RESEARCH ARTICLE **(Open Access)**

Influence of Climatic Temperature Variability on the Development of Biology of *Scaphoideus titanus* in Kosovo

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Abstract

Scaphoideus titanus Ball is the primary vector of *Flavescence dorée* phytoplasma (FDp), one of the most destructive grapevine diseases in Europe. The population dynamics and transmission potential of *S. titanus* are strongly influenced by climatic factors, particularly temperature. In Kosovo, where viticulture represents a key agricultural sector, rising temperature variability linked to climate change is expected to alter the biology and ecology of this vector. This study investigated the effects of temperature fluctuations on *S. titanus*, focused on egg hatching, nymphal development and adult emergence. Throughout the three years of monitoring, field observations combined with climate data revealed that warmer winter and spring temperatures accelerate egg hatching and shorten nymphal development stage, leading to earlier adult emergence. These findings suggested that temperature variability will be a key determinant in shaping the life cycle of *S. titanus* under the climatic conditions of Kosovo. Understanding these dynamics is essential for assessing future risks of potential spread of FDp and for designing sustainable, climate-adapted integrated pest management strategies.

Keywords: Temperature variability; *Scaphoideus titanus*; life cycle; Kosovo.

1. Introduction

Scaphoideus titanus Ball (Hemiptera: Cicadellidae) is a univoltine leafhopper native to North America and recognized as the primary vector of *Flavescence dorée* phytoplasma (FDp), a quarantine disease posing a severe threat to European viticulture (EFSA, 2020). Since its accidental introduction to Europe in the mid-20th century, the species has successfully established across major grape-growing regions, adapting its life cycle to diverse environmental and climatic conditions (Ripamonti et al., 2021).

Temperature is a key abiotic factor influencing the developmental rate, fecundity, and survival of *S. titanus* populations. Variations in temperature regimes can modify the synchronization between insect phenology and grapevine growth stages, thereby affecting both vector activity and the epidemiology of *Flavescence dorée* (Trivellone et al., 2016). Understanding these temperature-dependent developmental patterns is crucial for predicting population dynamics under changing climatic conditions and for refining integrated pest management (IPM) programs (Lessio et al., 2021). Kosovo, a country in the central Balkan Peninsula, has a continental climate with significant seasonal variations in temperature (Hoxha et al., 2021). In Kosovo, viticulture represents a key component of agricultural production, yet limited information is available regarding the biology and seasonal development of *S. titanus* under local climatic conditions. The viticulture of Kosovo is especially susceptible to these climate variations. While extreme summer heatwaves and mild winters have become more frequent, mean annual temperatures have risen over the last 20 years. The biology of confirmed vineyard pests, such as *S. titanus* may be greatly impacted by these trends. Although it has only recently been established in vineyards in

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Kosovo (Gjinovci et al., 2022), little is known about how local temperature variability affects its life cycle dynamics and developmental parameters in the field.

The present study aims to assess the influence of climatic temperature variability on the development of *S. titanus* populations in the Rahovec region of Kosovo. The findings are expected to provide baseline data to better understand the pest's adaptive responses to temperature and to support more precise monitoring and control strategies within regional IPM frameworks.

2. Material and Methods

2.1. Study area

The study was conducted over three consecutive grapevine growing seasons from 2023 to 2025 in the Rahovec region, located in southwestern Kosovo. This region represents one of the main viticultural zones of the country, characterized by a continental–Mediterranean climate, with hot, dry summers and mild winters. The surveyed vineyards were predominantly planted with local and commercially important grapevine cultivars.

2.2. Climatic Data Collection

To assess the influence of temperature variability on the developmental dynamics of *Scaphoideus titanus*, daily temperature data were collected and subsequently averaged to obtain monthly mean temperatures to each surveyed site. These data were obtained from the nearest meteorological stations of Prizren, managed by the Hydrometeorological Institute of Kosovo, and were recorded throughout the monitoring periods (April–October) in 2022, 2023, and 2024. These data were used to analyze the relationship between temperature fluctuations and the occurrence of different developmental stages (first nymphs and adults).

2.3. Monitoring of Nymph Emergence

The initial occurrence of *Scaphoideus titanus* nymphs was monitored from late April to early July across three consecutive growing seasons (2023–2025). Weekly observations were conducted by visually inspecting the undersides of the oldest grapevine leaves. Within the surveyed viticultural area, three representative vineyard plots were selected for detailed monitoring. Nymphs collected during field inspections were transferred to the Plant Protection Laboratory of Kosovo Institute of Agriculture for morphological identification under a stereomicroscope (Olympus SZX16, Tokyo, Japan).

2.4. Monitoring of Adult Population

The emergence of the first *Scaphoideus titanus* adults was monitored from mid-June to early October during the 2023, 2024, and 2025 growing seasons using yellow sticky traps (Insect Trap Aria®, 10 × 25 cm). Traps were placed at canopy height in each vineyard and replaced weekly. The first adult captures were recorded each year to determine the timing of adult emergence and to assess its relationship with interannual temperature variations.

