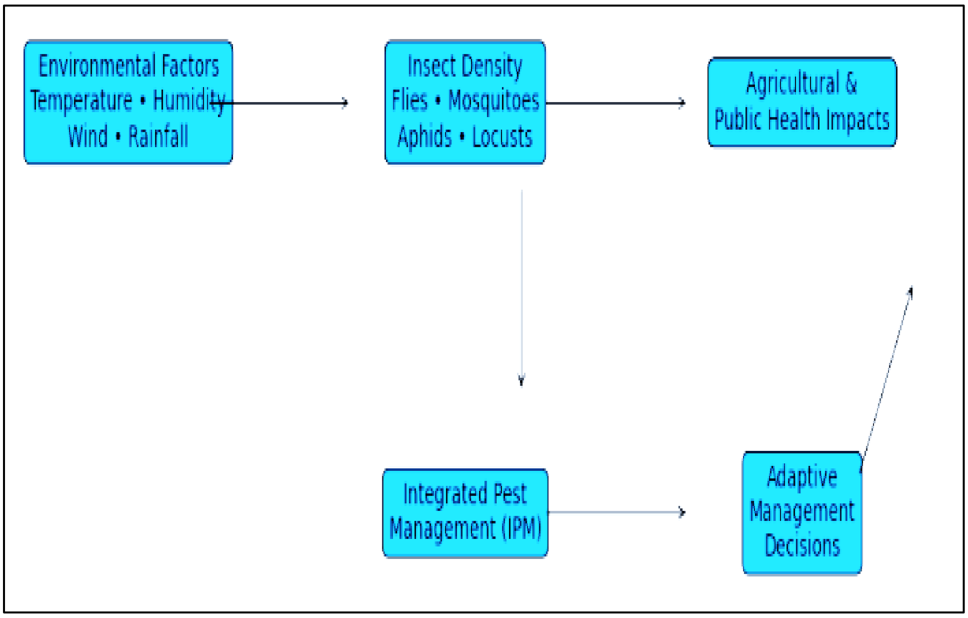

Figure 1 : Causal loop diagram of insect control,Environmental drivers and adaptive management

MATERIALS AND METHODS

Study Area

The experiment was carried out in a few chosen locations that consist of different kinds of environments (agricultural, urban and semi-natural) to assess the effectiveness of insect control programs in different environmental conditions. The sites were selected on the basis of existence of target insect groups and frequent use of the control programs. Geographic location of every site was also recorded, as well as the general environment description (type of vegetation, soil type, and human activity).

Study Design

The time series experimental approach was used to monitor the time-based variation in insect density and abundance in order to determine the effectiveness of the pest control programs. The design will enable the comparison of pre- and post-treatment measures, which will enable the identification of the effect of the program rather than the natural differences. The research was split into three phases, in which the pre-control phase was to determine the initial levels of insects, the active control phase to measure the immediate responses and the post-control/follow-up phase to determine the persistence of the effects and the possible re-emergence of populations.

Target Insects

The research was based on the most prevalent and significant insects found in the study areas, disease vectors like flies and mosquitoes, agricultural pests like aphids and local locusts. Standard taxonomic keys were used to identify the species with the order and family of each species recorded**.**

Pest Control Programs

Some of the pest control programs were compared, such as chemical control with registered insecticides, biological control with natural enemies or environmental factors, and Integrated Pest Management (IPM) with the combination of several strategies. The specifics of every program such as the kind of control, active ingredients, dose of application, application method and timing were recorded correctly**.**

Time-Series Data Collection

Insect Sampling Methods

Insect data were collected using a variety of techniques that included light and sticky traps, periodic manual collections, ground or aerial traps by different species of insect based on the species of interest(Sahayaraj, K., & Hassan, E. 2023). Systematic collection of data was done on a daily or weekly basis over the period of study, and at the same time of sampling was used in all sites to reduce the possibility of bias by time, as well as to facilitate comparative analysis.

