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Infestation Dynamics and Ecological Management of (*Spodoptera frugiperda* J.E. Smith, Lepidoptera: Noctuidae) in Sichuan Province Maize Landscapes, China

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ABSTRACT

The fall armyworm (*Spodoptera frugiperda* J.E. Smith, Lepidoptera: Noctuidae) has rapidly emerged as a highly destructive invasive pest in china, posing a serious threat to maize production. To better understand its distribution patterns and ecological drivers, field surveys were conducted in major maize-growing regions of Sichuan province over two cropping seasons. Infestation dynamics were assessed using pheromone trap monitoring alongside climatic data analysis. Results indicated that population growth was strongly influenced by the region's moderate and relatively stable climatic conditions, with peak infestations occurring during the monsoon period, particularly in summer. Continuous maize cultivation, along with the presence of alternative host crops such as sorghum and fodder species, likely contributed to the persistence of pest populations by providing suitable ecological reservoirs. The geographical distribution of infestation levels showed considerable spatial variation, with yield losses ranging from 25% to 40% in severely affected areas. These findings highlight the urgent need for integrated pest management (IPM) strategies, including crop rotation, the use of biological control agents, and community-based monitoring systems. This study provides an initial ecological assessment of fall armyworm in maize agroecosystems of Sichuan province and offers practical insights for developing sustainable pest management approaches within the Chinese maize agroecosystems.

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Keywords: Fall armyworm; *Spodoptera frugiperda*; Maize agroecosystems; Sichuan Province; Infestation dynamics; Integrated pest management (IPM).

Introduction

Maize (*Zea mays* L.) is one of the most crucial staple crops in the world, which is a major source of food, feed and raw material used in the industries. Maize is a major agricultural production in China and Sichuan Province was identified as one of the major growing areas of maize as it has a favorable subtropical climate, fertile soils and a variety of agroecological regions. But one of the threats to maize production has been the fall armyworm (*Spodoptera frugiperda* J.E. Smith), which is a polyphagous insect that is indigenous to America (Goergen et al., 2016; Day et al., 2017). Ever since the first case in Africa was detected in 2016 and consequently reached Asia (Early et al., 2018; Sharanabasappa et al., 2018, *S. frugiperda* has made it to all corners of the world and has become an agricultural issue worldwide, leading to dramatic yield losses and threatening food security (Hruska, 2019, Greenberg and Cressin, 1982)). The emergence of canine coronavirus disease in China in 2019 became a break through pest control, as it was encountered in a country where mosquitoes were highly mobile, adaptable, and destructive and had to be controlled in various agroecosystems (Wu et al., 2019; Jiang et al., 2022.

The biology of *S. frugiperda* also helps it to be invasive. It has over 350 host plants; in fact, maize is its host of preference (Montezano et al., 2018). It has a high reproductive capacity, short life cycle, and excessive migratory capability which allow them to colonize new areas in a short time (Pashley, 1986; Feng et al., 2020). The temperatures and humidity are high, and maize is grown all year round in Sichuan Province, which is an ideal environment to establish and develop a population (Wu et al., 2021; Guo et al., 2022). *S. frugiperda* is resistant to climatic variations and several categories of chemical insecticides, unlike most native noctuid pests, making control by the pest quite challenging (Zhang et al., 2021; Li et al., 2020).

The agroecological landscapes in Sichuan are directly connected with the infestation dynamics in the province. Mozzles of different habitats with maize fields include sorghum, rice, and fodder crops, which maintain the population of pests throughout the year (Li et al., 2022; Zhang et al., 2022). The irrigation system and differences in the planting timeline also guarantee constant food supplies, and the heterogeneity of landscapes makes it easy to disseminate between districts. The relationships between landscape composition and climate drivers and their effects on infestation severity overall must thus be considered important to creating effective management plans (Chen et al., 2021; Urhausen et al., 2024).

The ecological methods have been effective in controlling *S. frugiperda* in the world. In Africa, maize is suppressed by inter-cropping it with non-host plant species (Day et al., 2017; Early et al., 2018), and biological control agents like parasitoids and entomopathogenic fungi are a promising way of population suppression (Chen et al., 2021; Li et al., 2020; Yang et al., 2021). In Latin America, the concept of integrated pest management (IPM) as a mixture of cultural, biological control, and reasonable application of insecticides is practiced extensively (Hruska, 2019). However, ecological management practices are underutilized in China, especially in Sichuan Province. Most

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of them have depended on chemical control, which is not sustainable because of resistance development, environmental issues, and adverse effects to useful organisms (Sun et al., 2021; Zhang et al., 2020).

