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Meteorological Effects on *Drosophila suzukii* Dynamics and Infestation among Strawberry Genotypes under Protected Cultivation

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Abstract

Strawberry growers face several challenges that negatively affect yield and fruit quality, particularly damage caused by the spotted-wing drosophila, *Drosophila suzukii.* This study aimed to investigate the population dynamics of *D. suzukii* in a protected strawberry crop, evaluate the influence of meteorological variables on population fluctuations, and assess the natural infestation of different strawberry genotypes in the highland region of Santa Catarina, Brazil. Population dynamics were monitored weekly from 2020 to 2023 using baited fly traps with Droskidrink attractant. Adult capture data were correlated with meteorological variables, and natural infestation was assessed through fruit sampling during the ripening period. Temperature was the main factor associated with population fluctuation, with reduced or absent captures during winter and population peaks occurring in spring, summer, and autumn. Female catches were consistently higher than male catches throughout the monitoring period. Relative humidity and precipitation showed no significant influence on population fluctuations. Natural infestation was detected in all fruit sampling periods and genotypes evaluated. These findings demonstrate that *D. suzukii* is well established in the highland region of Santa Catarina and provide valuable information for monitoring programs and integrated pest management strategies in protected strawberry production systems.

Keywords: integrated pest management, monitoring, abiotic factors

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Efectos de variables meteorológicas sobre la dinámica de *Drosophila suzukii* y la infestación de diferentes genotipos de fresa bajo cultivo protegido

Resumen

Los productores de fresas enfrentan varios desafíos que afectan negativamente la productividad y la calidad de la fruta, principalmente el daño causado por la mosca de la fruta de alas manchadas, *Drosophila suzukii*. Este estudio tuvo como objetivo investigar la dinámica poblacional de *D. suzukii* en cultivos protegidos de fresa, evaluar la influencia de las variables meteorológicas en las fluctuaciones poblacionales y analizar la infestación natural en diferentes genotipos de fresa en la región montañosa de Santa Catarina, Brasil. La dinámica poblacional se monitorea semanalmente entre 2020 y 2023 usando trampas cebadas con el atrayente Droskidrink. Los datos de captura de adultos se correlacionaron con variables meteorológicas y la infestación natural se evaluó mediante el muestreo de frutos durante el período de maduración. La temperatura fue el factor principal asociado con la fluctuación poblacional, con capturas reducidas o ausentes observadas durante el invierno y picos poblacionales en primavera, verano y otoño. Las capturas de hembras fueron consistentemente mayores que las de machos durante todo el período de monitoreo. La humedad relativa y la precipitación no influyeron significativamente en las fluctuaciones poblacionales. Se detectó infestación natural en todas las muestras de fruta y genotipos evaluados. Estos resultados demuestran que *D. suzukii* está establecida en la región montañosa de Santa Catarina y proporcionan información valiosa para los programas de monitoreo y las estrategias de manejo integrado de plagas en los sistemas de producción de fresas en ambientes protegidos.

Palabras clave: manejo integrado de plagas, monitoreo, factores abióticos

Efeitos de variáveis meteorológicas sobre a dinâmica de *Drosophila suzukii* e a infestação de diferentes genótipos de morangueiro sob cultivo protegido

Resumo

Os produtores de morango enfrentam diversos desafios que afetam negativamente a produtividade e a qualidade dos frutos, destacando-se os danos causados pela drosófila-da-asa-manchada, *Drosophila suzukii*. Este estudo teve como objetivo investigar a dinâmica populacional de *D. suzukii* em cultivo protegido de morango, avaliar a influência de variáveis meteorológicas nas flutuações populacionais e analisar a infestação natural em diferentes genótipos de morangueiro na região serrana de Santa Catarina, Brasil. A dinâmica populacional foi monitorada semanalmente entre 2020 e 2023, utilizando armadilhas iscadas com o atrativo Droskidrink. Os dados de captura de adultos foram correlacionados com variáveis meteorológicas, e a infestação natural foi avaliada por meio da amostragem de frutos durante o período de maturação. A temperatura foi o principal fator associado à flutuação populacional, observando-se capturas reduzidas ou ausentes durante o inverno e picos populacionais na primavera, no verão e no outono. As capturas de fêmeas foram consistentemente superiores às de machos ao longo de todo o período de monitoramento. A umidade relativa e a precipitação não apresentaram influência significativa nas flutuações populacionais. A infestação natural foi detectada em todas as amostragens de frutos e genótipos avaliados. Esses resultados demonstram que *D. suzukii* está estabelecida na região serrana de Santa Catarina e fornece informações valiosas para programas de monitoramento e estratégias de manejo integrado de pragas em sistemas de produção de morango em ambiente protegido.

Palavras-chave: drosófila-da-asa-manchada, manejo integrado de pragas, fatores abióticos

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch) is an accessory fruit belonging to the Rosaceae family, widely appreciated by consumers for its combination of sweet and acidic flavors (Kårlund et al., 2015). Its nutraceutical properties, including antioxidants, phenolic compounds, and vitamin C, show significant preventive and

therapeutic potential for various human pathologies, which has increased the demand for and consumption of strawberries (Nunes & Novello, 2020).

