

Beekeeper practices associated with Varroa mite (*Varroa destructor*) infestation and colony losses in Eastern Slovakia

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Abstract

Varroa destructor – external parasitic mite is among the most serious biotic threats affecting honey bee colonies worldwide. This study evaluated associations between beekeeper practices, reported infestation, colony losses and perceived effects on honey production in Eastern Slovakia. Data were obtained from a questionnaire survey of 154 beekeepers and analysed using descriptive statistics and the chi-square test of independence. Regular monitoring was significantly associated with lower reported infestation levels ($\chi^2 = 26.24$, $df = 9$, $P = 0.0019$, Cramér's $V = 0.24$). Regular treatment frequency was significantly associated with lower colony losses ($\chi^2 = 27.58$, $df = 9$, $P = 0.0011$, Cramér's $V = 0.24$). A significant relationship was also found between infestation level and perceived reduction in honey production ($\chi^2 = 33.05$, $df = 9$, $P = 0.0001$, Cramér's $V = 0.27$), and between beekeeper sex and monitoring frequency ($\chi^2 = 11.03$, $df = 3$, $P = 0.0116$, Cramér's $V = 0.27$). No significant associations were detected for beekeeper type and knowledge level, locality and infestation level, or perceived resistance and treatment type. The findings emphasise the practical importance of regular monitoring and treatment practices, together with beekeeper education, for effective varroosis management.

Keywords: *Apis mellifera*; apiculture; colony loss; honey production; monitoring; varroosis

Introduction

The western honey bee, *Apis mellifera* Linnaeus, 1758 (Hymenoptera: Apidae), is a key pollinator in both, natural and agricultural ecosystems. However, honey bee colonies are currently affected by multiple stressors, including habitat degradation, pesticide exposure, climate-related factors and pathogens. Among these, the ectoparasitic mite *Varroa destructor* Anderson et Trueman, 2000 (Mesostigmata: Varroidae) is regarded as one of the most harmful agents affecting colony survival and productivity (Genersch 2010; Rosenkranz et al. 2010; Toporčák 2012).

In addition to direct parasitism, *V. destructor* acts as an important vector of viral pathogens, particularly deformed wing virus and acute bee paralysis virus, thereby substantially worsening colony health (Martin et al. 2012; Ryabov et al. 2014). Because mite population growth may remain unnoticed until colony condition is already compromised, regular monitoring is considered essential for effective varroosis management (Dietemann et al. 2013; Nazzi & Le Conte 2016). Standard monitoring approaches include natural mite fall counts, alcohol wash, powdered sugar roll, CO₂ testing and other validated methods that differ in their sensitivity and practical application (Dietemann et al. 2013).

Control of varroosis generally relies on combinations of monitoring, chemical or organic treatments, and zootechnical or biotechnical practices, including drone brood removal, brood interruption and other integrated management measures. The success of these measures depends not only on the biology of the parasite, but also on beekeeper knowledge, experience and management consistency (Calderone 2005; Rosenkranz et al. 2010;

Toporčák 2012; Nazzi & Le Conte 2016; Ritter 2018; Rangel & Ward 2018; Toporčák & Chlebo 2018; Urban 2018; Bava et al. 2022; Porporato et al. 2022; Toporčák & Fiľo 2023; Cook et al. 2024; Horr & Krupan 2025a, b). The present study therefore aimed to evaluate whether selected beekeeper-reported management practices, particularly monitoring and treatment frequency, are associated with reported *V. destructor* infestation, colony losses and perceived effects on honey production in Eastern Slovakia.

Materials and methods

Study design

The study was based on a questionnaire survey conducted among 154 beekeepers in Eastern Slovakia. The questionnaire collected self-reported information on beekeeping experience, number of managed colonies, apiary locality, frequency of *V. destructor* monitoring, the monitoring method most commonly used (sticky boards, alcohol wash, powdered sugar test or other methods), perceived infestation level, colony losses, treatment method, treatment frequency, perceived treatment resistance, self-assessed knowledge of varroosis and the perceived impact of infestation on honey production. Monitoring frequency was classified into four categories (regularly, occasionally, rarely and no monitoring). Respondents also indicated the monitoring method they most used. The level of *V. destructor* infestation was recorded as the respondent's own assessment using the categories low, medium, high and unknown; no standardized quantitative thresholds were defined in the questionnaire.

