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Impact of Altitude on Maize Infestation by Fall Armyworm (*Spodoptera frugiperda*) in Nyiragongo Territory, Democratic Republic of Congo

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Abstract

The fall armyworm (Spodoptera frugiperda) is a major pest of maize in the Democratic Republic of Congo, significantly affecting yields. This study aims to evaluate the incidence and severity of infestation based on altitude and crop associations in the Nyiragongo territory (North Kivu) from May 2022 to October 2023. Observations were conducted in ten maize fields located between 1500 and 1950 meters above sea level. The average incidence ranged from 38% in the lowest areas (< 1600 m) to 17% in the highest areas (> 1850 m), with a statistically significant difference (ANOVA, p = 0,01). The severity of the damage, measured using a visual score (Davis scale 1–9), also decreased with altitude (mean = 4,8 at low altitude against 2,1 at high altitude). In contrast, the equivalent density coefficient (EDC) did not show a significant effect on incidence (p > 0,05). Higher altitudes (> 1850 m) lead to a significant reduction in the incidence and severity of fall armyworm infestations, likely due to cooler temperatures that slow down larval development. The tested intercropping associations did not have a measurable effect on the incidence of infestation in this region. These results suggest that growing corn at higher altitudes or selecting varieties adapted to these areas could reduce losses related to the fall armyworm. Further research on the interaction between microclimatic conditions and natural enemies is recommended to improve integrated pest management strategies.

Keywords: Spodoptera frugiperda, maize, incidence, altitude, Nyiragongo, Democratic Republic of Congo

RESUME

Impact de l'altitude sur l'infestation du maïs par la légionnaire d'automne (Spodoptera frugiperda) dans le territoire de Nyiragongo, République démocratique du Congo

La légionnaire d'automne (Spodoptera frugiperda) est un ravageur majeur du maïs en République Démocratique du Congo, affectant significativement les rendements. Cette étude vise à évaluer l'incidence et la gravité de l'infestation en fonction de l'altitude et des associations de cultures dans le territoire de Nyiragongo (Nord-Kivu) de mai 2022 à octobre 2023. Les observations ont été menées dans dix champs de maïs situés entre 1500 et 1950 mètres d'altitude. L'incidence moyenne variait de 38% dans les zones les plus basses (< 1600 m) à 17% dans les zones les plus hautes (> 1850 m), avec une différence statistiquement significative (ANOVA, p = 0,01). La sévérité des dégâts, mesurée à l'aide d'un score visuel (échelle de Davis 1–9), diminuait également avec l'altitude (moyenne = 4,8 à basse altitude contre 2,1 à haute altitude). En revanche, le coefficient de densité équivalente (CDE) n'a pas montré d'effet significatif sur l'incidence (p > 0,05). Les altitudes plus élevées (> 1850 m) entraînent une réduction significative de l'incidence et de la gravité des infestations de légionnaire d'automne, probablement en raison des températures plus fraîches qui ralentissent le développement larvaire. Les associations de cultures intercalaires testées n'ont pas eu d'effet mesurable sur l'incidence de l'infestation dans cette région. Ces résultats suggèrent que cultiver du maïs à des altitudes plus élevées ou sélectionner des variétés adaptées à ces zones pourrait réduire les pertes liées à la légionnaire d'automne. Des recherches supplémentaires sur l'interaction entre les conditions microclimatiques et les ennemis naturels sont recommandées pour améliorer les stratégies de gestion intégrée des ravageurs.

Mots-clés : Spodoptera frugiperda, maïs, incidence, altitude, Nyiragongo, République Démocratique du Congo.

INTRODUCTION

Cereals such as maize, rice, wheat, sorghum and millet are the main source of energy in the global diet. Unfortunately, in recent years cereal production has declined globally, contributing to rising food prices (Malanno et al., 2019). Maize cultivation, in particular, faces multiple constraints, such as abiotic stress (eg : temperature, water, poor soil fertility) and biotic pressures such as diseases and insect pests, all of which reduce yield and grain quality. Among the insect pests that cause significant damage to maize, fall armyworm (*Spodoptera frugiperda*), is responsible for yield losses ranging from 30-70% (Ranum et al., 2014). In the Democratic Republic of Congo (DRC), armyworm infestations have become increasingly widespread, affectingmany territories. This pest is now established across many African countries. In the Kivu region, maize production has declined in recent seasons and the incidence of the fall armyworm has increased (MINAGRI, 2018). Fall armyworm attacks are most noticeable during two phenological stages of the maize crop, namely leaf development and pre- flowering (Kapiri et al., 2022 ; Boukari et al., 2022). Despite pest's growing impact, the damage caused by the fall armyworm on maize and the control methods used in Nyiragongo territory are poorly documented. There is a need for local data to better understand the epidemiology of this caterpillar and to find ways of controlling it. The aim of this study is to assess the level of infestation of the fall armyworm on maize in the Rusayo and Mudja clusters, with specific attention to altitudinal gradients and crop associations.

