

The local environmental factors impact the infestation of bee colonies by mite *Varroa destructor*

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ABSTRACT

Colony collapse disorder has become a global problem for beekeepers, and agriculture, which depends on bee pollination. Among other factors, the impact of the parasitic mite *V. destructor*, which causes *varroosis*, increases the risk of bee colony collapse. Global climatic changes can affect honey bee colony fate on multiple levels, including the spread of its antagonist, the ectoparasite mite *V. destructor*. In this work, we presumed that local meteorological conditions and the choice of appropriate beekeeping management significantly influence the number of *Varroa* mites falling off of honey bees. Therefore, we examined using statistical analyses the relation between biotic (number of *V. destructor* in *A. mellifera* colonies, bee quine line) and abiotic factors (maximum, minimum and average daily temperature, maximum, minimum and average daily relative humidity, hive location). Ambient air temperature proved to be a significant factor in this issue. When the daily maximum temperature ranging from 25.1 to 31.7 °C and minimum daily temperature above 5.5 °C, there was an increase in the fall of *V. destructor*. The highest fall of *V. destructor* for the whole study period was recorded when the daily air temperature was increased between 13.9 and 28.7 °C and the humidity was decreased between 47.2 and 22.7 % in the hives located in the open space. This study shows that mite falls are also influenced by the hives' location and the beeline's hygienic characteristics. Therefore, beekeepers should consider these factors when planning management strategies.

1. Introduction

Bees and their products are important environmental indicators (Tonelli et al., 1990; Porrini et al., 2003; Guerzou et al., 2021), as bees ensure biodiversity through their role as pollinator (Bendifallah et al., 2018). However, colony losses due to the well-known phenomenon of colony collapse disorder (CCD), in which worker bees die suddenly, have been increasingly reported (Evans et al., 2009; Dainat et al., 2012). *V. destructor*, a parasitic mite and a primary pest of honey bees, has been detected in 98% of the colonies affected by CCD (Locke et al., 2012). Thus, the winter survival of honey bee colonies strongly depends on the of *V. destructor* infestation (Anderson and Trueman, 2000). Globally, the major factor in honey bee colonies loss is the ectoparasitic mite *V. destructor* (Hristov et al., 2020). Therefore, the fight against this mite should be a priority in current honey bee health research, and the inspection of mites is crucial for successful beekeeping (Dietemann et al.,

2012).

Varroa mites feed on the haemolymph but primarily on the adipose tissue of infected bees (Ramsey et al. 2019) and cause a disease called *varroosis*. Mites reproduce in brood cells of developing bees (Genersch et al., 2010; Rosenkranz et al., 2010). Current studies highlight the epidemiology of *V. destructor*, which is considered a complex problem influenced by multiple factors (e.g. Rosenkranz et al., 2010; Morawetz et al., 2019; Guichard et al., 2020). The elimination and reduction of the *V. destructor* are affected by beekeeping methods (e.g., chemical treatment, hive location, supplemental feeding; Underwood et al., 2019) and local meteorological conditions. Giacobino et al. (2017) recently provided evidence that environmental factors influence the autumn mite infestation rate stronger than beekeeping management practices.

Several studies (Le Conte and Navajas, 2008; Potts et al., 2010; Schweiger et al., 2010; Neov et al., 2019; Smoliński et al., 2021) suggest that global climate change may affect the fate of the honey bee colony at

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multiple levels, including pressure from its antagonist, the ectoparasitic mite *V. destructor*. The environmental factors such as air temperature and humidity have both positive and negative effects on various bee activities (Ma et al., 2019; Joshi and Joshi, 2010) and affect many aspects of the bee life cycle such as metabolism, developmental rate, and quality, foraging, and queen rearing and mating (Kim et al., 2011). These environmental factors also affect the reproduction of the ectoparasitic mite *V. destructor*. The latest studies (e.g. Smoliński et al., 2021) show that raised spring (March-May) and autumn (October) temperatures reinforce autumn *V. destructor* infestation in the bee colonies.

Thus, integrating temperature and relative air humidity is essential for bee activity and survival (Hou et al., 2016), while microclimatic specifics of the environment must also be considered. Canopy microclimate in comparison with conditions at the standard climatological stations is characterized by reducing of temperature extremes, precipitation interception, reduced airspeed, diffuse solar radiation, and different air compositions (Středa et al., 2011).

This research paper focuses on filling gaps in the available knowledge about the relationships between the mite fall from honey bees and air temperature and relative humidity in the inland temperate climate zone.