Recorded Variables

Time-series data were recorded that comprised the number of insects caught at a given unit time, species, site of collection, collection date and time, and control stage (pre- or post-treatment) (Kavallieratos, N. G. 2025). These variables were utilized in generating accurate time-series data to examine temporal variation of insect density and

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abundance and determine how control programs change with time.

Associated Environmental Variables

In order to understand temporal changes in insect populations, environmental variables that were measured simultaneously with each of the sampling periods included the use of temperature, relative humidity, wind speed, and rainfall wherever it occurred (Mazarire, T. T. *et al.*, 2024). These variables were analyzed to determine their association with the dynamics of insect communities and to aid in the explanation of fluctuations in abundance and density of insects over time other than the direct impact of the control programs.

Data Processing

Data obtained passed through pre-processing stages, that is, data validation, using outliers, missing values, and standardization of time intervals so that there would be uniformity in analysing the time-series. The data were then arranged in numerical tables with the help of suitable statistical software to be used in further analysis.

Statistical Analysis

Time-Series Analysis

Time-series graphs were used to analyze temporal data to demonstrate the variation over the various periods and trend analysis and seasonal analysis to show patterns that are related to insect population changes (Basset, Y. *et al.*, 2023).

Assessment of Control Effectiveness.

The level of control was determined by determining the proportion of the change in the abundance of insects at the pre-treatment and post-treatment stage by the use of the following formula:

Percentage Reduction (%)= $_{post}$ N_{pre}−N / $_{pre}$N ×100

This metric was used to quantify the success of programs in reducing insect densities (PATIL, M. R. D. 2024).

Statistical Comparisons

The t-test comparing the periods before and after treatment and the analysis of variance (ANOVA) comparing sites or among various control programs were used as proper statistical tests. The effects of the control programs and other environmental factors were also estimated through time-series regression models. All analyses were adopted at a level of significance of (P \leq 0.05).

Statistical Software

Data were analyzed via R analyses, with the supplement of SPSS to organise and give descriptive analyses, and to assure the results of the analysis were accurate and interpretable.

RESULTS

Temporal variation of the Insect Density.

The table depicts a definite reduction in the abundance of insects after the control programs were implemented and flies were the ones which were reduced by the highest percentage of around 50% as compared to the baseline stage and then the mosquitoes, aphids and locusts. The figures of values are shown as the mean standard deviation per trap/day.

Table 1. Mean Number of Insects that were caught/pest control stage.

Stage	Flies (No./trap/day)	Mosquitoes (No./trap/day)	Aphids (No./trap/day)	Locusts (No./trap/day)
Baseline (Pre-control)	120 ± 15	85 ± 10	50 ± 8	30 ± 5
During Control	70 ± 12	40 ± 7	25 ± 5	15 ± 4
Post-Control & Follow-up	60 ± 10	35 ± 6	20 ± 4	12 ± 3

The bar chart (figure 2) shows that the population of insects has steadily decreased during the three phases, which has been caused by pest control programs.