2.5. Specimen Preservation and Identification

Collected adult specimens were preserved in 75% ethanol for subsequent morphological examination. Identification of both nymph and adult stages was conducted using diagnostic keys provided in the EFSA Pest Survey Card (2020). This reference ensured reliable identification and differentiation of *Scaphoideus titanus* from morphologically similar cicadellid species.

2.6. Data Analysis

The relationship between temperature variation and the biological development of *Scaphoideus titanus* was assessed by comparing the temporal distribution of its developmental stages (nymphs and adults) with corresponding temperature data. Descriptive and correlation analyses were performed to evaluate the influence of climatic temperature on the timing of the first emergence of nymphs and adults across the three monitored sites.

3. Results and Discussion

3.1. Results and Discussion for monthly temprature

The monthly temperature data from 2022 to 2024 (Table 1) exhibit a typical continental–Mediterranean climatic pattern, characterized by cold winters, a rapid warming trend in spring, and hot, dry summers followed by a gradual cooling in autumn. Average temperatures ranged from approximately 2–5 °C in January to 24–27 °C in July, reflecting the marked thermal amplitude of the Rahovec–Prizren region in southwestern Kosovo.

Across the three years (Figure 1), 2024 exhibited the highest average temperatures, particularly from March to September, suggesting a warmer and possibly drier growing season. In contrast, 2022 recorded the lowest values, especially during spring and autumn, which

may have led to delayed biological activity for both grapevines and *S. titanus*. The 2023 season presented intermediate conditions, with a smoother temperature progression toward the summer peak. Such interannual temperature variability is ecologically relevant because the development of *S. titanus* is strongly temperature-dependent. A recent study conducted by Rigamonti et al. (2020) demonstrated that nymphal development accelerates as temperatures rise, with optimal growth between 22–28 °C and a lower threshold around 10 °C. Therefore, the warmer conditions in 2024 likely favored faster nymphal maturation and earlier adult emergence, while cooler spring temperatures in 2022 may have postponed the onset of nymphal appearance and adult flight activity.

These findings are consistent with observations by Comte et al. (2024), who reported that warmer microclimates in vineyards lead to earlier emergence and extended adult activity of *S. titanus*. Such shifts can significantly increase the potential risk period for phytoplasma trasmission. Consequently, the elevated temperatures observed in 2024 may have prolonged the adult flight period, enhancing potential phytoplasma transmission.

From a viticultural perspective, temperature fluctuations also influence grapevine phenological stages, such as budburst, flowering, and berry ripening. As noted by Palliotti et al. (2014), warmer spring and summer conditions can advance phenophases, potentially synchronizing them with *S. titanus* activity peaks. This overlap further underscores the importance of integrating climatic monitoring into pest management programs to better predict the dynamics of the vector for the possible preventing spread of associated pathogen under changing climatic conditions.

3.2. Results and Discussion for yearly temprature

The yearly average temperature data from 2022 to 2024 demonstrate a clear upward trend, reflecting progressive climatic warming within the study region of southwestern Kosovo. The mean annual temperature increased from approximately 12.8 °C in 2022 to 13.4 °C in 2023, and further to 14.7 °C in 2024. This steady rise of nearly 1.9 °C over three years aligns with the broader pattern of temperature increases reported for the Balkan Peninsula and southeastern Europe during the past decade (Hoxha et al., 2021; Spinoni et al., 2015).

The observed warming may be attributed to regional manifestations of global climate change, which are increasingly affecting the thermal regime of viticultural areas. According to Ceglar et al. (2019), the central and southern Balkans have experienced a pronounced rise in mean annual temperature, particularly during spring and summer months, leading to altered phenological and ecological processes in both crops and insect populations.

In the context of *Scaphoideus titanus* biology, even modest increases in mean annual temperature can have significant implications. Studies by Bocca et al. (2020) and Comte et al. (2024) have demonstrated that elevated temperatures accelerate the insect's development rate, potentially advancing nymphal emergence and extending the adult activity period. The higher yearly mean in 2024, therefore, suggests conditions more favorable for the faster completion of *S. titanus* generations and possibly a longer transmission window for *Flavescence dorée* phytoplasma.

In the Rahovec region, where grapevine cultivation is economically vital, such temperature increases could necessitate adjustments in pest monitoring schedules and integrated management practices to mitigate potential outbreaks linked to climate-driven phenological shifts. Overall, the consistent temperature rises from 2022 to 2024 reflects a local expression of ongoing climatic change, reinforcing the need for continuous environmental monitoring and the integration of climate-based modeling in pest management programs for *S. titanus* in Kosovo's vineyards.

Table 1. Average monthly temperatures for the years 2022, 2023, and 2024.