MATERIALS AND METHODS

Study area

The territory of Nyiragongo is located in the east of the Democratic Republic of Congo (DRC). It experiences two rainy seasons and two dry seasons due to its proximity to the equator. The dry seasons are from January to February and June to August (Kapiri et al., 2022). The territory lies in high altitude mountainous zone, with temperatures varying between 15 and 30°C. The geographical coordinates of the study sites are : the Rusayo cluster is at 1°35'S and 29°10'14" E, with an average altitude of 1630 m, while the Mudja cluster is at 1°37'3" S and 29°11'45" E, with an average altitude of 1587 m.

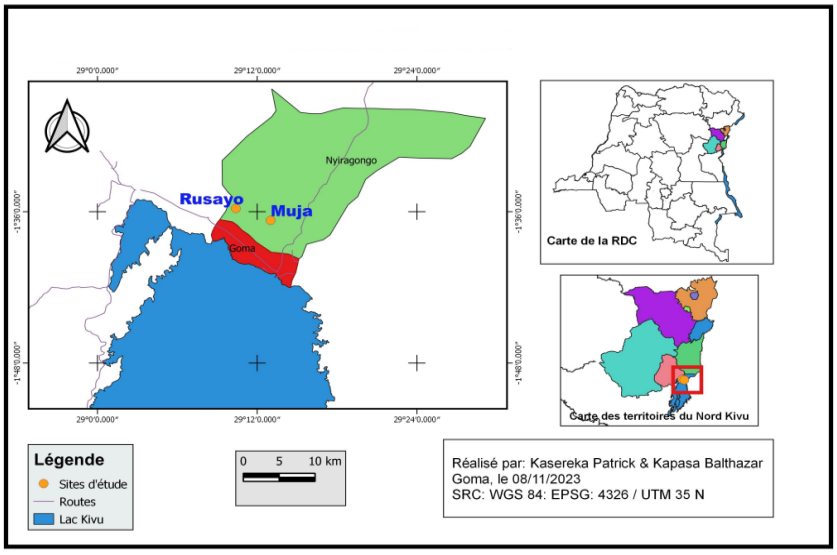


Figure1. Map of study sites

Data collection

The fields were selected at random and in these fields maize was grown alongside other crops, but maize was the main crop. However, these fields were separated by 200 meters from each other. A total of 20 fields were taken into account, with 10 fields per group. In each field, a sample of 20 plants was taken from each 5x5m quadrat. Each field was divided into four sections and a 5x5 m quadrat was placed in each following a sampling protocal for maize borer caterpillars described by Kankonda et al. (2016, 2017). Within each quadrat, the following data were recorded : the total number of plants (all species) present to assess the impact of plant associations in the field, the total number of maize plants, the number of maize plant showing signs of infestation and the number of damaged leaves (Démolin, 1969). A maize plant was considered infested when its leaves showed characteristic symptoms such as pinhole punctures until the leaves are whorled, leaf curling and complete leaf destruction. Severe cases were marked by long lesions and full defoliation. Average field altitude was recorded using a handheld GPS unit. .

Statistical analysis

The incidence of *S. frugiperda* infestation in maize was calculated using the following formula (FAO, 2017). Incidence is the ratio between the number of infected maize plants and the total number of maize plants.

$$Incidence = \frac{\text{Number of infested maize plants}}{\text{Total number of maize plants}} X\ 100 \quad (1)$$

The severity of damage was estimated using visual leaf damage scale from Davis *et al.* (1992) and Navik *et al.* (2021). Severity was computed as :

$$Severity = \frac{\Sigma(n * b)}{(N-1)T} X\ 100 \quad (2)$$

Where n = number of plants at each damage level; b = damage score; N = number of severity categories (which is equal to 9) and T = total number of maize plants assessed in the whole field. The use of a generalized linear model (GLM) with binomial linkage made it possible to quantify the effect of altitude on the probability of infestation, test the statistical significance of the variations observed, and isolate the influence of altitude in order to control for other environmentalfactors and thus ensure the clarity of the conclusions. Results were visualized through correlation plots showing regression lines, correlation coefficients (R), and associated p-values, implemented in R software (version 4.3.2, 2023). All figures were generated using the ggplot2 package.The Welch two-sample t-test allowed for a statistical comparison of infestation averages between two different altitudes, even though the variances of the groups were unequal.