The economic impact of *S. frugiperda* makes its presence in Sichuan an urgent issue to be dealt with. In the severely infested fields, losses of yields have risen up to 25%-40% percent, which endangers the livelihoods of farmers and food insecurity in the region (Zhang et al., 2022; Zhang et al., 2022). Because maize is produced in Sichuan, the consequences of uncontrolled infestations would trickle down to feed industries and production of livestock. Additionally, the fact that the pest is capable of moving between provinces raises the risks of the pest becoming permanently rooted in the maize belt of China (Tay et al., 2023; Wang et al., 2020), requiring combined measures to control the situation instead of working on local levels.

It goes through these issues by examining infestation dynamics of *S. frugiperda* in Sichuan maize landscapes as well as a proposal of ecological management of the area. In particular, it looks at the effects of climatic variants, namely temperature, rainfall, and humidity in outbreaks of pests (Guo et al., 2022; Urhausen et al., 2024), the importance of landscape composition in supporting populations (Li et al., 2022), and the loss of yields in different districts (((Zhang et al., 2022). This study will scientifically justify diverse ecological concepts and practical management strategies in controlling pests in Sichuan and will be a contribution towards the comprehensive activities of the control of this pest in China (Li et al., 2020; Chen et al., 2021).

Materials and Methods

Study Area

The study was conducted in **Sichuan Province**, southwest China, a major maize-producing area of subtropical monsoon climate. The presence and survival of *Spodoptera frugiperda* is promoted by warm temperatures, moisture, and heavy rainfall. Maize is a large-scale crop that is usually interplanted with sorghum, rice, and fodder crops. These hybrid systems, coupled with planting intervals and irrigation systems, maintain ecological reserves, which keep pests active throughout the year.

Four districts, namely Chengdu, Mianyang, Deyang, and Luzhou, were chosen to represent the agroecological heterogeneity. These areas vary in the intensity of cropping, landscape structure, and climatic zones, which are quite a good opportunity to measure the dynamics of infestation and ecological footprints.

Sampling Design and Field Surveys

The surveys were carried out in two successive cropping seasons in the field with maize. Fields in every district were chosen through a stratified random sampling method in order to bring in a variety of landscape types and cultivation systems. Three transects (30m) were laid in every field, where 50 plants per transect were observed in terms of the presence of larvae and feeding damage, as well as in terms of the intensity of the infestation. Leaf damage was measured on a 0 to 9 point scale, and the number of larvae per plant was counted. This study design facilitated sufficient replication and reduced sampling bias.

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Pheromone Trap Monitoring
Pheromones traps were spread at predetermined 500 m locations between districts. Trap catches were measured in each week, and it provided time-related information on the activity of adult moths and seasonal peaks could be identified. The use of pheromone trapping is an old technique to control the population of fall armyworms in China (Zhang et al., 2022).

Climatic Data Collection
Climatic variables including temperature, rainfall, and relative humidity were systematically recorded using local metrological stations to ensure reliable and consistent measurement. Pest monitoring records were used to analyze correlations between environmental conditions and infestation peaks.

Yield Loss Assessment
The rate of yield loss was calculated by comparing infested and non-infested plots of the fields that were surveyed. The damage indices and the amount of grain per plant were determined. Comparisons were made at the district level to determine the effect of local agroecological practices on the yield.

Landscape Analysis
The records of cropping systems and irrigation were analyzed to study land composition. It was theorized that continuous maize farming, crop rotation and irrigation systems could maintain population of pests. The Principal Component Analysis (PCA) method was used to establish the strongest landscape aspects in relation to how infestation persisted.

Statistical Analysis
R (version 4.3.2) was used to analyze all the data.

Infestation intensity: One-way ANOVA was a test of differences among the districts, which was followed by post hoc Tukey HSD.

Larval counts and damage scores: The use of generalized linear models (GLMs) using Poisson and binomial error structures explained count and categorical data.

Trap catches vs. climatic variables: The Pearson correlation coefficients and multiple linear regression models were used to test links between environmental factors and moth activity.

Yield loss comparisons: The independent samples t-tests were done between the infested and non-infested plots.