We are also investigating the ability of two popular bee lines in Slovakia, Singer and Sklenár, to remove *Varroa* mites from bees' body. Because environmental factors influence *Varroa* mite nature fall, relevant bee diseases must be observed under different local environmental factors and beehive management (Le Conte et al., 2020).

Consequently, as a result of the above facts mentioned earlier affecting the bee colonies, the goal of this study was to answer the following research questions:

1. Does the temperature and relative humidity outside the bee hive affect the removal of *V. destructor* mites from bee bodies?
2. Does the environment (hive location – open space and Apihouse) affect the amount of *V. destructor* mites in the hive?
3. Do the characteristics of different bee lines (Singer and Sklenár) affect the removal of *V. destructor* mites from bee bodies?

2. Experimental details

2.1. Description of the experimental area

2.1.1. Location

The experimental area and bee colonies were located in Slovakia, Central Europe, in a rural area in the locality of Horná Liešna. The area is situated at 48°30'32.9"N 19°25'59.0"E (48.509029, 19.433027) at an elevation of 535 m a.s.l. in the cadastral area of Detva town (Fig. 1).

The northern part is covered by the geomorphological unit of Poľana and Devianske predhorie. The southern parts belong to Ostrôžky and Javorie. A major part of the Detva region is deforested. Continuous broadleaved, coniferous and mixed forests can be found on the north-west and the south-west. Forest covers approximately a quarter of the area, and two-thirds of the area is covered by permanent grassland and arable land. The most common soils are polymerised and gleyed soils (Sály, 2000).

2.1.2. Meteorological conditions

1. The collected 30-year-long mean (1981–2010) for the study area is given in the climate diagram (Fig. 2). The hottest months in the area are July and August. On average, the most precipitation fell in June. The annual temperature is around 7.9 °C, the yearly mean precipitation total is approximately 745 mm, and the mean annual air humidity is 75.2% (Climate Atlas of the Slovak Republic, 2015).

Fig. 3 presents the temporal trend of the daily average, minimum and

maximum air temperature in the observed period. The trend of the daily average, minimum, and maximum relative humidity in the observed period from 15 May 2020 to 30 March 2021 is presented in Fig. 4. The climate of the studied area is mild. The annual mean temperature in the monitored period was 8.7 °C, which is 0.8 °C more than the long-term mean temperature from 1981 to 2010. The collected mean relative air humidity during the monitored period was 85.2%. The highest mean daily air temperature was 30 August 2020 (23 °C) and of the observed period, 13% were days with 100% mean relative humidity (the most since 19 – 23 November 2020).

2.2. Establishment and location of the experimental colony

The subject of our study was to analyse various factors that influence *Varroa* mite falls in bee colonies. Therefore, the experiment was carried out on four different colonies located at two sites about 40 m apart. Every bee colony was assigned a number from 1 to 4 (Figs. 5 and 6). On 10 May 2020, cages with Singer queens¹ were placed in two hives (No. 1 and 4). On 15. May 2020, we placed queen bees of the Sklenár² line (Fig. 5) in the other two hives (No. 2 and 3). All mated queens were placed in hives using the traditional cage method (Harbo and Hoo-pingarnier, 1997; Čermák et al., 2017). The delivery of the Singer queens was delayed. Bee colonies were placed in insulated hives of B10 type (10 frames per one hive). The worker bees were released from the cages, while the mated queens remained in the cages. The hives remained closed for 24 h. The mated queens were released the following day.

As observed in Figs. 5 and 6, beehives were placed under two different weather conditions, hives no. 1 and 2 at an open space (Fig. 6, marked yellow), while hives no. 3 and 4 were placed in an Apihouse (Fig. 6, marked red). This allowed the assessment of the impact of beehive placement on the *Varroa* mite fall. The research was carried out by experienced and certified beekeepers who have been beekeeping for many years. The environment in which the hives are located is free of external disturbances, clean, secluded, and dominated by mixed deciduous (linden, birch, aspen, oak, and acacia) and fruit trees (apple, pear, plum, cherry, and mulberry).

2.3. Data acquisition chain

2.3.1. Collection of meteorological data

Similar to Středová et al. (2021), the system for monitoring temperature and humidity consisted of three subsystems: i) data collection, ii) data transfer, and iii) data processing. An automatic meteorological station with an EMS33 sensor (EMS Brno, Czech Republic) to measure air temperature and relative humidity were established in an open field close to the research stand (approximately 10 m from bee colonies). Meteorological variables were measured every 5 min and stored in 20-min intervals, following Nalevankova et al. (2018). This approach is applied due to attempt to get a more precious average temperature value because of the potential impact of micrometeorological variability when measuring only single value in 20-minute intervals.

