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Population fluctuation patterns of winged cereal aphids and their parasitoids in the subtropical region of Brazil

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Cereal crops in southern Brazil (subtropical region) are affected by different aphid (Hemiptera: Aphididae) species; the main ones are *Rhopalosiphum padi* (L.), *Schizaphis graminum* (Rondani), *Metopolophium dirhodum* (Walker) and *Sitobion avenae* (F.), which are vectors of phytopathogens, mainly barley yellow dwarf virus (BYDV, *Tombusviridae*). For mitigating the damage caused by these aphids, in 1978, the Biological Control Program of Wheat Aphids (BCPWA) was implemented by Embrapa Trigo and partners (Lau et al. 2021).

The BCPWA introduced 12 parasitoid (Hymenoptera) species from different regions of the world (Chile, Greece, England, Israel, Italy and Switzerland). Despite the rapid success of biological control of aphids in cereals in southern Brazil, after that time few studies were carried out, leaving a knowledge gap on the status of these aphids and their parasitoid community over time, mainly in the analysis of the factors that regulate the patterns of population fluctuation and interspecific synchrony (Santos et al. 2019). Currently, of the braconid species released by the BCPWA in the past and the native parasitoid species, *Aphidius platensis* (Brèthes), *Aphidius rhopalosiphi* (De Stefani-Perez), *Aphidius uzbekistanicus* (Luzhetzki) and *Diaeretiella rapae* (M'Intosh) are predominant in winter cereals (Engel et al. 2021). Basically, the main association between these parasitoids and aphids can be organized into two groups: *A. platensis* and *D. rapae* with Aphidini (*R. padi* and *S. graminum*) and *A. rhopalosiphi* and *A. uzbekistanicus* with Macrosiphini (*M. dirhodum* and *S. avenae*).

Aphid-parasitoid synchrony is regulated by meteorological factors. Air temperature and rainfall are the main factors that affect the population dynamics of aphids and parasitoids, which can change the rate of development, reproduction, survival and migration at different time scales, affecting the trophic compatibility between these organisms. (Moiroux et al. 2015; Wiest et al. 2021).

This study investigated an eight-year aphid-parasitoid time series to determine patterns of population fluctuation and annual effects of mean air temperature and rainfall on these groups.

MATERIAL AND METHODS

The study was conducted at the Experimental Station of Embrapa Trigo, in the municipality of Coxilha, RS, Brazil (28°11'42.8"S, 52°19'30.6"W, 710 m altitude). Weekly sampling of winged aphids and parasitoids was carried performed by Moericke traps, in an area of 0.5 ha, cultivated in a no-tillage system, during the years 2011 to 2018. In autumn and winter, the area was cultivated with black oat, *Avena strigosa*; white oat, *A. sativa*; wheat, *Triticum aestivum*; triticale, x*Triticosecale*; forage turnip, *Raphanus sativus*; and fallow; and in spring and summer with soybean, *Glycine max*; maize, *Zea mays*; and brachiaria, *Urochloa ruziziensis*.

The patterns of population fluctuation were evaluated by graphical analysis. For understand the correlation of meteorological variables (temperature and rainfall) with aphid tribes and parasitoid species, a principal component analysis (PCA), based on the annual mean abundance of winged aphids and parasitoid, average air temperature, and average cumulative weekly rainfall over the eight years was performed. All analyzes were performed using the software R v. 4.0.2 (https://cran.r-project.org/) at the level of $p < 0.05$.

RESULTS AND DISCUSSION

The patterns of population fluctuation of Aphidini aphids showed higher abundance in summer-fall transition and winter-spring transition (Figure 1a). More specifically, winged *S. graminum* had a peak in early fall and early spring, while winged *R. padi* had a high population until the beginning of winter, with a second population peak also in the beginning of spring. Both species of parasitoid that prefer the Aphidini tribe showed a similar fluctuation pattern with each other, with a main peak in winter. However, *A. platensis* showed a secondary peak, in winter-spring transition, with higher synchrony with winged aphid population (Figure 1a).

Macrosiphini aphids also showed two population peaks (Figure 1b). The first one occurred in the summer-fall transition, with greater abundance of *S. avenae*. The second peak occurred in early spring, with greater abundance of *M. dirhodum.* The parasitoids of Macrosiphini aphids were more synchronized with their hosts. Both *A. rhopalosiphi* and *A. uzbekistanicus* showed higher population peak during the winter-spring transition (Figure 1b).