RESULTS

Infestation rate of Spodoptera frugiperda

The results below show the level of *S. frugiperda* infestation in Mudja and Rusayo.

Welch Two Sample t-test
Data : Severity Index by Locality
t = -0.82597, df = 5.6728, p-value = 0.4422
Alternative hypothesis : true difference in means between group Mudja and group Rusayo is not equal to 0
95 percent confidence interval :
Mudja : -15.857392 Rusayo : 7.937392
Sample estimates :
Mean in group Mudja Mean in group Rusayo
35.012 38.972

The mean infestation rate in Mudja was 35.0%, while in Rusayo it was 39.0%. The difference in means was not statistically significant (t = –0.83, df = 5.67, p = 0.44). The 95% confidence interval for the difference ranged from –15.86 to 7.94.

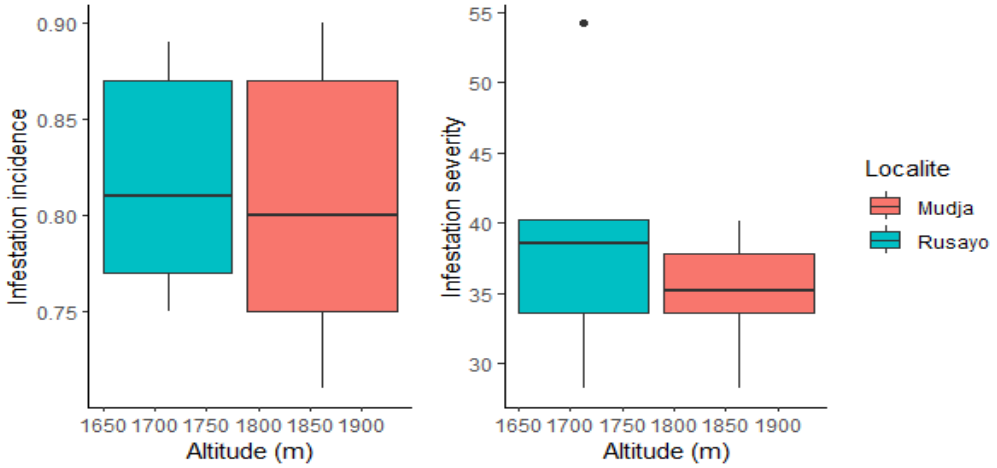


Figure2. Impact of altitude on the infestation rate

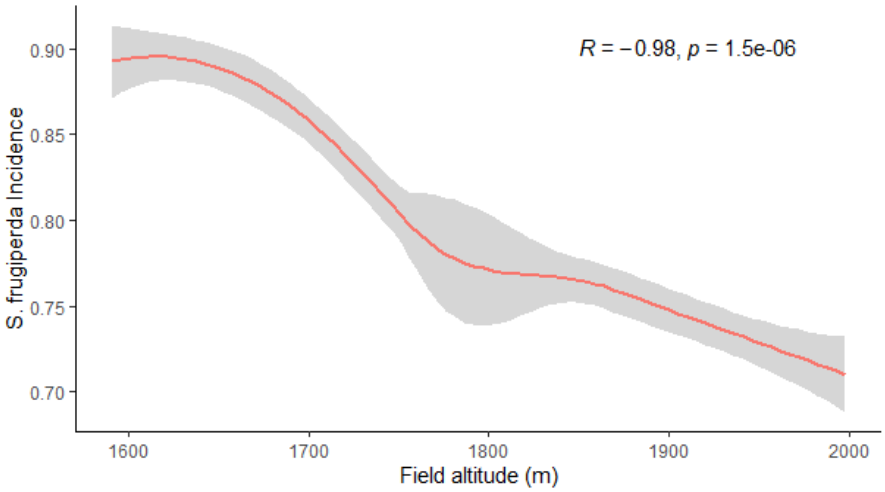
The results recorded in Figure 3 suggest that *S. frugiperda* infestation rates in maize decreased significantly with increasing altitude ($R = 0.96$; $p < 0.001$). These results can be explained by the fact that the rise in altitude corresponds to a reduction in ambient temperature, which would affect the dispersal of moths from their place of emergence to new fields. The low incidence of *S. frugiperda* infestations at altitude may be due to the biology of the pest.