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Treatment practices were recorded according to the respondents declared management strategy (chemical treatment, organic acids, biotechnical methods, combined treatment or no treatment) together with the reported frequency of treatment. The questionnaire did not record the seasonal timing of treatment applications or the specific biotechnical procedures used.

Variables analysed

The following relationships were tested:

1. reported monitoring frequency $\times$ reported infestation level
2. reported treatment frequency $\times$ reported colony loss
3. reported beekeeper type $\times$ reported knowledge level
4. reported locality $\times$ reported infestation level
5. reported infestation level $\times$ reported perceived impact on honey production
6. reported perceived resistance $\times$ reported treatment type
7. reported beekeeper sex $\times$ reported monitoring frequency

It should be noted that, since the study was based on questionnaires, no independent verification was conducted of the reported levels of infestation or the procedures used to manage them.

Statistical analysis

Data were processed using descriptive statistics, graphical presentation and the chi-square test of independence. Associations were considered significant at $\alpha = 0.05$. Effect size was expressed as Cramér's V .

Statistical analyses were performed using GraphPad Prism version 5.01 (GraphPad Software Inc., San Diego, CA, USA).

Results

Beekeeping profile of respondents

A total of 154 respondents participated in the questionnaire survey. Their responses were analysed using descriptive statistics and the chi-square test of independence to evaluate relationships among beekeeper practices, infestation level, colony losses and perceived production effects.

Most respondents had long-term beekeeping experience. As shown in Figure 1, 40% of respondents had more than 10 years of beekeeping experience, 30% had 6–10 years, 22% had 2–5 years, and 8% had less than 2 years of practice.

With respect to the number of managed colonies, 40% of respondents kept 11–30 colonies, 35% kept 1–10 colonies, 15% managed 31–50 colonies, and 10% kept more than 50 colonies (Figure 2). The surveyed sample therefore predominantly represented small-scale beekeeping operations.

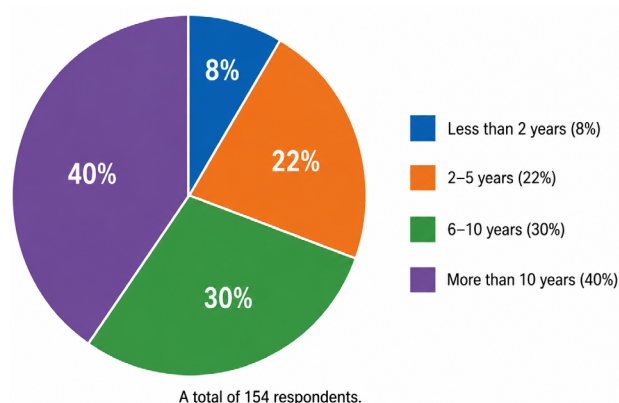


Figure 1. Length of beekeeping experience among respondents.

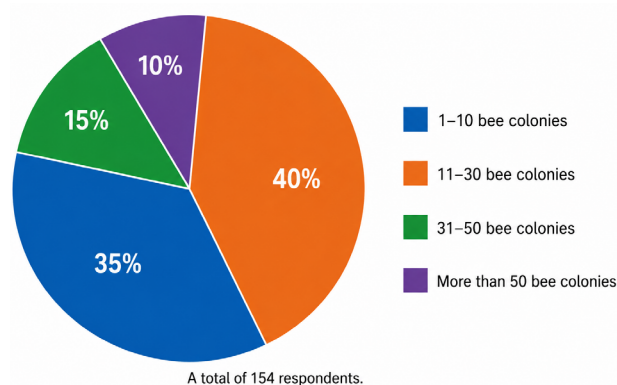


Figure 2. Number of honeybee colonies managed by respondents.

Monitoring and infestation level

The frequency of *V. destructor* among respondents is shown in Figure 3. Regular monitoring was reported by 40% of respondents, occasional monitoring by 35%, rare monitoring by 15%, while 10% stated that they did not monitor mite occurrence at all.

The relationship between reported monitoring frequency and the reported infestation level is presented in Table 1. Respondents who monitored their colonies regularly more frequently reported low infestation levels, whereas respondents monitoring rarely or not at all more frequently reported medium or high infestation levels. The chi-square test revealed a statistically significant association between monitoring frequency and infestation level ($\chi^2 = 26.24$, $df = 9$, $P = 0.0019$, Cramér's $V = 0.24$).