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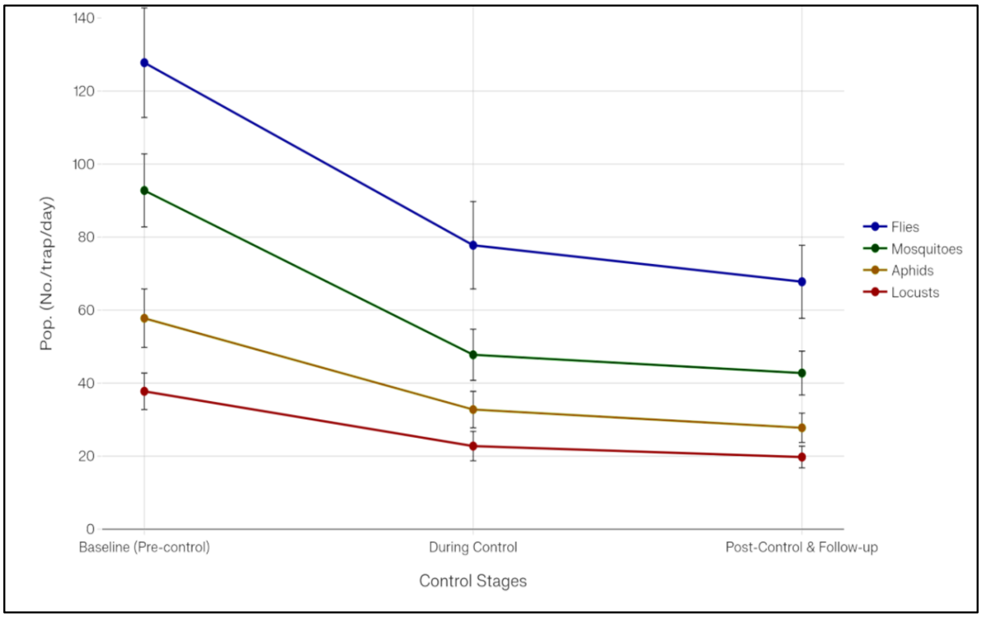

Figure 2 :Population density of pests across control stages

Pest Control Effectiveness Assessment.

The table indicates the relative decrease in insect population after adoption of the control programs and during the follow up period which indicates the effectiveness of the control programs in the reduction of densities of various insect species. The decreases varied between 41.7 percent and 60 percent, according to the species and the post-control period meaning that the control effects lasted longer than the time the control was done.

Table 2. Percentage Relative Decrease in the Insect Numbers after Control

Insect Type	Reduction After Control (%)	Reduction After Follow-up (%)
Flies	41.7	50
Mosquitoes	52.9	58.8
Aphids	50	60
Locusts	50	60

The figure 3 shows that the relative decrease in density of both species of insects following control application and follow-up period indicates the disparity in the instant decrease in density during treatment and delayed decrease in density during follow-up, which reflects the short- and medium-term efficacy of the programs.

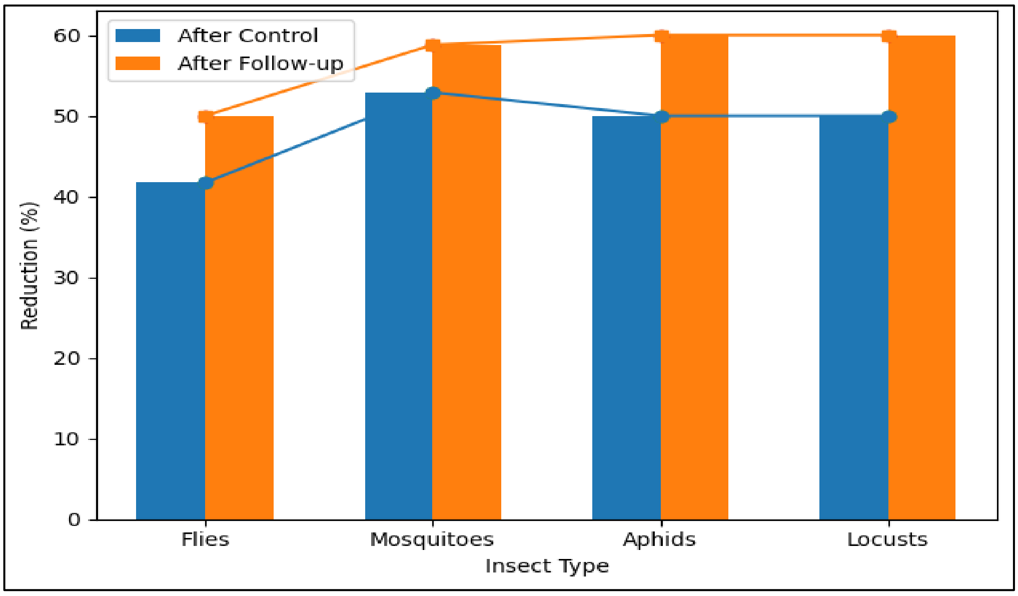

Figure 3:- Reduction percentage of insects after control and follow-up

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Relationship between Environmental Variables. The analysis of correlation shows that the influence of humidity was the most beneficial on the abundance of insects, and the negative influences were high temperatures and wind speed on densities. These findings underscore the need to watch the environmental variables in considering the efficiency of pest control programs.