¹ Singer: the queens in the first year are very good brooders. They belong to a tranquil line of bees. Swarming in the first year is almost nil. There is a marked loss of the above characteristics in the second year, except for mildness, which remains either as the queen grows older or in subsequent generations. It is a line more suitable for nectar layers, but it can also use honeydew, but not as well as other lines (Chlebo, 2017).

² Sklenár: mild non-corrosive line but weak cleansing/hygienic instinct. F2 daughters retain a high percentage of maternal traits but a relatively high proportion (though significantly less than in previous lines) of "dilution" of features in F3. With increasing maternal age, the number of eggs laid decreases quite markedly (as early as the second year). The line is probably equally suitable for nectar and honey laying (Chlebo, 2017).

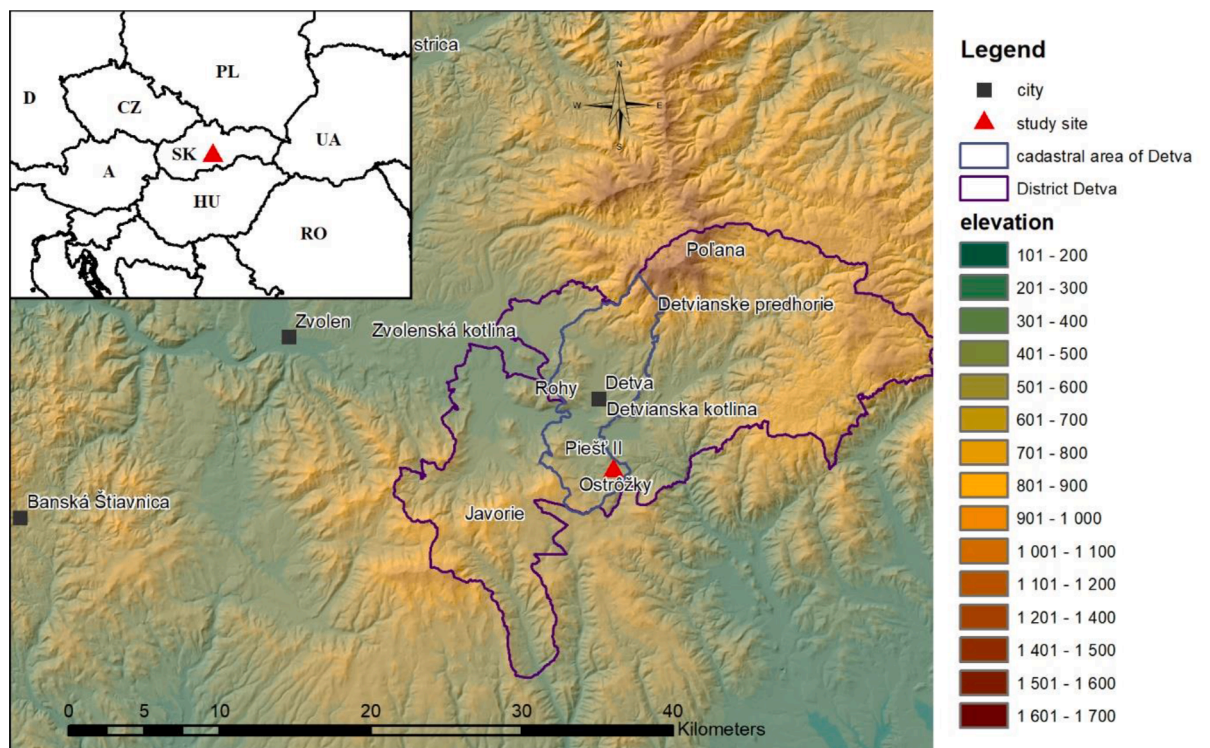


Fig. 1. The location of Horná Liešňa in Central Slovakia Product source Aerial laser scanning: Geodesy Cartography and Cadastre Authority of the Slovak Republic (2022).