Brazil ranks first in strawberry production among South American countries, with an annual production of 187,000 tons and an average productivity of 38.83 tons per hectare (Food and Agriculture Organization of the United Nations, n.d.). Strawberry cultivation plays an important economic role in Brazilian family farming by contributing to income diversification (Carvalho et al., 2016). Production is concentrated mainly in the South and Southeast regions of the country, particularly in the states of Minas Gerais (3,068 hectares), Paraná (1,020 hectares), Rio Grande do Sul (750 hectares), São Paulo (300 hectares), and Espírito Santo (292 hectares; Deleo et al., 2023). In Santa Catarina state, 250 hectares are dedicated to strawberry cultivation, and production is substantially increased in the summer due to the local mild climatic conditions, while other regions experience high temperatures that negatively affect flowering and fruiting (Antunes et al., 2023; Moraes, 2023).

One of the phytosanitary problems affecting strawberries is insect pests such as the spotted-wing drosophila, *Drosophila suzukii* (Matsumura, 1931) (Diptera: Drosophilidae). Over the past two decades, *D. suzukii* has become a global pest because of its polyphagous habit and preference for small fruits (EPPO, 2026b). Native to southwestern Asia, *D. suzukii* has been present in southern Brazil since 2013 (Deprá et al., 2014) and is currently also distributed in other South American countries, such as Argentina, Chile, and Uruguay (EPPO, 2026a).

Female *D. suzukii* flies pierce the fruit skin for oviposition, and the eggs give rise to larvae that feed on the fruit pulp, rendering the fruits unmarketable (Santos, 2020). In strawberry crops in the Trento region of Italy, economic losses caused by *D. suzukii* amounted to approximately € 501,637 in a single season (De Ros et al., 2013). In California, a 20% reduction was reported in the gross revenue of strawberry production infested by *D. suzukii* (Goodhue et al., 2011). These economic reports demonstrate the potential losses that *D. suzukii* can cause to global fruit production, particularly in temperate regions where the pest is more readily established (Walsh et al., 2011).

Monitoring *D. suzukii* adults using traps containing lures allows early detection of the pest in the season. This can enable growers to estimate insect population density and, based on this information, determine the most appropriate timing and control strategies (Bernardi et al., 2015). Moreover, this methodology can be combined with fruit sampling to better determine whether fruits are serving as hosts for the pest (Ørsted et al., 2021) and to identify potential oviposition preferences among host genotypes. In addition, data obtained through monitoring can be correlated with meteorological variables, providing insights into the behavior of pest populations under different environmental conditions. Such information may be extrapolated to regions with similar environmental characteristics, as insect populations tend to exhibit comparable patterns under equivalent conditions (Hickel et al., 2019).

Although previous studies have investigated aspects of *D. suzukii* population dynamics, climatic influences, or host susceptibility separately, studies integrating these factors under protected strawberry cultivation conditions remain scarce, particularly in southern Brazil. A comprehensive understanding of the relationships among pest population fluctuations, meteorological variables, and natural infestation patterns in different strawberry genotypes is essential for improving monitoring programs and supporting integrated pest management strategies. Therefore, this study aimed to investigate the population dynamics of *D. suzukii* in a protected strawberry crop, evaluate the influence of meteorological variables on population fluctuations, and assess the natural infestation of different strawberry genotypes in the highland region of Santa Catarina, Brazil.

2. Materials and Methods

2.1 Monitoring of *Drosophila suzukii* in a Protected Strawberry Crop

A protected strawberry cultivation area (umbrella-type greenhouse with open sides – 675 m²) was used to monitor adults of *D. suzukii*. The greenhouse is located at the Center for Agroveterinary Sciences of the State University of Santa Catarina (CAV/UDESC) in the municipality of Lages, Santa Catarina, Brazil, with geographic coordinates of 27°47'28" S and 50°18'14" W, at an altitude of 923 meters (Figure 1A).

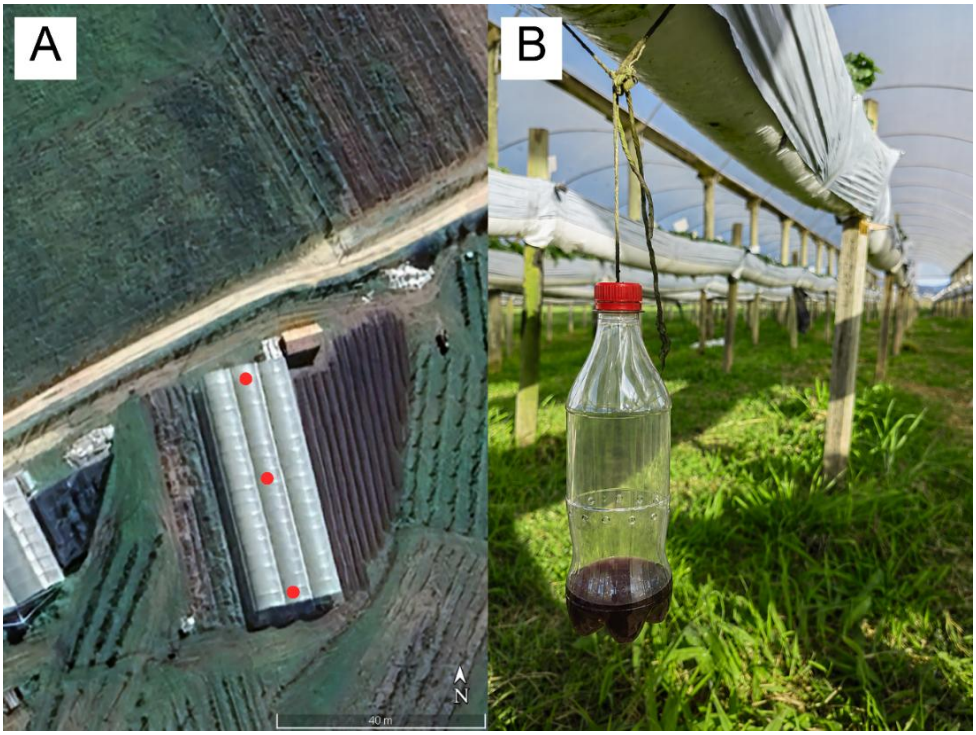


Figure 1. (A) Aerial image of the protected strawberry crop. The location of the traps was identified (red dots). (B) Trap model for capturing *D. suzukii* specimens

Source. (A) Adapted from Google (n.d.).