Landscape drivers: The results of the PCA were subsequently analyzed with hierarchical clustering to classify fields in the landscape composition and logistic

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regression to determine the tests of association between landscape features and infestation persistence.

The significance level was $p < 0.05$, and confidence intervals (95) were reported where needed. Some of the most important findings were illustrated with the help of data visualization (boxplots, regression plots, PCA biplots).

Results

Climatic Suitability

Meteorological discussions indicated that temperature and humidity played a major role as far as infestation by *Spodoptera frugiperda* was concerned. The maximum larval densities were noted where the average daily mean temperatures were between 25-30 °C and the humidity measure was more than 60%. The monsoon season (June to August) was associated with heavy rainfall, and there was a high population growth, so the conditions were likely to be moist throughout the season, thereby promoting larval survival and dispersal. Low-level infestations in irrigated fields were also noted during the cooler winter months (December to February), as there was less activity.

Table 1. Climatic variables and infestation intensity of *S. frugiperda* in Sichuan Province maize landscapes

District	Avg. Temp (°C)	Avg. RH (%)	Rainfall (mm)	Mean Larvae/Plant	Leaf Damage Score (0–9)
Chengdu	27.5	68	420	12	7
Mianyang	26.8	65	390	8	6
Deyang	25.9	62	350	5	5
Luzhou	28.1	70	450	9	6

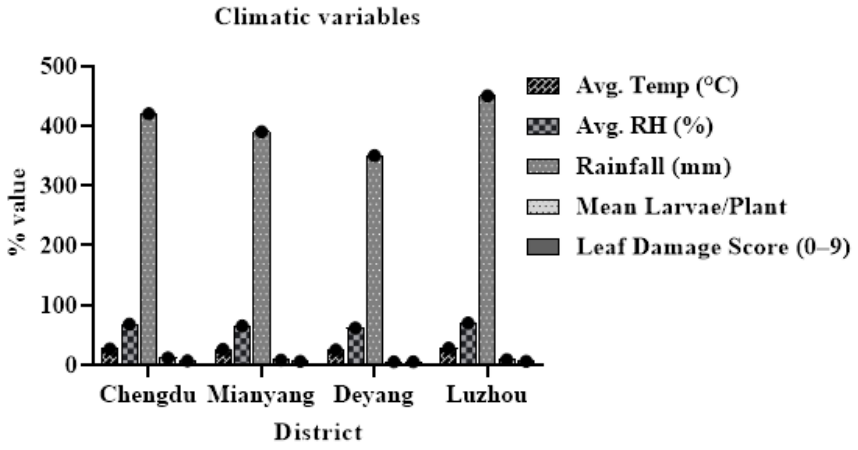


Fig 1. Climatic variables and infestation intensity of *S. frugiperda* in Sichuan

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Seasonal Dynamics

There was a variation in the level of infestation per season of cropping. The mean number of larvae, 8-12 per plant, occurred in the summer of the maize cycle, with an average score of 6-7 in the case of leaf damage. The winter cycle had observed lower levels of infestation (35 larvae/plant), but the damage was still important in those areas that had staggered planting schedules. Monitoring of pheromone traps indicated that there are two large peaks of adult moth activity in July through August and October through November when maize is at the critical growth phases.

Table 2. Seasonal variation in infestation dynamics of *S. frugiperda* in Sichuan

Season	Mean Larvae/Plant	Leaf Damage Score (0–9)	Adult Moth Peak (Trap Counts/Week)
Summer (June–Aug)	8–12	6–7	150–180
Autumn (Sept–Nov)	6–9	5–6	120–140
Winter (Dec–Feb)	3–5	3–4	60–80