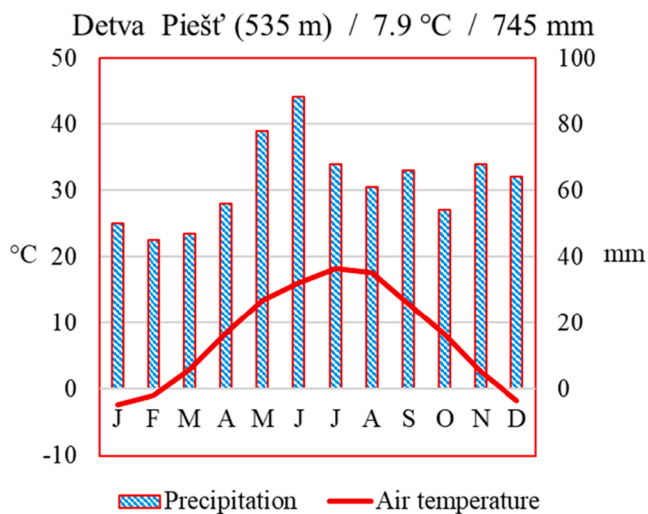


Fig. 2. Climate diagram for Detva Piešť, 48°30'32.9"N 19°25'59.0"E (48.509029, 19.433027) at an elevation of 535 m a.s.l. (1981–2010) Source: Climate Atlas of the Slovak Republic (2015).

2.3.2. Data collection on Varroa destructor fall

We used simple field and laboratory diagnostic procedures to assess the overall Varroa mite infestation within entire colonies of bees, as described by Gregorc and Jelenc (1996). The “manual” collection of V. destructor mite was used to estimate the colony infestation as it was performed in other studies in the field (Devlin, 1998; Dietemann et al., 2013; Poonia et al., 2014). This method is based on counting mites that fall from combs and bees onto the Varroa monitoring board (Fig. 7), which acts as a removable drawer. The Varroa monitoring board was painted with edible oil to prevent live mites from escaping. The mites were separated from other debris; then they were counted. Colonies with

approximately equal gross weights of the hive, brood frames, honey frames, and pollen frames were selected for the experiment. The weight of the experimental hives was measured on 14.5.2022, one day before the start of the research. The net weight of a single B10 hive is approximately 7 kg ± 100 g (base, tank, and lid). The weight of honey and pollen frames in individual hives was about 4 kg ± 200 g and the brood frames were 8 kg ± 100 g and an empty frame with an intermediate wall was 200 g ± 5 g. The gross weight of the hive was 23 kg ± 500 g. The weight of the bees in the hive was 4 kg ± 10 g.

Three standard methods for estimating the Varroa population in a hive exist: i) killing the mites with an acaricide, ii) estimating the infestation level in adult bees and brood cells, and iii) sampling the natural mortality of the mite.

Branco et al. (2006) point out that sampling the natural mortality is a reliable method for estimating absolute population size if some conditions are satisfied (colonies must be brood right and not collapse). V. destructor natural mortality can be estimated using floorboard traps. This method helps to calculate the approximate mite population size. As many of the studies showed good linear relationship between natural mite mortality and the population size (Devlin, 1998; Dietemann et al., 2013; Poonia et al., 2014). Thus, in this study, we also presumption a linear relationship between mite falls and colony size.

The counting of V. destructor falls on the Varroa monitoring board was conducted in several steps:

1. Colony control before application of a natural veterinary product. Bee colonies were checked daily, and natural mite mortality rates were sampled.
2. The natural veterinary product application. As soon as the colony reached the natural fall of more than three Varroa, we applied the natural veterinary medicinal product. We then intensified our observation of the bee colonies and the bottom board. The natural veterinary medicinal product was applied, in months when no honey was collected (from month to month). This product was provided in wooden veneer stripes impregnated with ecologically pure oils from

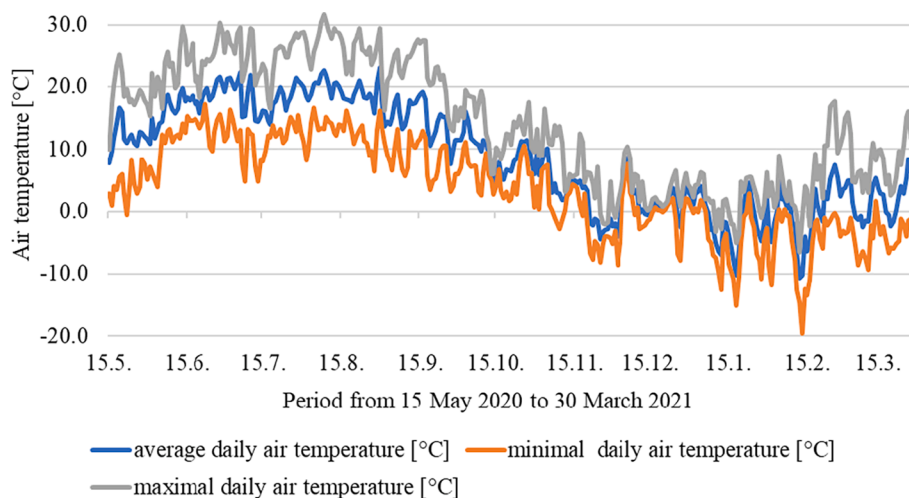


Fig. 3. The trend of the daily average, minimum and maximum air temperature in the observed period (Horná Liešňa).