The strawberry cultivation area was composed of short-day cultivars such as CAV 107.7, Randoce, Kiara, and Pircinque, and day-neutral cultivars such as Bellalinda, Alpina 10, and San Andreas. All genotypes begin fruiting from September onward. Short-day genotypes produced fruit until approximately December, while day-neutral genotypes usually maintained production until March. The plants were grown on suspended benches with slabs consisting of plastic bags filled with a commercial substrate (40% charred rice husk, 40% decomposed pine bark, and 20% peat). The experiment used a semi-hydroponic cultivation system, with irrigation and fertigation applied through a drip system. The plants of the different genotypes were randomly distributed in four blocks with 10 plants within the greenhouse. Annually, between April and May, the seedlings were renewed and a new randomization was carried out, resulting in a new arrangement of the blocks in the experimental area. Regarding phytosanitary management, pesticide applications were carried out only for the control of powdery mildew, as well as the occasional removal of leaves, with the aim of improving plant aeration.

The monitoring was carried out over three years, from August 2020 to July 2023, covering three growing seasons. The first season (S1) corresponded to the period from August 2020 to July 2021; the second season (S2), from August 2021 to July 2022; and the third season (S3) lasted from August 2022 to July 2023. To capture *D. suzukii* adults, "fly-catcher" traps were installed, constructed from 600 mL transparent PET bottles (Figure 1B). The lower third of each trap contained 11 holes of 5 mm in diameter, allowing the selective entry of small insects (Santos, 2014). Considering the recommendation to install two to three fly traps per hectare for monitoring *D. suzukii*, three traps were installed in the strawberry crop, strategically distributed along the edges and in the center of the growing area (Figure 1B; Santos, 2014).

The traps were baited with the Droskidrink food attractant, composed of 75% apple cider vinegar (Heinig®), 25% red wine (Bailey's Dry Red Table Wine - Epagri), and 20 g of sugar (Native®) per liter of solution (Grassi et al., 2014). Traps were inspected weekly, the captured insects were removed, and the bait was replaced (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria, 2021). Collected specimens were preserved in 100 mL vials containing 70% ethanol. At the Entomology Laboratory of CAV/UDESC, the insects were sorted using a stereomicroscope (Model Q764ZT - Motic®). Subsequently, the *D. suzukii* adults were counted and sexed based on morphological characteristics (Van Timmeren et al., 2012).

Data from monitoring were also correlated with meteorological variables, including maximum, minimum, and mean air temperature, thermal amplitude, precipitation, and relative humidity. These data were obtained from the Center for Environmental Resources and Hydrometeorology Information of Santa Catarina (CIRAM/EPAGRI), based on the meteorological station located at CAV/UDESC, approximately 700 m from the experimental greenhouse. Because environmental variables were not continuously recorded inside the greenhouse, data from the nearby weather station were used as a proxy for greenhouse climatic conditions (open-sided greenhouse).

2.2 Natural Infestation by *Drosophila suzukii* in Strawberry Fruits

To assess the monthly natural infestation and infestation among strawberry fruit genotypes by *D. suzukii*, fruits were sampled throughout the fruiting period (Table 1). The strawberry fruits were supplied by the Fruit Growing Laboratory of CAV/UDESC. The quantity of fruits evaluated each month varied according to the laboratory's production availability, which resulted in the absence of sampling in some months of the experimental period.

Table 1. Number of strawberry fruits sampled per month and genotype for the evaluation of natural infestation by *Drosophila suzukii* during the 2020/2021, 2021/2022, and 2022/2023 growing seasons

Season	Month	Alpina 10	Bellalinda	CAV 107.7	Kiara	Pircinque	Randoce	San Andreas	Total
2020/2021	Sep.	10	10	10	0	10	0	8	48
	Nov.	14	16	20	0	20	0	17	87
	Dec.	10	10	10	10	10	10	10	70
	Jan.	9	10	10	0	10	0	10	49
	Feb.	10	10	0	0	0	0	0	20
2021/2022	Sep.	0	0	10	10	9	7	8	44
	Oct.	5	10	10	10	10	10	2	57
	Nov.	6	10	10	10	10	9	10	65
	Dec.	10	10	10	0	10	8	8	56
	Feb.	9	8	12	13	12	12	11	77
2022/2023	Nov.	9	9	9	8	6	3	7	51
	Dec.	3	3	3	5	3	3	5	25
	Jan.	3	3	3	0	2	3	3	17
Total		98	109	117	66	112	65	99	666

At the Entomology Laboratory, fruits were placed individually in 145 mL plastic containers, sealed with perforated lids covered with *voile* fabric, and maintained under controlled conditions (23 ± 2 °C and a 12-hour photoperiod) for 15 days. After the incubation period, the emerging insects were collected and identified using a stereomicroscope. From these data, the emergence of adults per fruit and the percentage of infested fruits were calculated by dividing the number of infested fruits per sample by the total number of fruits sampled.