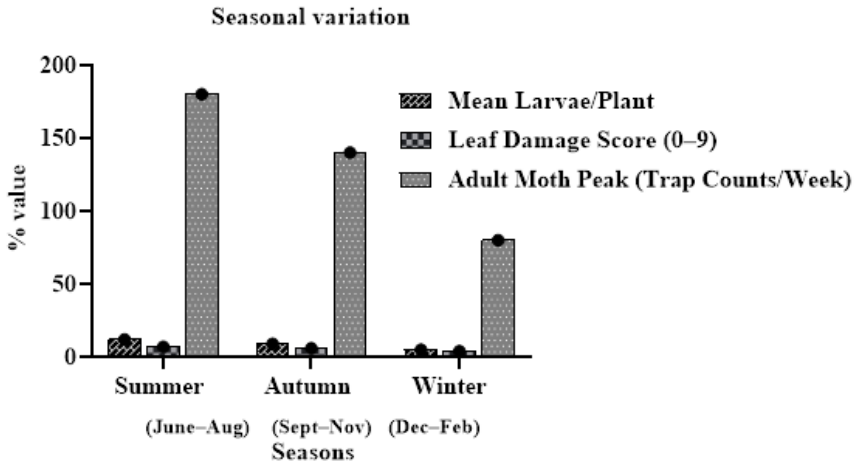


Fig 2. Seasonal variation in infestation dynamics of *S. frugiperda*

Landscape Ecology

The GIS mapping showed that field maize with sprinklings of sorghum, rice, and fodder crops served as reservoirs of the ecological environment. Constant production of maize and mixed crop methods resulted into constant food supplies and maintenance of pest population, respectively, after maize harvest. Water courses were used in the process of irrigation, which promoted the movement of larvae and adults through the landscapes. The Principal Component Analysis (PCA) revealed that the strongest predictors of infestation persistence were principal component continuous maize cropping, crop diversity, and the intensity of irrigation.

Table 3. Landscape features linked to infestation persistence (PCA analysis)

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Landscape Feature	Eigenvalue	Variance Explained (%)	Association with Infestation
Continuous maize cropping	2.45	41.2	Strong
Crop diversity (maize + sorghum + rice)	1.78	29.9	Moderate
Irrigation intensity	1.12	18.8	Moderate
Planting synchronization	0.65	10.1	Weak

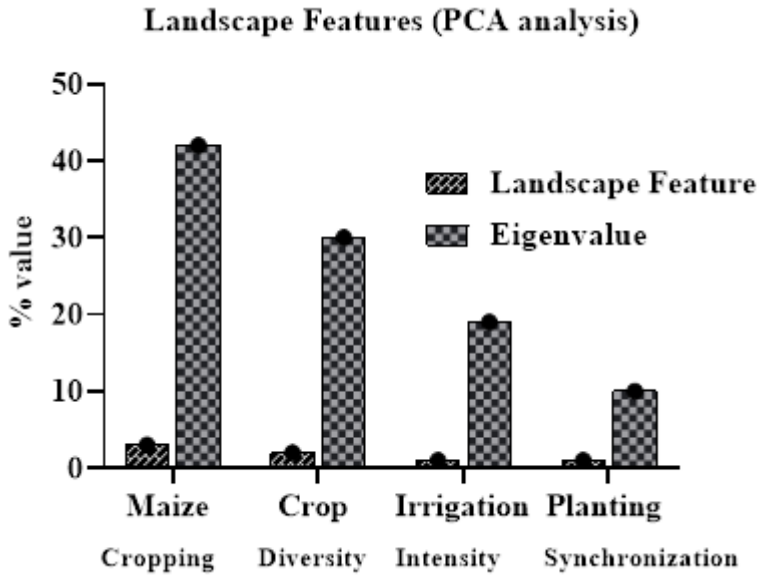


Fig 3. Landscape features associated with infestation persistence (PCA analysis)

District Variation

The level of infestation varied from one district to another also, the infestation intensity in the city of Chengdu was the greatest number of the larvae per plant with yield losses of up to 40%. Mianyang had moderate level infestations (8 larvae per plant, 30% yield loss), whereas Deyang had a lower level of infestations (5 larvae per plant, 25% yield loss) but it remained vulnerable because of the continuous maize cultivation. Individual cities were found to have variable levels of infestation and segregated movements were associated with mixed cropping systems in Luzhou.

Table 4. District-wise yield losses due to *S. frugiperda* infestation

District	Mean Yield (kg/ha, Non-infested)	Mean Yield (kg/ha, Infested)	Yield Loss (%)
Chengdu	6,200	3,700	40
Mianyang	6,000	4,200	30
Deyang	5,800	4,600	25
Luzhou	6,100	4,000	34