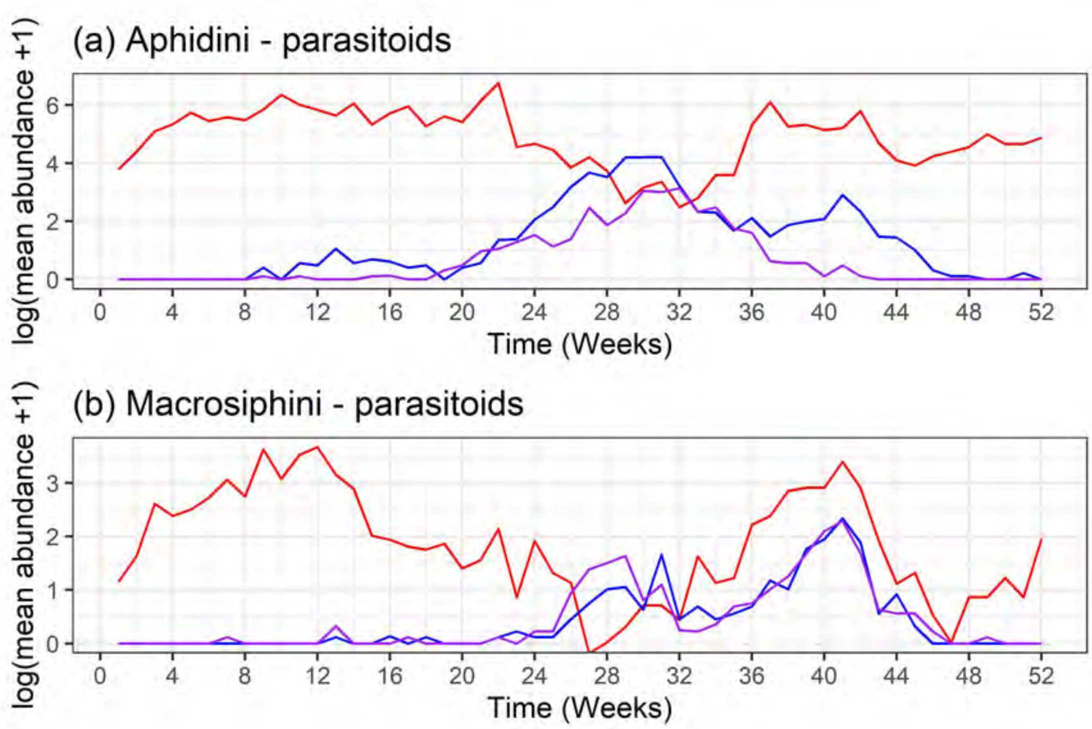

Figure 1. (a) Population fluctuation of Aphidini aphids [*Rhopalosiphum padi* + *Schizaphis graminum*] (red line) and parasitoids (Braconidae) *Aphidius platensis* (blue line) and *Diaeretiella rapae* (purple line); **(b)** Population fluctuation of Macrosiphini aphids [*Metopolophium dirhodum* + *Sitobion avenae*] (red line) and parasitoids (Braconidae) *Aphidius rhopalosiphi* (blue line) and *Aphidius uzbekistanicus* (purple line). Data are in insects per trap per week.

The PCA analysis for Aphidini aphids and their parasitoids had 83.74% of explained variance, with 48.48% in PC1 and 35.26% in PC2 (Figure 2a). Based on eigen-vectors *v*, in PC1, Aphids [*v* = 0.93] showed a negative correlation with rainfall [*v* = -0.81] and positive correlation with *D. rapae* [*v* = 0.90] and temperature [v = 0.26]. In PC2, *A. platensis* [*v* = -0.89] present a positive correlation with *D. rapae* [v = -0.17], and both present a negative correlation with temperature [*v* = -0.64] and rainfall [v = 0.33].

For Macrosiphini aphids and their parasitoids, the PCA explained 72.67% of the variance, with 51.50% in PC1 and 21.17% in PC2 (Figure 2b). PC1 showed a positive correlation between *A. rhopalosiphi* [*v* = 0.96] and *A. uzbekistanicus* [*v* = 0.91], and both show negative correlation with aphids [*v* = -0.39], rainfall [*v* = -0.31] and temperature [*v* = -0.74]. PC2 showed a negative correlation between aphids [*v* = 0.72] and temperature [*v* = -0.37].

