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Altitudinal Variation in Trap-Based Abundance of *Bactrocera dorsalis* in Red Chili Fields of West Sumatra, Indonesia

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ABSTRACT

Altitudinal gradients strongly influence the distribution and abundance of insect pests by affecting microclimate, host availability, and cropping intensity. *Bactrocera dorsalis* (Hendel) is a major constraint to red chili (*Capsicum annuum* L.) production in Indonesia; however, empirical evidence linking altitude to its field abundance in Sumatra has not been fully elucidated. This study quantified the association between altitude and the abundance patterns of *B. dorsalis* using field data collected from 33 chili-growing sites across four regencies of West Sumatra, Indonesia, spanning elevations from <15 to 1,571 m above sea level, during the rainy season (October 2024-March 2025). Adult flies were monitored using methyl eugenol-baited modified Lynfield traps. Catch data were analyzed across altitudinal zones using ANOVA, correlation, and linear regression. Trap catches differed significantly among elevation categories ($p < 0.05$), with higher mean abundance generally recorded in pre-montane sites (>600 m) than in lowland sites (<600 m). Regression analysis indicated a positive association between altitude and trap catches ($r = 0.391$, $p = 0.024$), with altitude explaining 15.3% of the variation in abundance ($R^2 = 0.153$), and linear regression indicated a moderate increase in captures with increasing elevation ($B = 0.103$). K-means clustering of regencies based on mean elevation and total trap catches further separated Solok as a distinct group characterized by higher abundance. These findings demonstrate spatial structuring of *B. dorsalis* abundance across elevation zones and support the incorporation of elevation-informed surveillance into fruit fly monitoring programs in West Sumatra.

Keywords: Altitude, *Bactrocera dorsalis*, red chili, Lynfield trap

INTRODUCTION

Fruit flies are among the most destructive pests of chili production in tropical regions, causing substantial yield and economic losses through direct fruit damage and reduced market quality. Among them, *Bactrocera dorsalis* is widely recognized as a dominant and highly invasive species with strong ecological adaptability across diverse agroecological conditions. Understanding spatial variation in its abundance is therefore essential for improving monitoring and management strategies, particularly in regions characterized by complex topography such as West Sumatra, Indonesia (Clarke et al., 2005; Drew & Romig, 2013; Vargas et al., 2015).

Regrettably, West Sumatra province has the second-highest number of fruit fly species among other provinces, with 40 species, and the most dominant species is *Bactrocera* spp. (Schutze et al., 2015). Of which, the oriental fruit fly, *B. dorsalis*, is a notorious pest of tropical and subtropical horticultural crops, causing extensive economic damage through fruit infestation and subsequent yield loss. Approximately 70% are horticultural plants that present a formidable challenge to vegetable production in this province (Budiyanti et al., 2019; Hidayat et al., 2023). Its wide host range and high reproductive capacity enable rapid population expansion under favorable conditions (Clarke et al., 2005).

Another aspect that environmental variables, particularly altitude, play a critical role in shaping insect distribution and abundance of *B. dorsalis* (Duyck et al., 2006) through its influence on temperature, humidity, and host plant composition. Consequently, examining abundance patterns along altitudinal gradients provides a practical approach to exploring how environmental variation may be associated with pest distribution in heterogeneous landscapes (Hodkinson, 2005; Duyck et al., 2006; Vargas, Piñero, and Leblanc, 2015). For tephritid fruit flies, these environmental factors directly affect survival, reproduction, and dispersal, thereby determining population dynamics across landscapes (Clarke et al., 2005; Vargas et al., 2015). While previous studies have documented altitudinal effects on *B. dorsalis* populations in other tropical regions (Ye and Liu, 2007; Finnie et al., 2021), comparable field-based evidence from Sumatra remains scarce.