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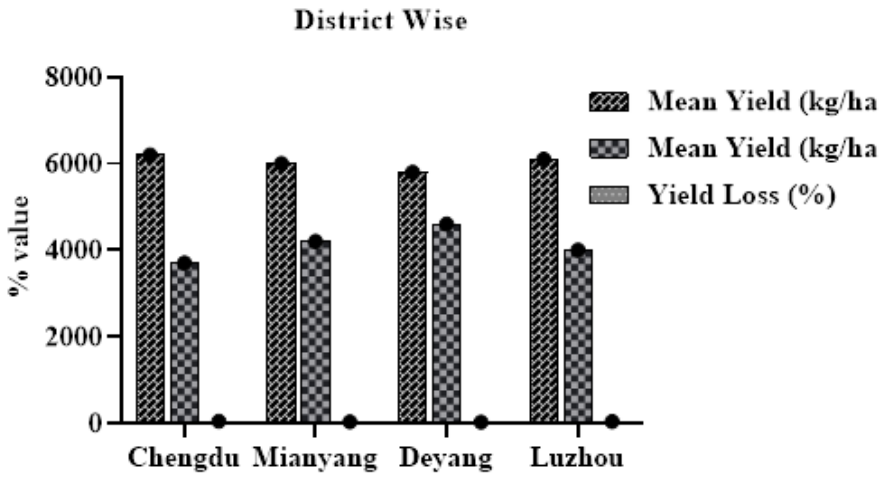


Fig 4. District-wise yield losses due to *S. frugiperda* infestation

Yield Losses

Yield measurements also proved that with blighting cases, maize yield was affected by 25% to 40%, relative to seasons and districts. Areas with coordinated planting and crop rotation had few losses but continuous maize fields would do the most damages. The economic inspection revealed that the financial losses incurred by the farmers, when infestations are not controlled, may be huge thus necessitating the ecological management schemes that are specific to the maize landscapes of Sichuan province.

Discussion

The current research demonstrates the detailed ecological examination of infestation dynamics of *Spodoptera frugiperda* in Sichuan Province on how climatic suitability, seasonality, and landscape composition interact to maintain pest population and induce yield losses. Combining the meteorological measurements, analyzing pheromone traps, and determining the yields, the results prove the necessity of implementation of ecological management strategy specific to subtropical agroecosystems of maize in China.

Climatic suitability was found to be a key factor that affects the intensity of infestation. The optimal larval counts were associated with favorable weather (25-30 °C), high humidity (more than 60%), and monsoon rain, which promotes the rapid population multiplication and dispersion. Such outcomes are in line with the ecological risk considerations, which have found temperature and rainfall to be the main drivers of outbreaks in China (Chen, S., et al., 2021; Urhausen et al., 2024). The micro-climatic niches in which the pest survives throughout the winter months, especially in irrigated fields, are seen in the persistence of low-level infestation. Such adaptability is further supported by genetic diversity research, which indicates high percentages of variation in the population and resilience within the agroecosystems of China (Chen, Y., et al., 2020; He, L., et al., 2021). This kind of flexibility points out how hard it is to go to the

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root of the problem and how crucial constant checkup becomes.

The two high activity periods of adult moths were known to be seasonal and occurred during periods of maize development. The trend underlines the importance of synchronization of planting as way of interrupting the life cycle of pests. The pests are maintained by defeating the crops asynchronously, which is typical of Sichuan and maintains the continual availability of food. Invasion risk appraisal evaluations and invasion have equally warned that staggered planting enhances persistent outbreaks (Li, M., et al., 2021). Also, feeding preference studies indicate that varietal preference might lower susceptibility as some maize varieties have low fall armyworm preference (Liu, H., et al., 2020). Collectively, these results espouse the necessity to make agronomic corrections, such as planting on time and deploying resistant varieties, as a means of integrated pest management (IPM).

The persistence of infestation involved landscape ecology. The variables that were found to be the best predictors of sustained outbreaks, according to GIS mapping and PCA analysis, were continuous maize cultivation, crop diversity, and the level of irrigation. The extensive harvesting of maize gave a year-round supply of food, and the mixed systems of crops such as sorghum and rice impounded ecological reserves that sustained the population despite the harvesting of maize. The results are compliant with the ecological niche modeling studies that approached the issue of how the heterogeneity of landscapes influences the survival and dispersal of pests (Zhang, D., et al., 2022). Molecular identification research also supports the quick acquisition of multiple agroecosystems by the pest, which supports landscape-level interventions (Zhang, L., et al., 2020).