Table 1. Relationship between monitoring frequency and infestation level.

Monitoring frequency	Low	Medium	High	Unknown	Total
Regularly	13	34	9	6	62
Occasionally	5	34	13	2	54
Rarely	1	8	9	5	23
Do not monitor	1	4	5	5	15
Total	20	80	36	18	154

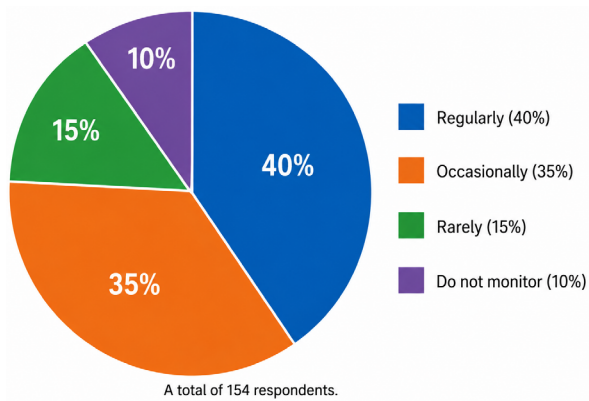


Figure 3. Frequency of *Varroa destructor* monitoring among respondents.

Treatment and colony losses

Annual colony losses associated with *V. destructor* infestation are summarised in Figure 4. The largest proportion of respondents (45%) reported colony losses of 11–25%, whereas 26% reported losses of 0–10%. Higher losses of 26–50% were reported by 19% of respondents, while losses exceeding 50% were reported by 10%.

The relationship between treatment frequency and colony loss is presented in Table 2. Respondents reporting regular treatment more frequently reported lower colony losses, whereas respondents treating only as needed, rarely or not at all more frequently reported higher colony losses. The chi-square test revealed a statistically significant association between treatment frequency and colony loss ($\chi^2 = 27.58$, $df = 9$, $P = 0.0011$, Cramér's $V = 0.24$).

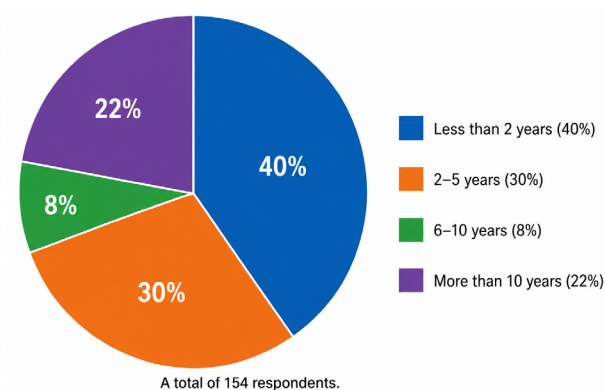


Figure 4. Annual colony losses attributed to *Varroa destructor* infestation.

Table 2. Relationship between treatment frequency and colony loss.

Treatment frequency	0–10%	11–25%	26–50%	>50%	Total
Regularly	29	35	9	4	77
As needed	9	23	8	6	46
Rarely	2	6	6	1	15
No treatment	0	5	7	4	16
Total	40	69	30	15	154

Beekeeper type and knowledge

The structure of respondents according to reported beekeeper type is shown in Figure 5. Hobby beekeepers represented the largest group (55%), followed by semi-professional beekeepers (30%) and professional beekeepers (15%).

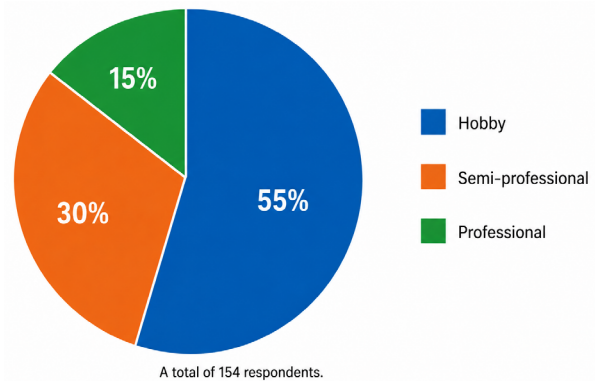


Figure 5. Type of beekeeping activity among respondents.