2.3 Data Analysis

Data collected during the monitoring period were summarized using descriptive statistics. Differences in *D. suzukii* catches among growing seasons were evaluated using generalized linear mixed models (GLMMs) with a negative binomial distribution, considering season as a fixed effect and trap as a random effect. Pairwise comparisons among seasons were performed using Tukey-adjusted tests. The proportion of females among captured adults was estimated using a binomial generalized linear model (GLM), considering the numbers of females and males recorded in each growing season. Female proportions and their respective 95% confidence intervals were then estimated for each season.

Monitoring graphs were generated in the R environment using the ggplot2 package (Wickham, 2016). For each sampling date, the mean number of *D. suzukii* adults captured per trap was calculated from the three monitoring traps. Population dynamics were represented by plotting the mean numbers of males, females, and total adults captured throughout each growing season. Natural infestation was expressed as the percentage of sampled fruits from which at least one *D. suzukii* adult emerged. The relationship between population fluctuations and external meteorological variables outside the greenhouse was determined using Spearman's correlation coefficient. Graphical representations were generated using the functions provided by Wei and Simko (2021).

Natural infestation was assessed by recording the emergence of *D. suzukii* adults from collected strawberry fruits. Infestation was expressed as the proportion of sampled fruits from which at least one *D. suzukii* adult emerged. For the statistical analysis of strawberry genotypes, data from the three growing seasons (2020/2021, 2021/2022, and 2022/2023) were pooled and analyzed jointly. The effects of sampling period, genotype, and their interaction on the proportion of infested fruits were evaluated using generalized linear models (GLMs) with a binomial distribution. The mean number of adults emerged per fruit was analyzed using generalized linear models with a negative binomial distribution. The numbers of fruits sampled, infested fruits, and total adults emerged were presented as descriptive data and were not subjected to statistical analysis. All analyses were performed in the R environment, considering a 5% significance level.

3. Results

3.1 Monitoring of *Drosophila suzukii* in a Protected Strawberry Crop

Considering the entire monitoring period, a total of 11,635 adult specimens of *D. suzukii* were captured. Of these, 3,531 were recorded during season 1 (S1), 5,383 during season 2 (S2), and 2,721 during season 3 (S3). Estimated mean captures were 24.2 ± 3.09 (95% CI: 18.9-31.1), 35.2 ± 4.37 (95% CI: 27.6-44.9), and 20.2 ± 2.68 (95% CI: 15.5-26.2) adults per sampling unit in S1, S2, and S3, respectively. Adult abundance was significantly higher in S2 than in S3 (ratio = 1.75, z = 3.06, p = 0.0063), whereas S1 did not differ significantly from S2 or S3. Compared with S1 and S3, S2 showed 1.96- and 1.97-fold higher male captures, respectively. Female captures followed a similar trend, being 1.32-fold higher than in S1 and 1.97-fold higher than in S3 (Table 2).

Table 2. Number of male and female *Drosophila suzukii* adults captured and percentage of females during the 2020/2021 (S1), 2021/2022 (S2), and 2022/2023 (S3) growing seasons in Lages, Santa Catarina, Brazil

Season	Males	Females	Females (%)	95% CI
2020/2021	1,112	2,419	68.5	0.670-0.700
2021/2022	2,189	3,194	59.3	0.580-0.606
2022/2023	1,106	1,615	59.4	0.575-0.612
Total period	4,407	7,228	62.1	-

The population fluctuation of *D. suzukii* exhibited distinct patterns across seasons. All monitored seasons showed a reduction or absence of captures between July and September (Figure 2), a period during which the mean temperature was 12.9 °C. Across the three growing seasons, the population of *D. suzukii* increased between October and December (mean temperature of 18.11 °C in S1, 17.89 °C in S2, and 18.10 °C in S3) and again from February to May (mean temperature of 16.79 °C in S1, 16.80 °C in S2, and 17.85 °C in S3) (Figure 2). In S2, several population peaks were observed between mid-October and May, culminating on December 30, 2021, when an average of 153 adults per trap was recorded (Figure 2). The mean weekly temperature during this period was 20.43 °C, with a maximum recorded temperature of 32.57 °C. In contrast, S3 showed a sharp increase in adult abundance from mid-March to mid-May, with the seasonal peak occurring on May 19, 2023, when a mean weekly temperature of 11.88 °C and an average of 136 adults captured per trap were recorded. Although S3 exhibited a pronounced population peak during May 2023, high captures were concentrated within a shorter period than in S2, which showed elevated adult abundance over several consecutive months.