Table 3. Pearson (r) Correlation of Environmental Factors and Insect Numbers.

Environmental Variable	Flies	Mosquitoes	Aphids	Locusts
Temperature (°C)	-0.35	-0.42	-0.30	-0.28
Humidity (%)	0.55	0.60	0.50	0.48
Wind Speed (m/s)	-0.25	-0.20	-0.18	-0.22
Rainfall (mm)	0.30	0.35	0.28	0.25

The figure 4 gives a graphical comparison of the effect of each environmental variable on various species of insects making it easy to identify the most effective factors on insect distribution and density.

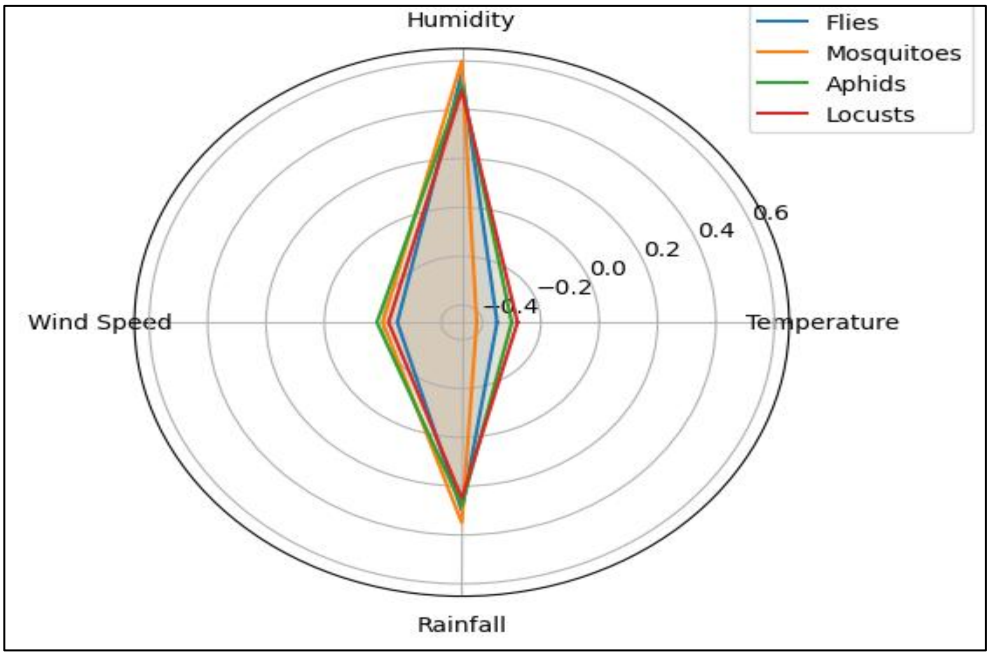

Figure 4 : Correlation patterns between insects and environmemtal variables

COMPARISON OF THE STATISTICAL ANALYSIS

Those differences between the insect abundance before and after the control application are statistically significant and prove the efficiency of the applied programs and indicate the differences in the reaction of sites and programs.

Table 4. t-test and ANOVA Results Insect Numbers by Control Stages

Test	Insect Type	Test Statistic	P-value
t-test	Flies	5.23	<0.001
t-test	Mosquitoes	6.12	<0.001
ANOVA	All species	F = 12.45	<0.001

The visual representation of the statistical findings is depicted in the figure which shows how the average numbers of each type of insect were decreased with the application of control programs, which makes it easy to compare the changes of each stage in each insect species.