Self-reported knowledge of varroosis is summarised in Figure 6. More than half of respondents (51%) considered their knowledge sufficient, whereas 26% reported insufficient knowledge. High knowledge was reported by 16% of respondents, while 7% stated that they had no knowledge of the issue.

The relationship between reported beekeeper type and reported knowledge level is presented in Table 3. Although professional beekeepers more frequently reported high or sufficient knowledge than hobby beekeepers, the association was not statistically significant ($\chi^2 = 8.30$, $df = 6$, $P = 0.217$, Cramér's $V = 0.16$).

Table 3. Relationship between beekeeper type and knowledge level.

Beekeeper type	High	Sufficient	Insufficient	None	Total
Hobby	9	42	28	6	85
Semi-professional	9	24	10	3	46
Professional	6	13	2	2	23
Total	24	79	40	11	154

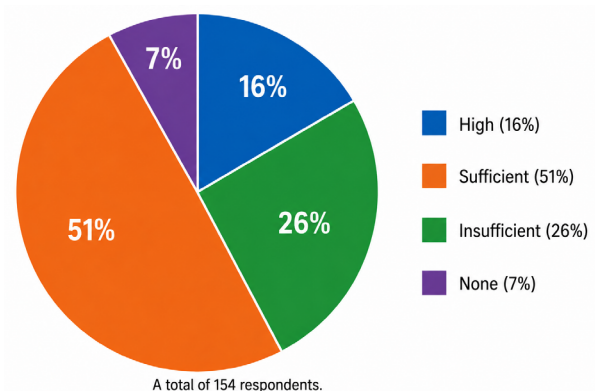


Figure 6. Self-reported knowledge of beekeepers about varroosis.

Locality and infestation level

The reported infestation level of *V. destructor* is shown in Figure 7. Medium infestation was the most frequently reported category (57% of respondents), followed by high infestation (22%) and low infestation (12%). The remaining 9% of respondents were unable to assess the infestation level in their apiaries.

The relationship between reported locality and reported infestation level is presented in Table 4. Although respondents from rural and mountainous areas more frequently reported medium or high infestation levels, the association between locality and infestation level was not statistically significant ($\chi^2 = 13.02$, $df = 9$, $P = 0.1619$, Cramér's $V = 0.17$).

The seasonal period of the highest occurrence of *V. destructor* is shown in Figure 8. Most respondents reported the highest occurrence at the end of summer (45%), followed by autumn (30%) and summer (15%). Lower frequencies were reported for spring and winter (5% each).

Table 4. Relationship between locality and infestation level.

Locality	Low	Medium	High	Unknown	Total
Urban	1	6	4	1	12
Rural	12	55	15	10	92
Mountain	2	14	12	3	31
Lowland	4	13	2	0	19
Total	19	88	33	14	154

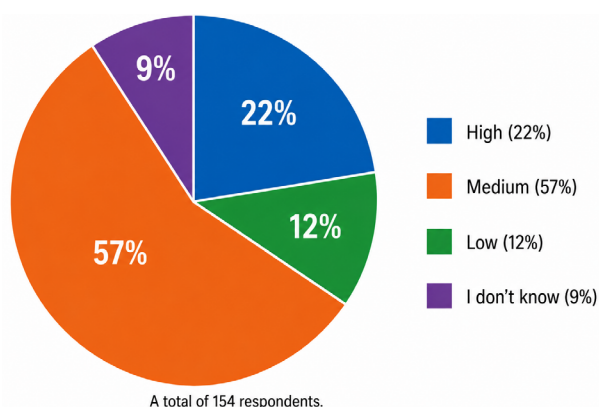


Figure 7. Reported level of *Varroa destructor* infestation in apiaries.

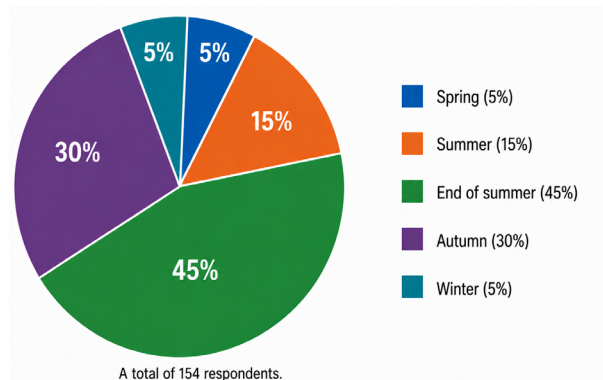


Figure 8. Seasonal period of the highest occurrence of *Varroa destructor*.