Severity of damage

Figure 4 indicates that the severity of *S. frugiperda* infestations in maize showed a slight decrease with increasing altitude, but the relationship was not statistically significant (R = - 0.25; p = 0.49). This indicates that altitude per se does not influence the severity of infestations. Similarly, infestation severity was only weakly correlated with the rate of maize infestations (R = 0.27; p = 0.45) by *S. frugiperda* (Figure 4).

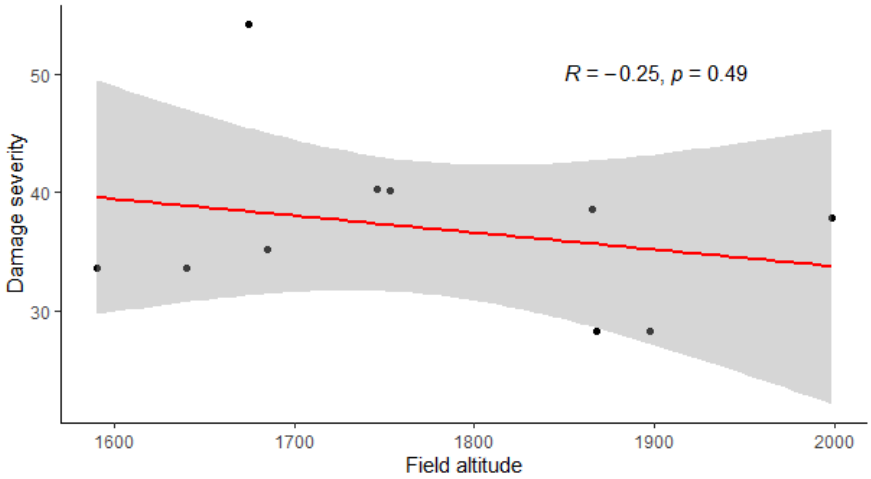
Effectiveness of plant associations

The Coefficient of Equivalent Density factor was used to assess the effectiveness of the different plant associations, taking into account the density of plant species found within each quadrat. Figure 5 shows the influence of the CDE factor on the number of diseased plants in relation to altitude. The fields with higher total plant density generally had fewer infested maize plants, suggesting a potential buffering effect of intercropping on infestation incidence. However, Figure 4 shows that there is no correlation between the incidence of infestations and their severity.



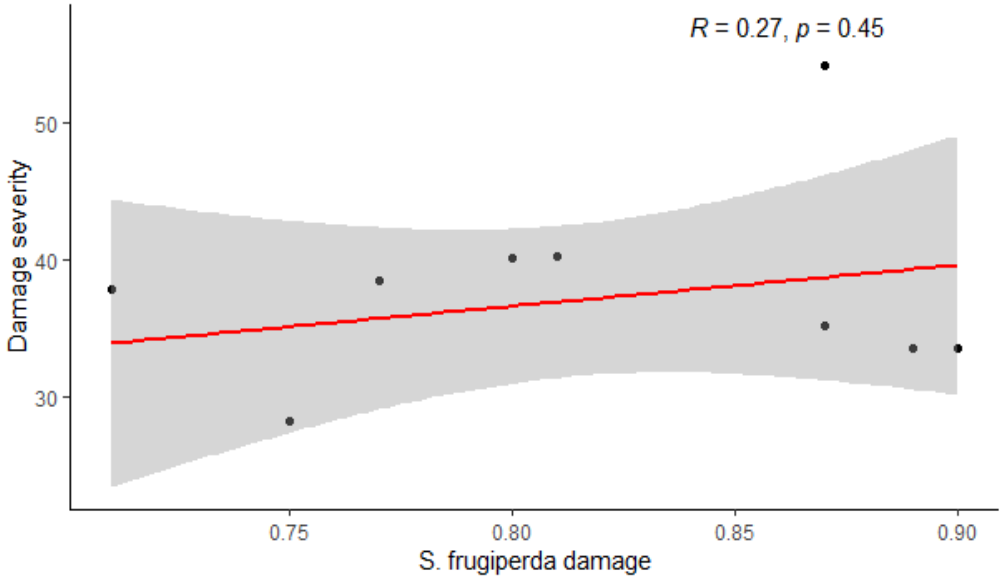
Rusayo → Mudja

Figure 3. Effect of elevation on the rate of infestation of maize by *S. frugiperda*.



Rusayo → Mudja

Figure4. Relationship between altitude and severity of damage



Rusayo → Mudja

Figure5. Relationship incidence of *S. frugiperda* - severity of infestations.