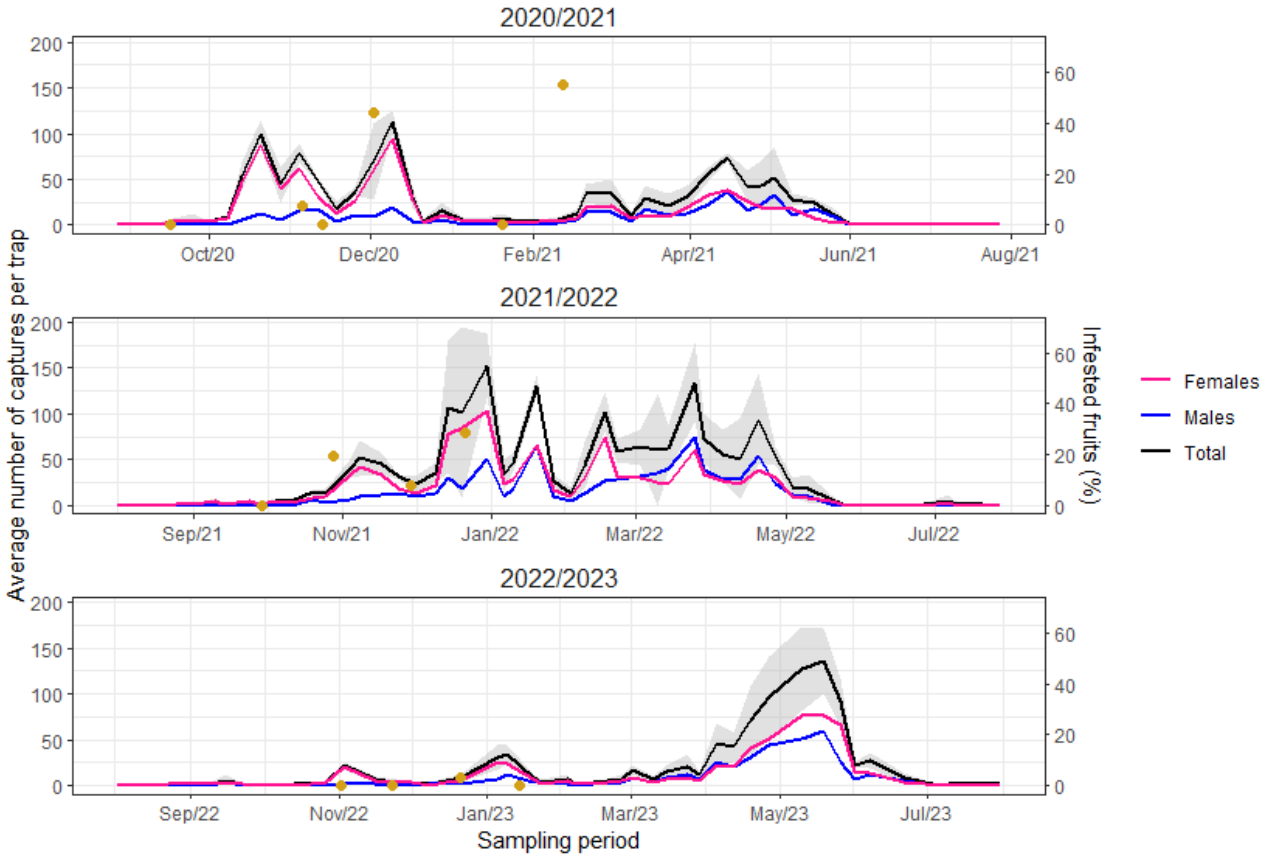


Figure 2. Population fluctuation of *Drosophila suzukii* adults in a protected strawberry crop in the municipality of Lages, Santa Catarina, during the 2020/2021 (S1), 2021/2022 (S2), and 2022/2023 (S3) growing seasons

Note. Lines represent the mean number of males, females, and total adults captured per trap on each sampling date. The shaded area represents ±1 standard deviation of total captures among traps. Yellow points indicate the percentage of infested fruits estimated from adult emergence.

3.2 Meteorological Variables

Meteorological data on maximum temperature, minimum temperature, average temperature, thermal amplitude, precipitation, and relative humidity were correlated with *D. suzukii* population fluctuations using Spearman's correlation. In this analysis, values close to 1 indicate a positive correlation, whereas values close to −1 indicate a negative correlation.

Rainfall and relative humidity were not significantly correlated with *D. suzukii* abundance, as the values were close to 0 and nonsignificant (−0.2-0) (Figure 3). In contrast, when the total number of captured *D. suzukii* adults was correlated with maximum temperature, average temperature, and thermal amplitude, positive correlations were observed (0.2-0.4) (Figure 3).