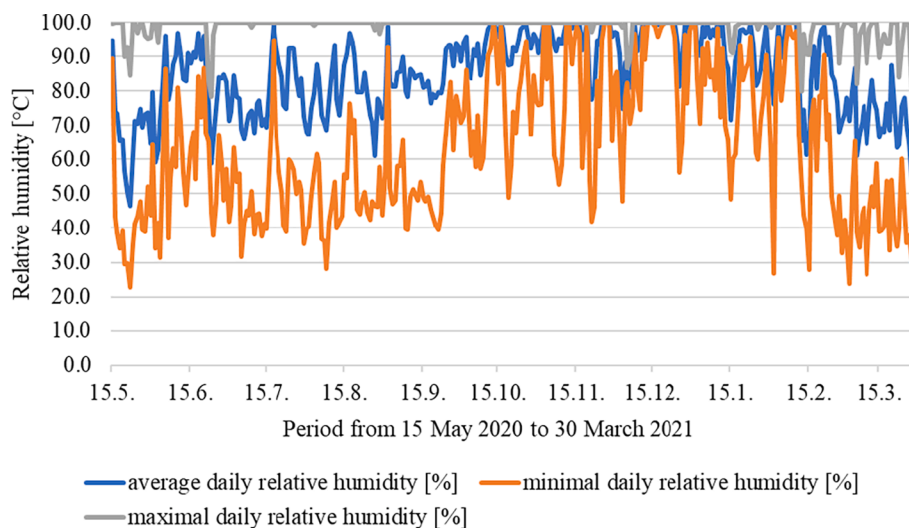


Fig. 4. The trend of the daily average, minimum and maximum relative humidity in the observed period (Horná Liešňa).

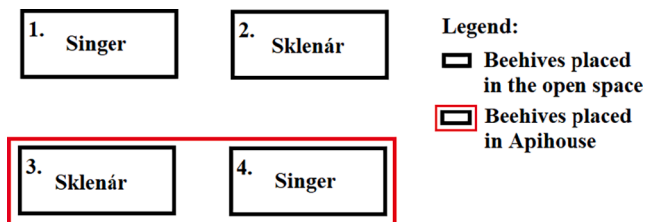


Fig. 5. A scheme of bee colony locations.

wormwood, thyme, and mint, which have an unpleasant scent for mites and parasites. The natural veterinary product was placed in a bee colony after the first spring inspection and in the summer and autumn months, but only in the months when honey was not extracted. Two stripes per 10 to 12 deep frames are applied. One stripe is placed between the 3rd and 4th frames, and the second one between the 7th and 8th frames.

3. Colony control after the application of a natural veterinary product. After applying of the medicinal product, the control of bee colonies was performed daily for *Varroa* mite fall count. Stripes were left in a hive for approximately 14 days. Afterwards, they were removed.

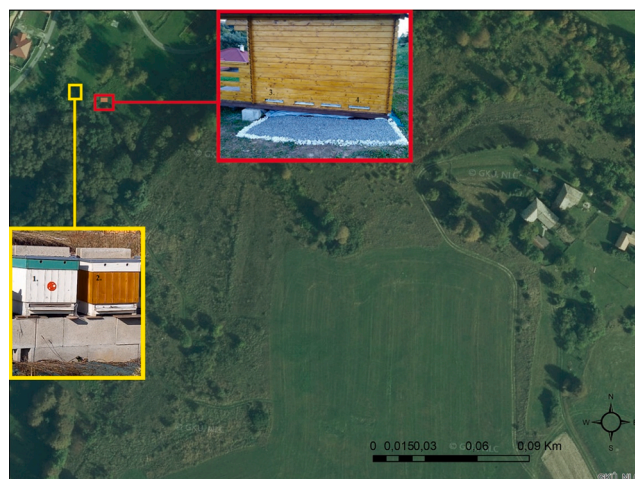


Fig. 6. Location of bee colonies at orthophoto map in the Apihouse (marked red) and the open space (marked yellow) Source: Geodetic and Cartographic Institute Bratislava, 2022, National Forest Centre (2022) and Photo archive of authors.