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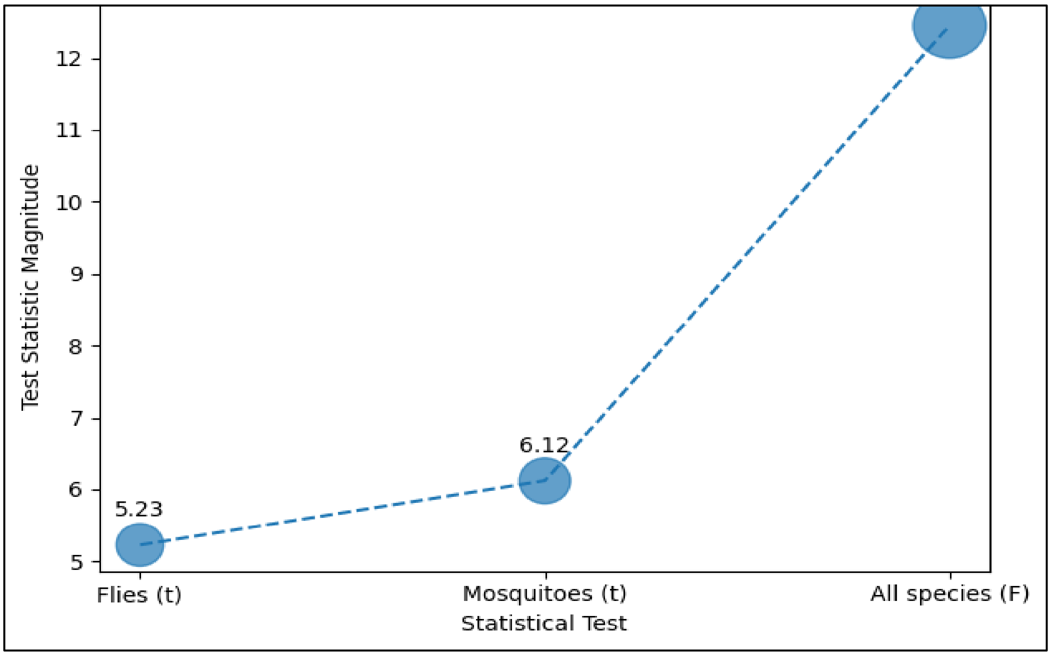

Figure 5: Bubble-line visualization of statistical test strength

DISCUSSION

The findings of the present research showed that there was a definite decrease in the number of insects after the adoption of pest management programmes as indicated by Table 1 and Figure 1. Flies showed the greatest reduction of about 50 per cent against the base level with the other insects taking second place with mosquitoes, aphids and locusts. This slow decline in the three phases suggests that the control programs influenced the instant and deferred abundance of insects, which depicts the effectiveness of the strategies utilized, be it chemical, biological or as a part of integrated pest management (IPM) programs (Yarahmadi, F., & Rajabpour, A. 2024). The higher mortality rate of flies compared to locusts or aphids can be explained by biological variation in species (Sharma, S., and Mohanty, S. 2024); flies have short life cycles, have high reproductive capacity, and live in more open habitats, and thus are more vulnerable to pesticides (Hodjat, S. H. 2025) than locusts or aphids which may live in shelters or grow in social groups and can be less affected by chemical treatments (Meissle, M. *et al.*, 2022). These results align with other earlier reports that have indicated that species that are more active and mobile are more susceptible to the insecticides as opposed to those hidden and widely distributed.