Monitoring of *B. dorsalis* commonly relies on traps baited with methyl eugenol, a male-specific attractant widely used in surveillance programs. While effective for detecting presence and relative abundance, trap catches primarily reflect male behavioral responsiveness rather than absolute population density. Consequently, trap data should be interpreted as indicators of abundance patterns or activity levels rather than direct estimates of total population size (Vargas et al., 2010; Shelly et al., 2014).

Despite the agricultural importance of chili in West Sumatra, information on how *B. dorsalis* abundance varies across elevation zones remains limited. We hypothesized that abundance patterns differ along the altitudinal gradient due to elevation-related environmental constraints, particularly temperature effects on fly activity and survival. Accordingly, this study examined whether trap-based abundance differs among elevation zones, whether altitude is associated with trap catches across regions, and whether abundance patterns cluster geographically. Field data from chili-growing sites spanning a wide elevation range were analyzed using analysis of variance (ANOVA), correlation and regression analyses, and cluster analysis.

METHODS

Study area and sampling design

Sampling was conducted once at each of the 33 chili-growing sites from four regencies Agam, Padang Pariaman, Tanah Datar, and Solok between October 2024 and March 2025, corresponding to the main production season. At each location, traps were deployed for approximately 24 h before retrieval for specimen collection and counting. These regions span altitudes from below 15 to 1571 meters above sea level, encompassing diverse agro-ecological zones. The altitude classifications classified by Michael (2019) are as follows: lowland is defined as 0-600, pre-mountainous as 600-1500, low mountain as 1500-1800, mid-mountain as 1800-2700, high mountain as 2700-3300, and sub-alpine as 3300->3300.

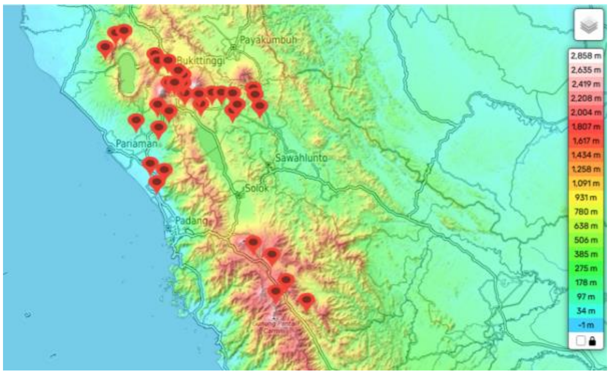

Figure 1. Field surveys in 33 sites across four regencies of West Sumatra at altitudinal variation

Field trapping and species identification

One modified Lynfield trap, supported by wooden supports, was positioned in the center of each diagonal rectangular sample plot in a chili plantation. The trap was 1.5 meters above the ground. Traps were set up and taken down between 7:00 a.m. and 5:00 p.m. According to Mayasari et al. (2019), each treatment solution was prepared, equipped with a Lynfield trap, and allowed to soak in a cotton wick for a whole day. To prevent the deterioration and desiccation of dead fruit flies, a liquid preservative might be added to the bottom of each Lynfield trap, preserving around 15 mL of a 70% ethanol solution (Bronnec and Alexeyev, 2022). Locally, traps might be made from unused bottled water bottles. After the plastic label was removed from these bottles, four holes, each 6 to 8 mm in diameter and just big enough to let fruit flies in, were punctured with a heated GI wire. The holes were made on a plastic bottle along the upper 5 cm band of the label. A hook was then fastened to the top of the plastic container. The hook was taken off the rope and GI wires and added for hanging in order to make it easier to attach the trap mechanism to the host tree limb. Customized trap had identity labels with the date, locations, and trap numbers affixed (Gupta and Regmi, 2022). Dead fruit flies were extracted with tweezers and put in a 70% alcohol film container before being labeled. A pictorial guide from the Australian handbook for the identification of fruit flies (Plant Health Australia, 2018) and identification guidelines from Sarango (2014); Suputa, SS, and P. (2006); Larasati et al. (2016) were used to further count and identify each fly individual at the Insect Bioecology lab of Andalas University's Faculty of Agriculture.