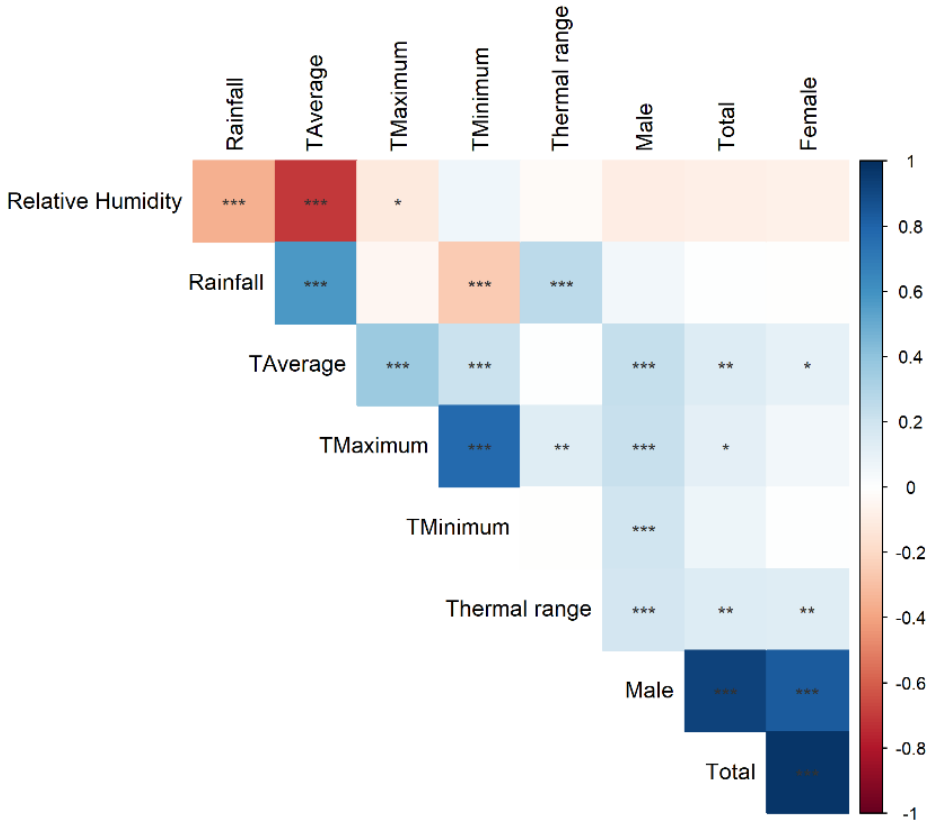


Figure 3. Estimated Spearman´s correlation values for monitoring of *Drosophila suzukii* in a protected strawberry crop from August 2020 to July 2023, Lages, SC

Note. *** p-value < 0.001; ** p-value between 0.001 and 0.01; * p-value between 0.01 and 0.05.

Moreover, average, maximum, and minimum temperatures, and thermal amplitude were more significant for males compared with females (*** p-value < 0.001). For females, only the average temperature (* p-value between 0.01 and 0.05) and thermal amplitude (** p-value between 0.001 and 0.01) were significant, with minimum temperature having no influence on the number of captured *D. suzukii* adults.

3.3 Natural Infestation by *Drosophila suzukii* in Strawberry Fruits

The proportion of infested fruits was significantly affected by the sampling period ($p < 0.0001$), whereas genotype ($p = 0.476$) and the interaction between genotype and sampling period ($p = 0.999$) were not significant. Similarly, the number of adults that emerged per fruit was significantly affected by the sampling period ($p < 0.0001$), while genotype ($p = 0.073$) and the interaction between genotype and sampling period ($p = 0.777$) were not significant.

Both the proportion of infested fruits and the number of emerging adults per fruit varied significantly among sampling periods (Table 3). The highest infestation rates were observed in S1 and decreased in S2 and subsequently in S3, and the mean number of adults emerging per fruit remained below 2 in all seasons (Table 3).

Table 3. Natural infestation of strawberry fruits by *Drosophila suzukii* during the 2020/2021, 2021/2022, and 2022/2023 growing seasons in Lages, Santa Catarina, Brazil

Season	Month	Number of fruits sampled	Number of infested fruits	Number of adults emerged	Proportion of infested fruits (%)	Mean adults emerged per fruit
2020/2021	Sep.	48	0	0	0	0
	Nov.	87	3	19	3.4 a	0.2 a
	Dec.	70	31	111	44.3 c	1.6 b
	Jan.	49	0	0	0	0
	Feb.	20	11	23	55 c	1.1 ab
2021/2022	Sep.	44	0	0	0	0
	Oct.	57	11	41	19.3 abc	0.7 ab
	Nov.	65	5	10	7.7 ab	0.1 a
	Dec.	56	16	47	28.6 bc	0.8 ab
	Feb.	77	0	0	0	0
2022/2023	Nov.	51	0	0	0	0
	Dec.	25	1	1	4 abc	0.1 ab
	Jan.	17	0	0	0	0

Different letters within a column indicate significant differences among sampling periods according to post hoc comparisons ($P < 0.05$); values followed by the same letter do not differ significantly.

Natural infestation by *D. suzukii* did not differ among strawberry genotypes in terms of the proportion of infested fruits ($p = 0.476$). Adult emergence was recorded in all evaluated genotypes, and the proportion of infested fruits ranged from 7.07% in San Andreas to 16.12% in Randoce (Table 4). Likewise, the mean number of adults emerging per fruit did not differ among genotypes ($p = 0.073$), ranging from 0.2 in San Andreas to 0.5 in Pircinque, Kiara, and Randoce.

Table 4. Natural infestation of strawberry genotypes by *Drosophila suzukii* in Lages, Santa Catarina, Brazil

Genotype	Number of fruits sampled	Number of infested fruits	Number of adults emerged	Proportion of infested fruits (%)	Mean adults emerged per fruit
Alpina 10	98	13	32	13.3	0.3
Bellalinda	109	17	48	15.6	0.4
CAV 107.7	117	12	35	10.3	0.3
Kiara	66	6	32	9.1	0.5
Pircinque	112	13	56	11.6	0.5
Randoce	65	10	32	16.1	0.5
San Andreas	99	7	17	7.1	0.2

4. Discussion

Monitoring is a key tool in the study of pest insect population dynamics, as it provides information on density, fluctuations, and migration patterns (Gallo et al., 1988). From a practical perspective, it allows tracking insect population dynamics and ensures that control measures maintain populations below levels capable of causing economic damage (Zawadneak et al., 2020).