DISCUSSION

Since its detection in Africa in 2016, *Spodoptera frugiperda* has emerged as one of the most destructive pests of maize across the continent. Its polyphagous naturure and high migratory capacity contribute to widespread infestations and substantial yield losses. The results of this study confirm the presence of *S. frugiperda* in Rusayo and Mudja, where all fields of maize wherther in pure stand or intercropped with beans, soybeans, groundnuts, sweet potatoes or banana showed signs of infestation . Similar observations have been reported in other regions of the DRC with maize-groundnuts, maize-rice and maize-cabbage associations (MINAGRI, 2018).

Effect of altitude on the rate of fall armyworm infestation in maize

The results show a significant decrease in the incidence of fall armyworm with altitude, with 64,5% between 1500 and 1600 m, compared to 44,84% between 1900 and 2000 m (p = 0,0001). This trend confirms the observations of Kapiri et al. (2022), who reported an average severity of 7,24%. These results suggest that cooler temperatures at higher altitudes limit larval development and the spread of infestations. They also highlight the importance of incorporating the variable "altitude" into epidemiological models and integrated pest management strategies. The results of our study confirm that altitude plays a decisive role in the infestation dynamics of *Spodoptera frugiperda* in the Nyiragongo territory. The incidence and severity of attacks decrease significantly above 1850 m, suggesting that microclimatic conditions specific to high altitudes, particularly cooler temperatures, limit larval survival and development. These observations corroborate those of Pimentel et al. (2010), who showed that caterpillar fertility and survival are highly dependent on temperature, with higher mortality in colder environments. Bouhot-Delduc and Lévy (1994) established a significant correlation between altitude and infestation intensity in the processionary caterpillar (F = 4.9879; p = 0.00887), while Mecheri et al. (2018) observed that higher altitudes reduce caterpillar survival in Alep pin forests.

Role of plant associations in infestations control

Our findings also indicate that intercropping may reduce armyworm incidence. The Coefficient of Equivalent Density (CDE) exceeded 1 in all fields, suggesting strong plant associations. At low altitude, CDE was 2.96, and at high altitude, it rose to 3.83, indicating that denser, more diverse plant systems may help suppress pest pressure. These findings are supported by Kra et al. (2022), who noted that damage rates (severity index) varied between species and were relatively related to the level of weed cover in the fields. For weed cover equal to 5%, the rate of armyworm damage was zero. Cokola et al. (2021), also reported lower *S. frugiperda* incidence in onion fields under intercropping systems (*p = 0.013*). Tchegueni et al. (2022) further demonstrated that the crop associations maize-cassava and maize-soybean provided tangible evidence that polyculture significantly reduced infestation (40-56%) of armyworm compared tomonoculture (*F = 6.57; p = 0.004*). However, Agboka et al. (2006) found that polyculture systems (maize-manioc and maize-soybean) significantly reduced ear borer populations, although grain yield trade-offs were observed. Niyibizi (2020) believes that increasing plant diversity and managing natural habitats helps to maintain the diversity of natural enemies of *S. frugiperda*, which is in line with our observations (Figure 4). Thus, crop association and or the promotion of secondary habitats in fields improves biological control of pests, by simultaneously creating barriers to pests, while providing food resources and favourable living sites for natural enemies (Fillatre et al.,2014). These results reinforce the idea of taking the equivalent density coefficient into account in order to mitigate armyworm infestations, particularly in areas known to be invaded. This being the case, Tables 5 and 6 confirm the second specific hypothesis that plant associations reduce fall armyworm (*Spodoptera frugiperda*) infestations in the Rusayo and Mudja clusters. The results of Kankonda et al. (2016) show the increase of habitats rich in wild grasses in the low tropical forest region leads to the increase of parasitism of noctuid moth eggs on maize, which joins the idea of favouring plant diversity and that the attack rate of fall armyworm is higher in pure cultivation than in associated cultivation (Chaubet, 1992; Looli et al., 2021). Finally, our results also support the hypothesis that monoculture influences *Spodoptera frugiperda* infestations compared to polyculture.

CONCLUSION

This study demonstrates that both altitude and plant associations significantly influence *S. frugiperda* infestation patterns in maize fields in Nyiragongo. the results of the analysis show that, depending on altitude and the types of crops associated with maize, the number of diseased plants, the number of larvae per unit area, the number of leaves attacked per plant, the incidence and the severity index associated with armyworm vary from one field to another. However, environmental factors such as host plant availability, microclimate, and natural enemies likely also contribute and should be further investigated. These findings suggest that landscape-level strategies incorporating crop diversity and elevation may improve sustainable pest management in maize production systems

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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