Statistical analysis

Data were analyzed using ANOVA to compare mean catches among altitudinal zones. Pearson correlation assessed the relationship between altitude and catch numbers. Linear regression modeled the predictive effect of altitude on *B. dorsalis* abundance. Statistical analyses were conducted using SPSS, with significance determined at the $p < 0.05$ level.

RESULTS AND DISCUSSION

Altitude gradient and B. dorsalis population trends

A total of 1,080 adult *B. dorsalis* were captured across all sampling locations. To allow comparisons among sites, trap catches were standardized and expressed as flies per trap (FPT). The results of this investigation, Figure 2 showed clearly that mean abundance differed significantly among elevation categories ($p < 0.05$), with generally higher FPT values recorded at elevations above 600 m compared with lowland areas. Particularly, places with altitudes over 600 meters asl, such as Agam Solok and Tanah Datar, consistently recorded higher trap captures *B. dorsalis* (446, 1080, and 665 individuals), while areas with altitudes below 600 meters asl, such as Padang Pariaman, recorded fewer captures, with 130 *B. dorsalis*. Among the surveyed regencies, the highest standardized catches were observed in Solok Regency, which also corresponded to higher elevation zones. Additionally, correlation analysis revealed a significant positive association between altitude and trap catches, and regression analysis indicated that altitude explained 15.3% of the variation in abundance patterns ($R^2 = 0.153$), suggesting a moderate relationship. Diagnostic evaluation of regression assumptions, including inspection of residual normality and homoscedasticity plots, indicated that model assumptions were adequately satisfied. Furthermore, cluster analysis revealed clear spatial grouping among sampling sites, with Solok forming a distinct high-abundance cluster relative to other regencies, indicating regional heterogeneity in *B. dorsalis* distribution.

The higher trap catches observed at elevations above 600 m differ from many previous reports indicating that *B. dorsalis* populations are typically more abundant in warmer lowland environments, where elevated temperatures accelerate development, reproduction, and population growth (Clarke et al., 2005; Shelly et al., 2014; Vargas et al., 2015; Kausar et al., 2022; Ziyuan Li et al., 2024). However, the pattern detected in the present study likely reflects local agroecological conditions rather than a direct physiological preference for cooler environments. Highland chili production areas in West Sumatra, particularly in Solok Regency, are characterized by intensive cultivation, continuous fruit availability, and diverse host plants throughout the year, which may support sustained fly activity despite relatively lower temperatures. For instance, Masselière et al. (2017) and Facon et al. (2021) stated that fruit crops are usually grown in these areas all year round, giving *B. dorsalis* populations constant nutrients. Moderate thermal conditions in upland environments may also prolong adult longevity and activity periods, potentially increasing cumulative trap captures during short sampling intervals. Similar context-dependent variation in fruit fly abundance has been reported in tropical production systems, where host availability and cropping intensity strongly influence population patterns independent of elevation alone (Drew & Romig, 2013; Morán-Tejeda et al., 2013). Conversely, as elevation increases over 1500 m above sea level, environmental conditions become progressively less favorable. Cooler temperatures at higher altitudes slow the metabolic and reproductive rates of tropical insects like *B. dorsalis*. Moreover, host availability tends to decrease with altitude due to changes in agricultural practices and natural vegetation, further limiting population growth (Hodkinson, 2005). For examples, studies conducted in Taiwan and Nepal have shown that the number of Bactrocera spp. decreases with elevation, and this decrease is correlated with gradients in temperature, humidity, and host plant availability (Geurts et al., 2014; Odanga et al., 2018; Finnie et al., 2021).