In this study, differences in the population dynamics of *D. suzukii* were observed among the growing seasons. Interannual variation in temperature, humidity, winter severity, availability of alternative hosts, and crop management intensity may all influence *D. suzukii* population levels (Aguiar et al., 2024; Brilinger et al., 2024;

McCabe et al., 2025; Ørsted et al., 2021). Temperature was one of the main factors associated with *D. suzukii* population fluctuations throughout the monitoring period. For example, in all three monitored seasons, there was a reduction and/or absence of adult captures during the winter. It is hypothesized that this decrease in captures is primarily associated with the lower temperatures in the region. Low temperatures were recorded in the region during this period, including sub-zero readings, reaching −3.22 °C on June 19, 2022. For Brazilian populations of *D. suzukii*, the optimal temperature range for survival and development ranges between 23 °C and 25 °C (Schlesener et al., 2020), while temperatures below 10 °C and above 32 °C gradually reduce the reproductive parameters of the species (Kinjo et al., 2014). Moreover, extreme temperatures below 0.5 °C are lethal to *D. suzukii* adults (Juliet, 2014), which may explain the reduction or absence of captures from June to September.

Despite the significant reduction in *D. suzukii* populations during the winter, some individuals were still captured. The persistence of *D. suzukii* in the field during the cold season is associated with its phenotypic adaptation linked to its winter morphotype (Winkler et al., 2021). This morphotype is characterized by darker coloration, which enhances radiation absorption (Valério et al., 2022), and by larger body and wings, which may facilitate dispersal (Little et al., 2020). Another adaptation to unfavorable winter conditions is diapause, during which drosophilids reduce their metabolism (Shearer et al., 2016). Consequently, the spotted-wing drosophila can tolerate negative temperatures; as a result, previously mated females that survived this period can establish new generations in early spring (Winkler et al., 2021). This phenomenon was evident during the monitoring period, with *D. suzukii* populations gradually increasing from September and October onward in all growing seasons.

Population peaks of *D. suzukii* were associated with periods characterized by suitable temperatures and the availability of host fruits. In Lages, Santa Catarina, which is characterized by a temperate climate, the ideal temperatures for spotted-wing drosophila occurred mainly during spring, summer, and early autumn. The results found in this study are consistent with those reported for *D. suzukii* in protected strawberry crops in South Korea (Hwang et al., 2019). The authors reported that rising temperatures during the warm seasons increased the spotted-wing drosophila population, with up to 10 adults captured inside greenhouses and 449 adults in surrounding areas (Hwang et al., 2019). Differences in peak abundance among growing seasons likely resulted from the interaction between temperature conditions and host availability. Although suitable temperatures occurred during all seasons, variations in their duration and timing may have influenced population growth rates and, consequently, the magnitude of adult captures.

However, even during population increases in the warm seasons, there were decreases in pest captures. In small fruit orchards in Rio Grande do Sul, Brazil, there were significant reductions in *D. suzukii* captures during periods with temperatures around 30 °C (Wollmann et al., 2019). This may occur because temperatures above the maximum developmental threshold of the species (31.6 °C) can have deleterious effects on *D. suzukii* (Juliet, 2014). December, January, and February are typically the hottest months of the year in the highland region of Santa Catarina. Throughout the monitoring period, 60 days were recorded with maximum temperatures exceeding 30 °C.

Similar patterns of *D. suzukii* population dynamics in strawberry crops have been reported in other studies conducted in southern Brazil. In Vacaria, Rio Grande do Sul, Klesener et al. (2018) found that captures in strawberry crops occurred mainly between December and May, with the highest numbers recorded during summer and early autumn, while no captures were observed during winter. Likewise, Wollmann et al. (2019), monitoring *D. suzukii* populations in organic strawberry crops in southern Rio Grande do Sul, recorded the highest population peaks between late spring and mid-autumn, coinciding with the fruiting period of the crop. The authors also highlighted temperature as the main factor associated with the pest's population dynamics, with a marked reduction in captures during colder months (Wollmann et al., 2019). These findings corroborate the patterns observed in the present study, in which the highest captures occurred during periods of fruit production, whereas populations were reduced or absent during winter.

Relative humidity, in turn, was not significantly associated with *D. suzukii* population dynamics in the evaluated strawberry crop. This effect is likely related to the fact that the Lages region is characterized by high and consistent relative humidity throughout the year (78% to 80%; Secretaria de Estado de Desenvolvimento Regional, 2003). This was confirmed by meteorological data, which showed that the mean relative humidity during the entire monitoring period was 80.73% ± 10.08 (standard deviation). These values are considered ideal for *D. suzukii*, as relative humidity levels above 71% are known to increase adult longevity as well as oviposition rates (Tochen et al., 2016). Similarly, increases in *D. suzukii* populations at relative humidity levels exceeding 70% were reported during monitoring in rosaceous crops and forested areas of Argentine Patagonia (Martínez et al., 2025).

Likewise, captures of spotted-wing drosophila during the monitoring period were not influenced by precipitation. Rainfall may affect *D. suzukii* both positively and negatively. On the positive side, regions with regular rainfall regimes tend to maintain consistently high relative humidity levels. Areas receiving between 500 and 2,500 mm of annual precipitation correspond to those with the greatest distribution of *D. suzukii* (Santos et al., 2017). During S1, 1,330 mm of rainfall was recorded, while S2 and S3 recorded 1,480 mm and 1,655 mm, respectively. However, rainfall may also negatively affect *D. suzukii* by impairing adult flight activity and limiting dispersal (Manko et al., 2021). In protected strawberry production systems, plants are sheltered from direct rainfall, resulting in a relatively drier environment inside the greenhouse. Nevertheless, the open sidewalls may have reduced differences in temperature and relative humidity between the interior and exterior of the structure, although these differences were not directly quantified.