Fig. 7. The *Varroa* monitoring board with *Varroa* mites Source: Photo archive of authors.

4. The end of the data collection on *V. destructor* fall. The observation was stopped when no fall of *V. destructor* appeared.

To avoid unnecessary bee kills by colony infestation detection methods (see Dietemann et al., 2012), the total number of mites collected was considered to equal the mite population in the colony before treatment.

2.4. Statistical methods

The relationships between the counts of fallen mites and biological information related to the colonies studied and local meteorological conditions were investigated using regression/correlation analysis,

Table 1 Hypotheses and testing hypotheses.

Hypothesis number	Assumption	Significance of the hypothesis	Test hypothesis	Results and hypothesis testing
The first hypothesis	The temperature and relative humidity outside of the hive affect the removal of <i>V. destructor</i> mites from bee bodies.	Thus, the effect of the air temperature and relative humidity will be significant.	Shapiro-Wilk tests, Regression/Correlation analysis	Chapter 3.2
The second hypothesis	The environment (hive location – open space and Apihouse) affects the amount of <i>V. destructor</i> mites in the hive.	Thus, the effect of the hive location will be significant.	Shapiro-Wilk tests, Mann - Whitney U test	Chapter 3.3
The third hypothesis	The characteristics of different beelines (Singer and Sklenar) affect the amount of <i>V. destructor</i> mites removed from the bees.	Thus, the effect of the characteristics of beelines will be significant.	Shapiro-Wilk tests, Mann - Whitney U test	Chapter 3.4

Shapiro-Wilk tests, Mann - Whitney U test (Table 1). We treated the number of fallen mites as a dependent variable and as a independent variables mean, minimal and maximal air temperature, mean, minimal and maximal relative humidity, line of bee, and beehive location. For statistical analyses, we constructed a database consisting of the following variables: i) day of the year, ii) number of *Varroa* mite fallen, iii) day of treatment, iiiii) maximal and minimal daily temperature and iiiiii) maximal and minimal daily relative humidity. If the colony under consideration was treated against *varroosis* during the month, we inserted on a given treatment day the number '1' in the corresponding cell in the table. If no treatment was carried out, a '0' was inserted in the cell. A significance level of $\alpha = 0.05$ was used. We assumed a linear relationship between response and environmental variables. The statistical analysis was calculated using StatSoft Statistica pro version 12. Graphs were developed using Microsoft Excel (2020). The mean values of temperature and relative humidity were calculated from the minimum and maximum values measured during the day.

3. Results and discussion

3.1. Mites fallen in individual hives

The overall *V. destructor* fall in each month is shown in Table 2. The bigger *V. destructor* fall was observed in bee hives located in the open space. The *V. destructor* fall was considerably higher in case of the insertion of the queen Sklenár in both locations (Bee hive no. 2 – location open space, Bee hive no. 3 – location Apihouse).

3.2. Effect of environmental factors

Environmental factors, such as temperature and humidity, affect various bee activities (Heidinger et al., 2014). Temperature and humidity in the hive and in the outside environment affect the survival and reproduction of bees (Hou et al., 2016), which after all confirms general ecological relationships previously described also for other insect species (Středa et al., 2013). All activities of bee colonies are controlled by

Table 2 Total number of fallen mites in individual bee colonies during monitored periods.

Bee colony No. / Queen beeline	Location of a bee colony	Monitored period	Total fall in the observed period (pcs)	Total <i>Varroa mite</i> fallen (pcs)
1/ Singer	Open space	15 May – 5 June 2020	158	524
		3 – 31 August 2020	323	
		11 – 30 September 2020	43	
2/Sklenár	Open space	15 May – 2 June 2020	140	700
		3 – 31 August 2020	496	
		6 – 24 September 2020	64	
3/Sklenár	Apihouse	18 May – 24 June 2020	143	381
		30 July – 25 August 2020	160	
		10 September – 9 October 2020	78	
4/Singer	Apihouse	15 May – 15 June 2020	41	209
		29 July – 20 August 2020	132	
		11 September – 7 October 2020	36	

these factors (Abou-Shaara et al., 2012; Aldea et al., 2013). It is likely that environmental factors act indirectly via the host on the parasite, for instance, by modulation of honey bee brood amount, the relationship of the drone to worker brood, or the hygiene capabilities of the bees (Rosenkranz et al., 2010).