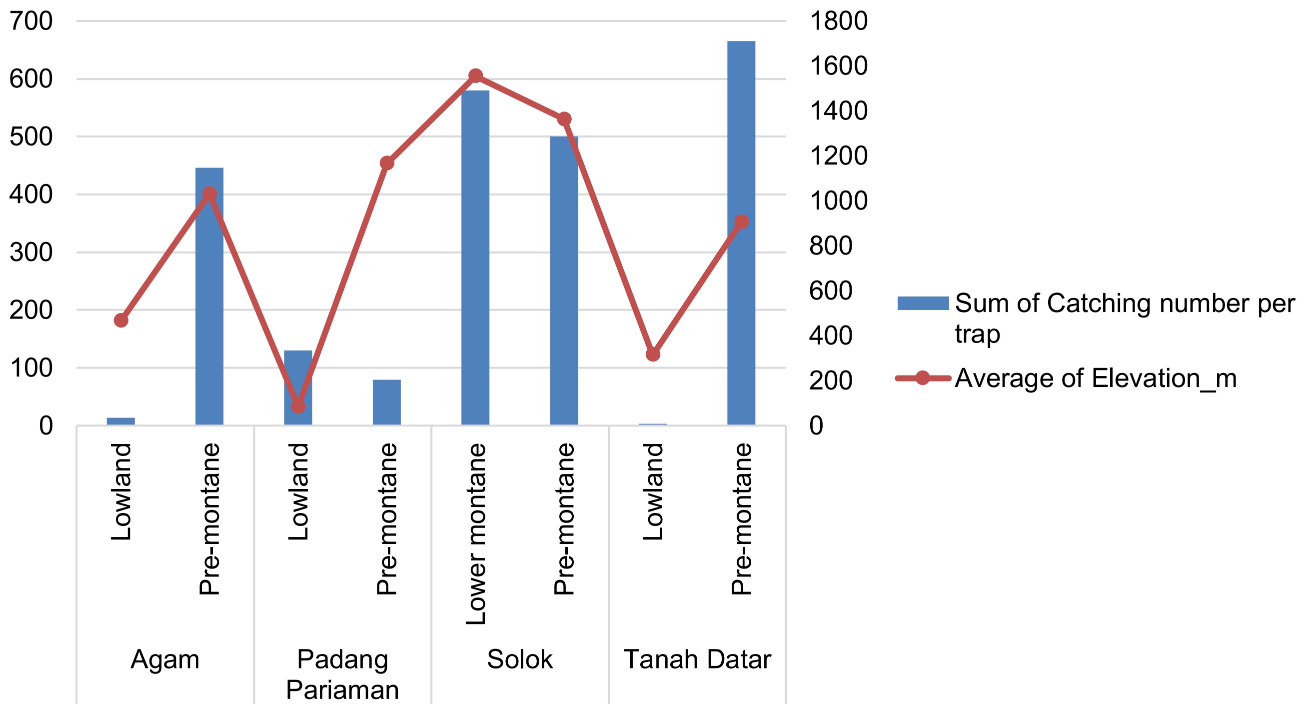

Figure 2. Correlation between altitude and catching number of *B. dorsalis* caught per zone

Statistical validation of findings

Correlation analysis (Figure 3) revealed a significant positive association between altitude and trap catches ($r = 0.391$, $p = 0.024$). Linear regression further indicated that altitude explained 15.3% of the variation in abundance patterns ($R^2 = 0.153$), suggesting a moderate relationship between the variables. Prior to analysis, regression assumptions were evaluated through examination of residual normality and homoscedasticity using Q–Q plots and residuals versus fitted value plots, which indicated that model assumptions were adequately satisfied. Although the correlation coefficient indicates a moderate relationship, altitude alone explained a meaningful proportion of variation in trap catches, highlighting its ecological relevance. In parallel, regression analysis supports this relationship with a predictive model suggesting that when altitude increases, the number of *B. dorsalis* per trap tends to increase moderately, approximately 10.3 individuals per trap for every 100 m increase in altitude. The moderate effect size suggests that altitude likely acts in concert with other environmental and agronomic factors rather than functioning as a sole determinant of population size, a pattern commonly reported in field-based insect ecological studies (Hodkinson, 2005; Duyck et al., 2006). Similar conclusions were drawn by Bateman (1972), who highlighted the importance of temperature thresholds in limiting the distribution of tropical tephritid fruit flies. Duyck et al. (2004) also observed comparable patterns in their studies on *Bactrocera* spp. across various altitudinal gradients.