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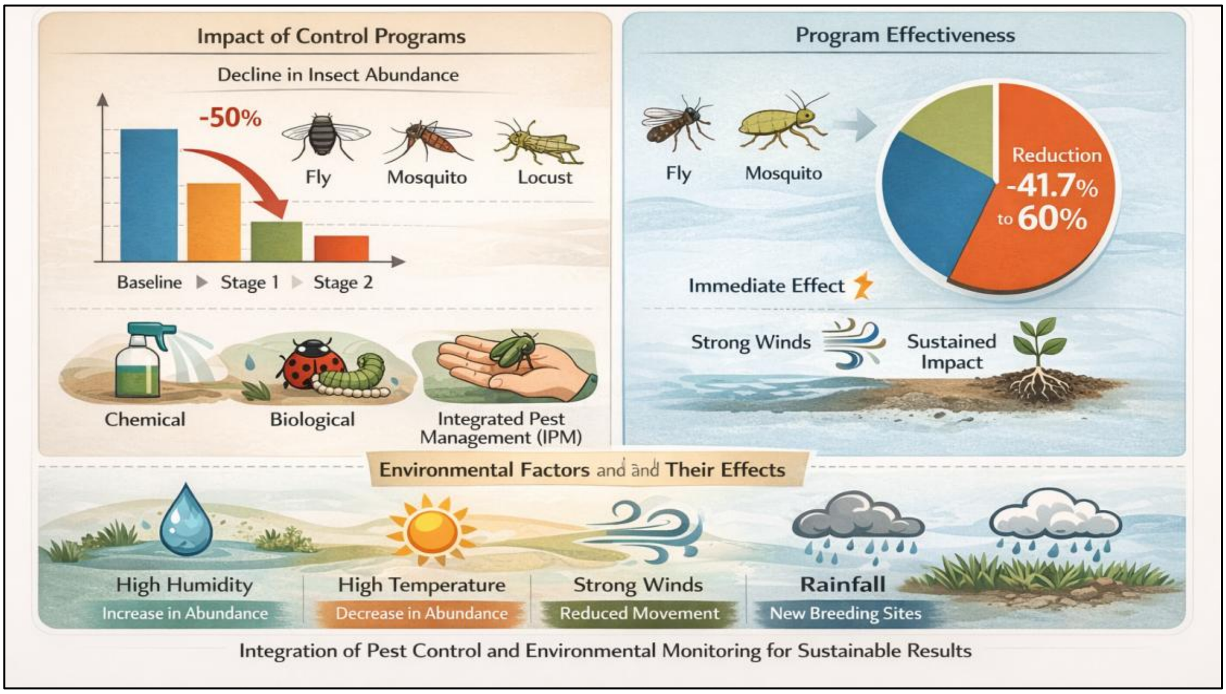

Figure 6 :- Impact of pest control programs and environmental factors on insect abundance

In relation to the impact of the environmental factors, correlation analysis (Table 3 and Figure 3) showed that there was a pronounced positive impact of humidity on the abundance of insects, but that high temperatures and wind speed had a negative impact on the densities of insects (Knop, E. *et al.*, 2023). The humid weather also offers good environment to propagation of insect species, especially the mosquitoes and flies, by increasing the survival of eggs and larvae (Prasad, P. *et al.*, 2024). Conversely, high temperatures can slow down insects or enhance water evaporation thereby lowering apparent abundance (Harvey, J. A. *et al.*, 2020). Wind speed affects insect dispersion and movement as well as may decrease trapping efficiency, whereas rainfall affects the formation of new breeding sites, which is why it was found to have positive relationships with insect abundance (Hodges, S. *et al.*, 2024). These findings highlight the need to infiltrate environmental monitoring in pest control initiatives (Yarahmadi, F., & Rajabpour, A. 2024), since climatic information may direct the most effective timeline of actions, thus enhancing effectiveness and minimizing waste patterns of pesticides (Afshari, M. *et al.*, 2021).

CONCLUSIONS

The analysis showed that the insect density had been reduced by a large margin after the introduction of pest control schemes with flies recording the most impact when compared to the mosquitoes, aphids and locusts. Relative analogy showed that the impacts of the control programs were experienced even after the application period thus depicting the efficiency of the programs in short term and medium term. It was found that the environmental factors played an important role in determining the number of insects, given that humidity was positively related to the abundance, and high temperatures and wind speed decreased the activity of insects. The results affirm that a combination of various strategies in IPM is more effective in controlling pests than approaches that apply one method of controlling pests. Environmental variables are suggested to be put in mind when planning and implementing so as to enhance efficiency of control and reduce dependence on chemical insecticides.

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