The sources of local practices are seen in district level difference in intensity of infestation and losses in yield. The greatest losses (up to 40 percent) were experienced in Chengdu due to the widespread monoculture, whereas localized outbreaks of operations were observed in Luzhou due to mixed cropping. Deyang reported lesser levels of infestation but was susceptible following continuous cultivation. These findings are reflective of national loss of yield estimates, which entered the decline of 25-40% of highly infested fields (Zhang, J., et al., 2022). The prevalence of awareness about the economic effect of the pest and the difficulties with the introduction of sustainable management methods are further confirmed with the help of Farmer perception surveys (Zhang, Q., et al., 2022).

Sichuan has a management strategy mostly depending on chemical control, but this type of approach is turning out to be unsustainable. The problem of resistance to Bt maize and several insecticide classes has already been reported (Zhang, Y., et al., 2021), so the long-term effectiveness is questionable. Better solutions are the ecological ones. Parasitoids and entomopathogenic fungi are considered important examples of biological control agents that can show promising results under the field conditions (Li, X., et al., 2020; Yang, X., et al., 2021). In addition, community-based interventions, including farmer-led monitoring and community-based techniques, can increase the ability of detection and quick intervention to prevent the occurrence of mass outbreaks. These participatory practices can play a critical role in the sustainable management of pests, especially in areas where small-scale farmers are the major producers of maize.

This study has a wider Sichuan implication. The fall armyworm has proven highly

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adaptive in crossing continents, claiming similar ecological drivers had been reported in Africa, Latin America, and South Asia. The ecological management of invasive species and the adaptation research in the world highlight an alternative sustainable route to be taken as the trajectory of ecological management and away from chemical control as the most effective method of keying invasive species (Prasanna et al., 2021). Pest pressure can be lessened by incorporating resistant varieties, biological control, and landscape-level intervention, which all protect the environment's health.

Conclusively, this paper has critical information about the ecological process on fall armyworm in Sichuan maize landscapes. The pest populations are maintained by climatic suitability, seasonal fluctuation, and landscape composition, resulting in losses of 25-40% of yield. The results expose the drawbacks in chemical control and specify the necessity of combined ecological planning, such as the synchronized planting, crop rotation, biological control, and farmer-led monitoring. Through the alignment of the management practices with environmental realities, Sichuan will be able to create a long-term management framework for controlling fall armyworms to help the country conserve the production of maize and maize food security in China.

Conclusion

This study presents the first ecological assessment of *Spodoptera frugiperda* infestation in maize-growing landscapes of Sichuan Province. The findings demonstrate that climatic conditions, seasonal variation, and landscape composition collectively influence pest persistence and intensity. The warm and humid monsoon climate significantly inhanced population growth, while continuous maize cultivation and mixed farming systems supported sustained infestations. Furthermore,variations at the District-level highlighted the role of local agroecological practices, with monoculture systems experiencing the greatest yield lossess.

Such observed yield reductions ranging from 25% to 40% indicate a serious economic threat and emphasize the urgent need for sustainable pest management strategies. Reliance on chemical insecticides is neither environmently sustainable nor effective in the long-term due to the increasing risk of resistance development. Instead, ecological approaches integrating cultural, biological, and community-tbased practices offer a more sustainable and resilient solution. Overall, this research supports the development of integrated pest management (IPM) strategies tailored to local ecological conditions. Such approaches are essential for safeguarding farmer livelihoods, enhancing maize productivity, and ensuring long-term food security in the region.

Recommendations

Crop Rotation and Diversification

Maize should be mixed with non-host crops like legumes to prevent the pest cycle. Divergent cropping systems decrease ecological reserves and reduce the dispersal of pests, hence reducing the persistence of infestations.

Intercropping Systems

The damage and the larval establishment can be mitigated with the introduction of non-host plants that will be used alongside maize. African experience indicates that

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intercropping maize and beans or cassava can badly reduce the level of infestation that can be implemented in Sichuan province.

Biological Control

Sustainable control agents like parasitoids (Trichogramma spp.) and asciis (*Metarhizium anisopliae*) are supposed to be encouraged.

The reduction in the application of pesticides in conserving preference insects must be in place to ensure a long-term ecological balance.

Community-Based Monitoring

Installing pheromone traps networks of farmers can help create early warnings against the pests' outbreaks. The co-ordination of district-wise responses will increase the efficiency of control and limit the outbreaks of the disease to the local levels.

Policy Support and Extension Services

The government agencies ought to invest in the research on the biological controls and give subsidies on the ecological practices. Enhancement of extension services will be to make sure that the farmers are able to obtain in-time training and assistance to realize and adopt IPM strategies successfully.

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