A histogram of standardized residuals was used to analyze the residual distribution in order to verify the assumptions of linear regression. The resultant histogram, which resembled a bell curve, showed that the residuals were about normally distributed. This implies that the residuals' normality requirement was logically satisfied (Field, 2009). Furthermore, the distribution showed no discernible skewness or kurtosis, confirming that the linear model was a suitable fit for this data. The regression estimates between elevation and the number of *B. dorsalis* that are caught per trap are more reliable when the residuals are normal. This result is significant because it guarantees the reliability of the stated significance levels and confidence ranges for the regression model by satisfying the condition of normalcy (Idrus, 2013). As a result, the conclusion that elevation increases result in a slight increase in the number of *B. dorsalis* that can be caught is supported by statistics and is not the product of anomalies in the data or deviations from regression assumptions.

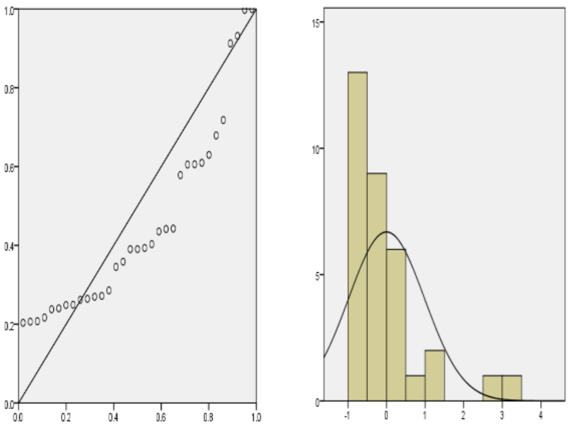

Figure 3. Normality check of residuals in the altitude-*B. dorsalis* regression model

Cluster analysis of regencies

Cluster analysis was conducted to classify the four regencies of West Sumatra based on the sum of *Bactrocera* spp. catches per trap and mean elevation. Using the K-means clustering method, the regencies were grouped into two distinct clusters, indicating heterogeneity in fruit fly abundance patterns at the regional scale (Figure 4). The first cluster comprised Padang Pariaman, Agam, and Tanah Datar, which were characterized by lower to moderate total trap catches and relatively lower mean elevations. In contrast, Solok Regency formed a separate cluster, distinguished by the highest fruit fly catch numbers and the highest mean elevation among the surveyed regions. This clear separation suggests that Solok exhibits a markedly different population pattern of Bactrocera spp. compared with the other regencies.

The cluster analysis revealed clear regional differentiation in *Bactrocera* spp. abundance across West Sumatra, with the regencies grouped into two distinct clusters. The separation of Solok into a single cluster, characterized by markedly higher trap catches and greater mean elevation, indicates that its population pattern differs substantially from those of Agam, Tanah Datar, and Padang Pariaman, which formed a second cluster with lower to moderate abundance levels. Such spatial clustering suggests that fruit fly populations are heterogeneously distributed at the regional scale rather than evenly dispersed across chili-growing areas. Similar applications of multivariate clustering in insect ecology have demonstrated its effectiveness in identifying spatially structured population patterns and supporting regional-scale comparisons (Duyck et al., 2006; Odanga et al., 2018). Overall, the cluster structure highlights the importance of considering regional differentiation when interpreting fruit fly abundance data and provides a useful framework for comparative analysis of pest populations across agroecosystems.