In general, the results showed an increase in the annual aphid population with higher temperatures and less rainfall, mainly for the Aphidini tribe in relation to Macrosiphini. In this scenario, the parasitoids had a negative correlation with the increase in temperature, with potential negative effects on their biological services (Tougeron et al. 2020). Considering previous studies in southern Brazil and the results of this study, global

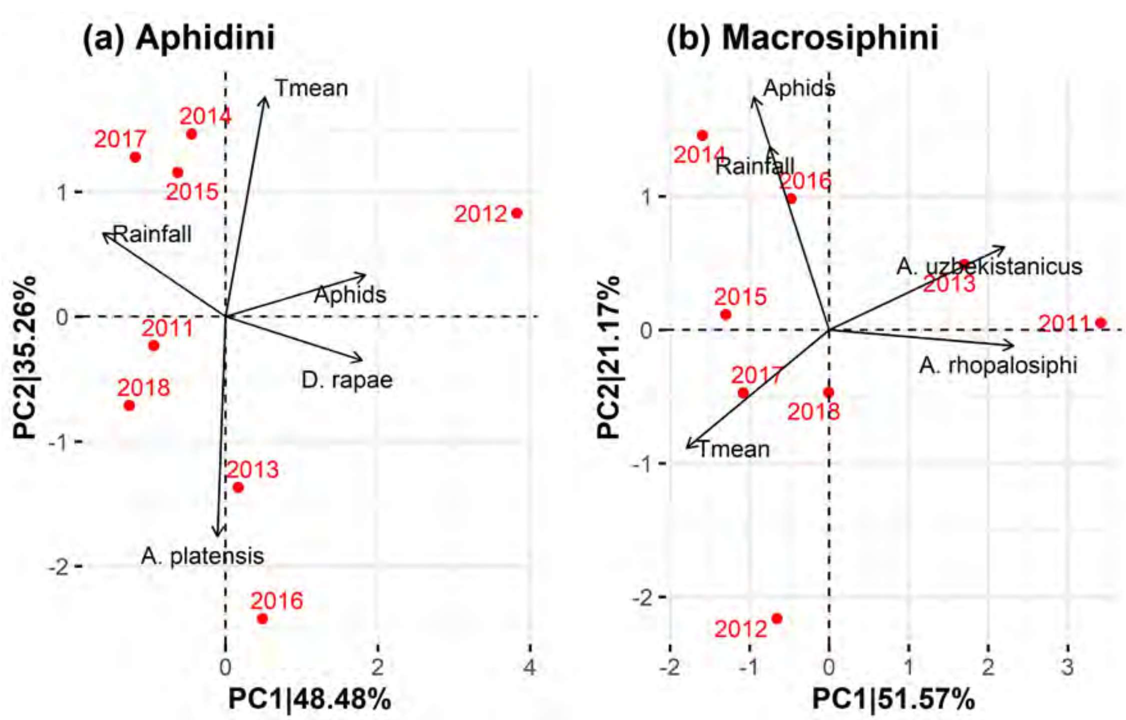

Figure 2. (a) Principal component analysis partitioning variance of average air temperature (Tmean), average cumulative weekly rainfall (Rainfall), Aphidini aphids (*Rhopalosiphum padi* +*Schizaphis graminum*) and parasitoid species: *Aphidius platensis* and *Diaeretiella rapae*; **(b)** Principal component analysis partitioning variance of average air temperature (Tmean), average cumulative weekly rainfall (Rainfall), Macrosiphini aphids (*Metopolophium dirhodum* + *Sitobion avenae*) and parasitoid species: *Aphidius rhopalosiphi* and *Aphidius uzbekistanicus*.

warming can cause aphids and parasitoids to move away throughout the year, with long-term (annual) consequences (Engel et al. 2021). Despite this, some studies have already demonstrated some ability of parasitoids to adapt to this scenario, with effects on their survival strategies (hibernation and use of new hosts) (Andrade et al. 2016; Tougeron et al. 2018). More long-term studies should be carried out to generate forecast models that aim to assess the impacts of global warming on the effectiveness of parasitoids in southern Brazil.

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