The relation between biotic (number of *V. destructor* in *A. mellifera* colonies, bee quine line) and abiotic factors (maximum, minimum and average daily temperature, maximum, minimum and average daily relative humidity, hive location) was calculated using the correlation matrix. The results of the correlation coefficient between the amount of *V. destructor* falls and the abiotic factors mentioned above are shown in Supplementary Table S1.

3.2.1. Effect of abiotic factors

V. destructor falls recorded during the season were positively correlated with air temperature in all experimental colonies (see Supplementary Table S1). The study revealed that in the hives located in the open space, the maximum daily air temperature played a significant role in *V. destructor* falls, especially in May, June, and September.

The positive values of the correlation coefficient revealed that with an increase in maximum daily temperature ranging from 25.1 °C to 31.7 °C and minimum daily temperature above 5.5 °C, there was an increase in the fall of *V. destructor*. Maximum mite falls were observed in August in all experimental colonies when the daily air temperature ranged from 10.5 °C to 31.7 °C. The highest fall of *V. destructor* for the whole study period was recorded when the air temperature was increased between 13.9 and 28.7 °C and the humidity was decreasing between 47.2 and 22.7 % in the hives located in the open space. In Apihouse, relative humidity proved to be an insignificant factor for mite falls.

Similar results were obtained by Poonia et al. (2014) on a sample of one hive. They observed that humidity is a non-significant factor. The maximum number of mites was observed in the second fortnight of May, which was significantly positively correlated with maximum and minimum temperature. However, *V. destructor* population was found to be negatively correlated with relative humidity. Their results showed an increase in maximum temperature ranging from 18.6 to 39.6 °C and minimum temperature ranging from 3.3 to 26.3 °C was a corresponding increase in the population of *V. destructor*.

Previous studies also have examined *Varroa* mite infestations in relation to climate change. These studies reported that *Varroa* mite infestation levels were lower in tropical areas compared to temperate areas. Populations of *Varroa* mite increase very rapidly in some regions such as Europe but remain at a low level in some tropical countries (De Jong et al., 1984; Ruttner et al., 1984; Webster et al., 2000). Harris et al. (2003) surveyed variability population growth of *V. destructor* in honey bees colonies. They found that the measured values of ambient temperature and relative humidity correlated to growth of mite populations over different years. Reduced growth rates were probably the result of diminished reproductive rates by *Varroa* mites during periods of hot and dry weather. Bahreini et al. (2004) researched of the efficacy of formic acid in controlling *V. destructor* and its correlation with temperature in Iran. They found that there was a significant correlation between formic acid mite mortality and temperature, but no such relationship between mite mortality and relative humidity. Kozak and Currie (2011) studied the effects of temperature and three ventilation rates on infestations of *V. destructor* in clusters of honey bees. This study demonstrates that at 25 °C, restricted ventilation, resulting in high levels of CO₂ in the surrounding environment of small clusters of honey bees, has the potential to substantially increase *Varroa* mite mortality.

We observed differences in mite falls from bees on the *Varroa* monitoring board in beehives placed in the open space compared to those in the Apihouse. Interestingly, mite falls in the Apihouse were 46.57% lower than that in the beehives placed in the open space (see Table 2) The Shapiro-Wilk tests showed (test hives) a significant departure from normality (see Supplementary Table S2). To test the third

hypothesis, we used Mann - Whitney *U* test (Table 3). A value for Z-Score (in bold) indicates a significant result.

The Mann - Whitney *U* test results showed a significant difference in *Varroa* mite fall between hives located in the open space and the Apihouse. Thus, we assume that the *Varroa* mite infestation was also lower. The temperature in the hive in Apihouse is probably different from the open space. This may be crucial for the mite fall since bee colonies placed in the Apihouse (placement of honey bee colonies in two protective timber hives) can reach different (higher) temperatures in the beehive already in spring. Hence, they use less energy to heat the brood. This idea could be examined by future research. Villagomez et al. (2021) found that increased mean temperatures in winter and early spring intensified the brood rearing activity of *A. mellifera*.

3.2.2. Effect of biotic factors

We observed different numbers of *Varroa* mite falls in bee colonies on the *Varroa* monitoring board, where queen bees of the Singer and Sklenár lines were introduced. Interestingly, the mite fall in the beehives with queen line Sklenár was 26.27% higher than in the beehives with the queen Singer (see Table 2). The difference between hives No. 1 and 2, 3 and 4 was insignificant (see Table 3), No. 1 and 3, 2 and 4 is significant. We partially confirm the third hypothesis. The effect of the characteristics of the Singer and Sklenár bee lines is significant for the fall of *Varroa* mite in bee colonies.