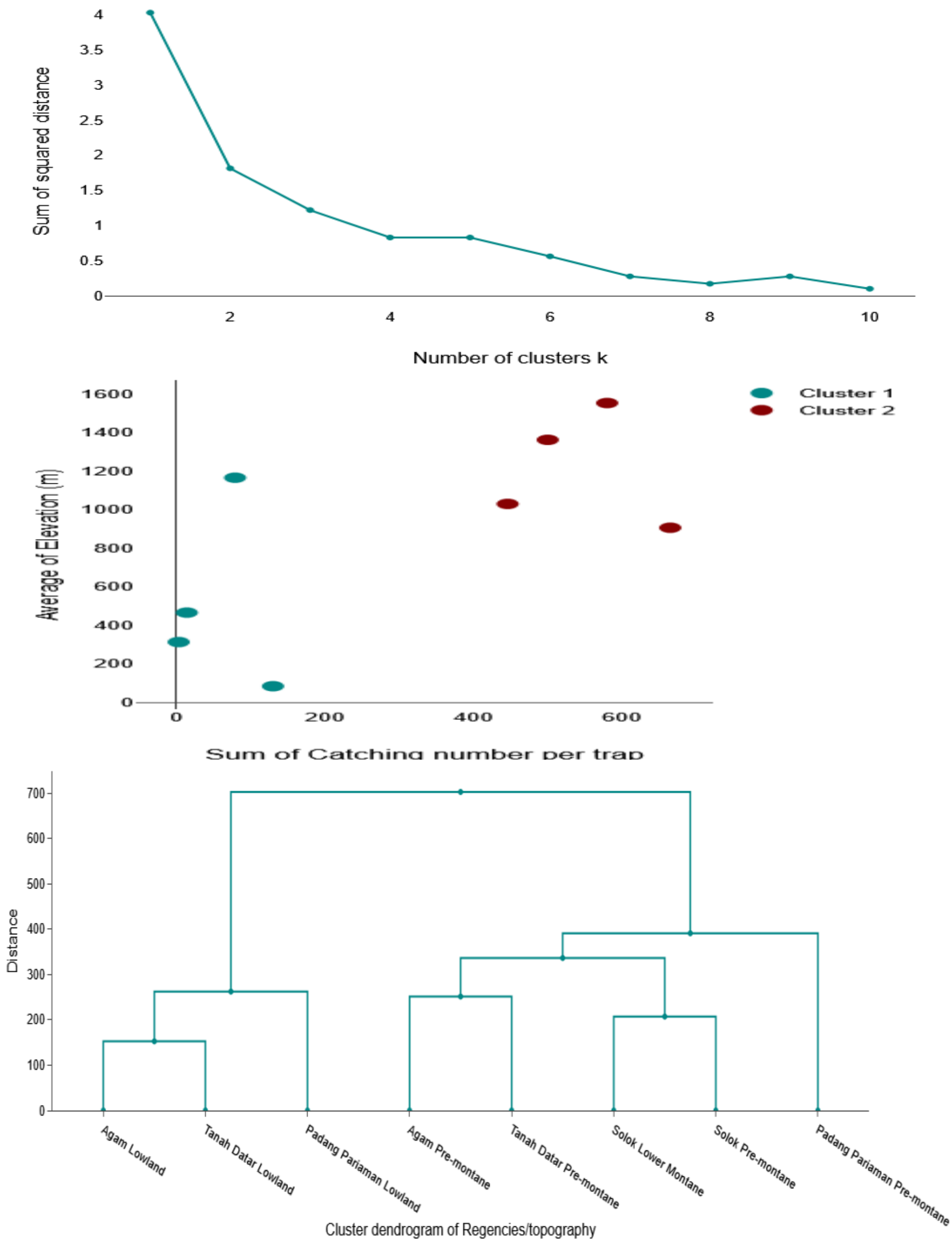

Figure 4. Cluster analysis of regencies based on *Bactrocera* spp. trap catches and elevatio

CONCLUSIONS

Field data from 33 sites across West Sumatra indicated that *Bactrocera dorsalis* trap catches differed significantly among altitudinal zones and were positively associated with elevation. Cluster analysis further demonstrated regional differentiation, with Solok forming a distinct group characterized by higher abundance. These findings support elevation-informed monitoring and highlight the importance of accounting for spatial heterogeneity when interpreting trap-based abundance patterns in chili agroecosystems.

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