Months	2022	2023	2024
I	1,3	3,9	3,6
II	5,2	4,6	9
III	5,3	8,9	10,5
IV	11,1	10	15,2
V	17,9	15,9	18,0
VI	22,4	19,8	25,3
VII	23,8	25	27,1
VIII	23,3	23,3	26,4
IX	17,5	20,8	19,6
X	12,9	16	13,8
XI	8,9	8,7	5,2
XII	5,5	5,1	3,3
Yearly average temp.	13 °C	13,5 °C	14,8 °C

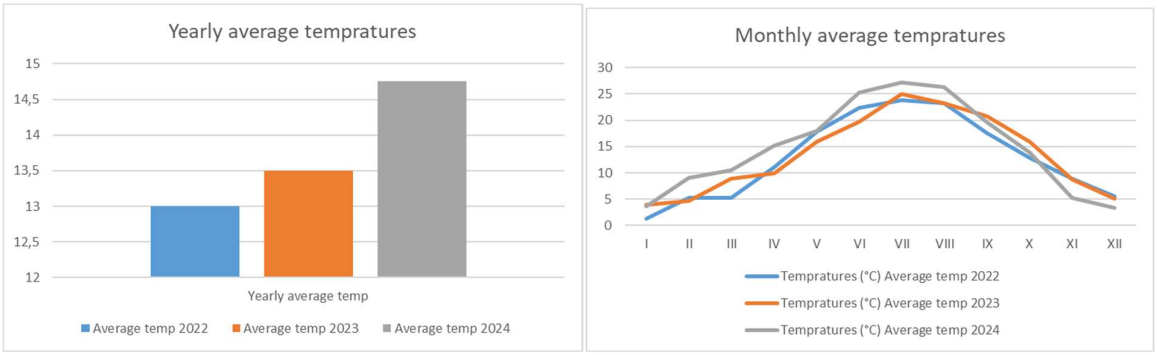

Figure 1. Average monthly temperatures (left) and yearly mean temperatures for 2022, 2023, and 2024 (right).

Table 2 presents the first appearance dates of the **first nymphal stage (Fig.2)** and the **first adults** of *Scaphoideus titanus* for three consecutive monitoring seasons (2023–2025). These observations allow assessment of interannual variability in developmental timing and potential relationships with climatic conditions. There is a clear shift towards an earlier appearance of first nymphs over the three monitoring years. Across 2023–2025, *Scaphoideus titanus* showed a consistent shift to earlier seasonal development for both nymphs and adults. These trends reflect warming climatic conditions and have direct implications for the timing of monitoring and control measures in vineyards. Continued multi-year observations combined with climate data will enable more reliable phenological models and improved management of grapevine diseases.

Table 2. The development of first nymph and adult of *S. titanus* for three consecutive monitoring seasons (2023–2025).

Year	Nymph	Adult
2023	02.06.2023	06.07.2023
2023	26.05.2024	01.07.2024
2025	17.05.2025	27.06.2025

Figure 2. *Scaphoideus titanus*: first-instar nymph (left) and adult (right) shown from both perspectives.

4. Conclusions

This study provides a multi-year assessment of climatic dynamics in the Rahovec viticultural region of Kosovo and their implications for the phenology of *Scaphoideus titanus*, the main vector of *Flavescence dorée* phytoplasma. The combined analysis of monthly and annual temperature patterns from 2022 to 2024, together with field observations of nymph and adult emergence from 2023 to 2025, demonstrated clear climate-driven shifts in the seasonal development of this economically important vineyard pest.

The phenological observations of *S. titanus* recorded from 2023 to 2025 showed a clear advancement in the onset of both nymphal and adult stages, corresponding closely with the documented increases in spring temperatures. First-instar nymphs appeared progressively earlier—from early June in 2023 to mid-May in 2025—while adult emergence advanced from early July to late June over the same period. This trend is biologically consistent with the species' temperature-dependent development, in which accelerated growth occurs above 20 °C and developmental thresholds are exceeded earlier in warmer years. The earlier onset and potential extension of the adult activity period imply an expanded temporal window for *Flavescence dorée* phytoplasma transmission, thereby amplifying epidemiological risks in affected vineyards.

From a viticultural perspective, these findings underscore an increased vulnerability of grapevine production systems to climate-driven changes in vector ecology. Warmer spring conditions may not only accelerate vector development but also increase synchrony between vector activity peaks and susceptible grapevine phenophases, thereby enhancing opportunities for pathogen transmission. As such, reliance on traditional monitoring calendars is likely to become insufficient under continued warming scenarios.

In conclusion, this study provides clear empirical evidence that rising temperatures in southwestern Kosovo are advancing the seasonal development of *S. titanus*, with direct implications of the vector management and a potential disease outbreak. Continued phenological monitoring, integration of high-resolution climatic datasets, and the adoption of temperature-based predictive models are essential steps toward improving early detection and optimizing intervention timing. These measures will be increasingly critical for maintaining effective surveillance and control of *S. titanus* and mitigating the spread of *Flavescence dorée* in the context of ongoing climatic change.

5. Acknowledgements

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