During all three growing seasons evaluated, the number of females captured was higher than the number of males. Similar trends have been reported in cherry, blueberry, and raspberry orchards in China, where female adults predominated (Wang et al., 2022). *D. suzukii* adults are generally attracted to orchards to feed on sugars and proteins found in damaged fruits, extrafloral nectaries, and foliar surfaces of fruit plants (Wang et al., 2022). However, the increased capture of females may be related to their search for fruits for oviposition, while males remain in adjacent areas (Plantamp et al., 2017).

Fruits infested by *D. suzukii* become unsuitable for consumption and commercialization, resulting in significant economic losses for growers (Santos, 2020). Depending on cultivation conditions, host susceptibility, and the management strategies adopted, losses may range from 60% to 80% of strawberry production (Santos, 2020). During the three growing seasons evaluated in this study, high infestation levels were observed, with up to 55% of fruits infested in February 2021. Furthermore, fruit infestation varied throughout the growing seasons, reflecting factors such as the availability of susceptible fruits (Grassi et al., 2011). Therefore, assessing fruit infestation represents an important tool for understanding the damage caused by *D. suzukii* and its relationship with host plants at different periods of the growing season.

When evaluating the emergence of *D. suzukii* adults from different strawberry genotypes, all materials assessed were found to be potential hosts of the pest. Similar findings have been reported in previous studies, demonstrating that different strawberry cultivars exhibit varying levels of susceptibility to infestation. In Spain, a study compared 16 strawberry cultivars and found that all were susceptible to *D. suzukii* infestation; however, the cultivars 'Calderón' and 'Plared0955' showed higher adult emergence than the others (Pérez-Guerrero et al., 2022). Likewise, Gong et al. (2016), when evaluating 107 genotypes belonging to 12 *Fragaria* species, identified substantial variation in susceptibility levels among the materials studied. These differences may be associated with intrinsic fruit characteristics, such as size, chemical composition, soluble solids content, acidity, and firmness. In general, fruits with firmer skin tend to reduce *D. suzukii* oviposition, whereas riper fruits, characterized by higher sugar content and lower firmness, become more susceptible to pest attack. Furthermore, compounds such as methyl anthranilate may influence the development of insect eggs and larvae (Bräcker et

al., 2020), while fruit size may affect the availability of space and resources for larval development, thereby influencing adult emergence (Gong et al., 2016).

The cultivars evaluated in this study represent the current scenario of strawberry production in Brazil. The San Andreas cultivar, of American origin, is widely grown by farmers. The cultivars Pircinque, Randoce, Alpina 10, Bellalinda, and Kiara were developed through the breeding program of the Fruit Growing Group at CAV/UDESC, in partnership with CREA-OFA-FRF (*Consiglio per la ricerca in agricoltura analisi dell'economia agraria*) (Farias et al., 2023). The Pircinque cultivar has been commercially available since 2017, while the Randoce, Alpina 10, Bellalinda, and Kiara cultivars were released in 2022. The CAV 107.7 cultivar is still in the experimental phase.

Overall, the findings of this study improve our understanding of the population dynamics of *D. suzukii*, its association with meteorological variables, and infestation patterns in protected strawberry crops. These findings provide valuable information for the development of improved monitoring programs and more effective pest management strategies, enabling timely implementation of control measures during periods of higher infestation risk and thereby reducing crop losses caused by this pest. Within the framework of Integrated Pest Management (IPM), knowledge of seasonal population fluctuations and infestation patterns can support decision-making regarding the adoption of cultural, physical, biological, and, when necessary, chemical control measures. Furthermore, improved monitoring and fruit sampling can help growers make more informed decisions regarding insecticide applications, reducing unnecessary pesticide use, lowering production costs, and minimizing the risks associated with insecticide resistance, environmental contamination, and impacts on human health.

Some limitations of this study should be acknowledged. The research was conducted at a single experimental site, which may limit the extrapolation of results to regions with similar environmental characteristics. Furthermore, the climate data were obtained from an external weather station and may not fully represent the microclimatic conditions within the protected cultivation system, even with the greenhouse having open sides. Therefore, further studies in different locations and using in situ environmental monitoring are recommended to validate and expand the findings reported here.

5. Conclusions

Drosophila suzukii is established in protected strawberry crops in the highland region of Santa Catarina, occurring throughout the production cycle and infesting fruits of all evaluated strawberry genotypes.

Temperature was the main meteorological factor associated with population fluctuations of *D. suzukii*, with population increases occurring during periods of mild to warm temperatures (October to May) and reduced captures during colder months (June to September). These findings indicate that meteorological conditions should be considered when planning monitoring and management programs for the pest.

Fruit infestation varied throughout the evaluated seasons, reaching high levels during specific periods and highlighting the potential of *D. suzukii* to cause economic losses in protected strawberry production systems. Therefore, combining adult monitoring with fruit infestation assessments can provide valuable information for improving pest management decisions.

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Transparency of Data

The entire data set that supports the results of this study was published in the article itself.

Author Contribution Statement

	M Fiedler	D. Brilinger	KTU Daboit	JM de Lima	AA Kretzschmar	MIC Boff
Conceptualization	■	■				■
Data curation	■	■	■	■		
Formal analysis	■	■				
Funding acquisition					■	■
Investigation	■	■	■	■		
Methodology	■	■	■	■		■
Project administration						■
Supervision		■				■
Validation	■	■				■
Visualization	■	■				
Writing – original draft	■					
Writing – review and editing		■				■

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