Keepers of queen bees of the Sklenár line describe as having a reduced cleansing and hygiene instinct. Hygienic behaviour is the ability of worker bees to detect and remove parasitised broods. The hygienic behaviour of bees towards broods parasitised by *Varroa* mites is very important for colony survival (Boecking and Genersch, 2008; Grindrod and Martin, 2021).

Currie and Tahmasbi (2008) researched the ability of high- and low-grooming lines of honey bees to remove the parasitic mite *V. destructor* affected by environmental conditions. They investigated mite mortality rates at different temperatures (10, 25 and 34 °C) and humidity (low, medium and high) under laboratory conditions. Differences in treatment between lines were greatest at 25 °C and were slightly higher in low humidity conditions than at higher levels. Mite mortality was higher in the high care cage groups than in the low care groups at 25 and 34 °C but was similar at 10 °C. Grindrod and Martin (2021) found that bees responded to an artificial increase in the mite infestation level by increasing their recapping behaviour. Spivak and Reuter (2001) observed that honey bees bred for hygienic behaviour performed as well, if not better, than other commercial lines of bees and maintained lower mite loads for up to one year without treatment.

The relationship between biotic (number of *V. destructor* in *A. mellifera* colonies, bee quine line) and abiotic factors (maximum, minimum and average daily temperature, maximum, minimum and average daily relative humidity, hive location) were the main focus of this study. As factors considered in the study are limited, the further research is needed/possible. The investigation of other factors as

Table 3
Mann - Whitney *U* test for *Varroa* mite falls.

Beehives (Combined Result)	U-value	Z-Score	p-value	significant/not significant
No. 1: No. 2	2282.5	-0.40684	0.3409	not significant at p < 0.05
No. 1: No. 3	2414	-3.12685	0.00087	significant at p < 0.05
No. 1: No. 4	1933.5	-3.37771	0.00036	significant at p < 0.05
No. 2: No. 3	2211.5	-3.3006	0.00048	significant at p < 0.05
No. 2: No. 4	1768.5	-3.5432	0.0002	significant at p < 0.05
No. 3: No. 4	3704.5	0.28455	0.38974	not significant at p < 0.05

precipitation and wind may influence the population dynamics of *V. destructor* and the fate of honey bee colonies in a very similar way. Precipitation and wind affect humidity, and low or high humidity levels during the season may hinder mite reproduction (Ogden and Lindsay, 2016).

4. Conclusion

Previous research mentioned above has shown that it is important to examine the impact of the environment on bee resilience, their ability to eliminate mites from their bodies, and the influence of meteorological factors on the reproduction and survival of mites outside the host. The more information we gather about this issue, the easier it will be to find the ideal prevention and treatment of varroosis.

The study results widen the understanding of the population dynamics of *V. destructor*. We examine how environmental factors (biotic and abiotic) affect the amount of fallen *Varroa* mite on the *Varroa* monitoring board. The research results showed that the temperature dependence of *Varroa* mite fall is significant, with relative humidity being a significant abiotic factor only at a certain temperature and only for hives located in the open space.

We found significant differences in the infestation of individual bee colonies between beehives in the open space and in the Apihouse. The number of fallen *Varroa* mites was substantially lower in the Apihouse than in the beehives placed in the open space. The *Varroa* mite fall in the beehives with queen line Sklenár was almost one-third higher than that in the beehives with queen Singer. All monitored bee colonies were treated with the natural veterinary product in different months (May, August, September, and October). In these months, bee colonies differed in the number of fallen *Varroa* mites on *Varroa* boards. The highest number of fallen mites was recorded in August. All bee colonies survived the winter period of 2020–2021.

We believe that our research on the effect of biotic and abiotic factors on *V. destructor* in honey bee colonies will help beekeepers in planning colony management strategies. We conclude that environmentally friendly beekeeping with the application of natural products is effective in varroosis prevention, based on the research conducted and our more than 10 years of experience in beekeeping.

CRedit authorship contribution statement

Michaela Korená Hillayová: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft. **Ľubomír Korený:** Methodology, Investigation, Funding acquisition, Writing – review & editing. **Jaroslav Škvarenina:** Writing – review & editing, Funding acquisition, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolind.2022.109104>.

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