Infestation level and honey production

The relationship between reported infestation level and the reported perceived effect on honey production is presented in Table 5. Respondents reporting medium or high infestation levels more frequently perceived a moderate or strong reduction in honey production, whereas respondents reporting low infestation more often reported little or no effect. The chi-square test revealed a statistically significant association between infestation level and perceived reduction in honey production ($\chi^2 = 33.05$, $df = 9$, $P = 0.0001$, Cramér's $V = 0.27$).

Table 5. Relationship between infestation level and honey production.

Infestation level	Strong decrease	Moderate decrease	No effect	Unknown	Total
Low	5	10	2	2	19
Medium	28	40	7	13	88
High	18	13	2	0	33
Unknown	1	5	7	1	14
Total	52	68	18	16	154

Treatment methods and perceived resistance

Preferred treatment strategies are summarised in Figure 9. Combined treatment approaches were the most frequently reported method (43%), followed by organic acid treatments (30%). Chemical treatment was reported by 14% of respondents, biotechnical methods by 10%, whereas 3% stated that they did not treat *V. destructor*.

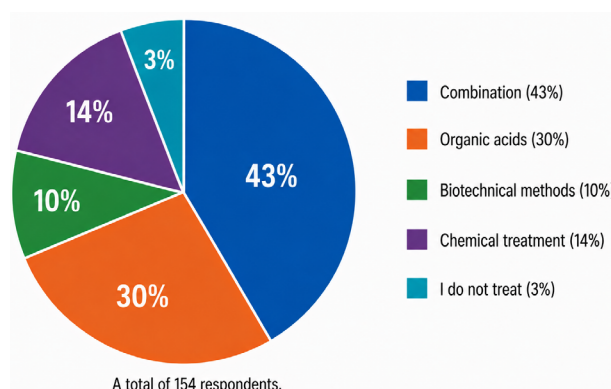


Figure 9. Treatment methods used against *Varroa destructor* by respondents.

Interest in new treatment methods is shown in Figure 10. Occasional interest in new treatment approaches was reported by 45% of respondents, whereas 30% regularly searched for and tested new methods. The remaining 25% of respondents reported no interest in new treatment strategies.

The relationship between reported perceived mite resistance and reported treatment type is presented in Table 6. Although some variation among treatment categories was observed, the association was not statistically significant ($\chi^2 = 11.52$, $df = 8$, $P = 0.1741$, Cramér's $V = 0.19$).

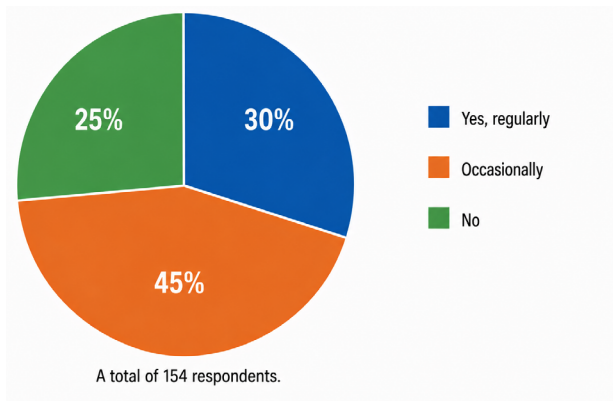


Figure 10. Interest of respondents in searching for and testing new treatment methods against *Varroa destructor*.

Table 6. Relationship between perceived resistance and treatment type.

Resistance	Chemical	Organic acids	Biotechnical	Combination	No treatment	Total
Yes	9	21	5	19	0	54
No	4	14	2	18	1	39
Unknown	9	11	9	29	3	61
Total	22	46	16	66	4	154

Table 7. Relationship between beekeeper sex and monitoring frequency.

Sex	Regularly	Occasionally	Rarely	No monitoring	Total
Male	56	47	15	10	128
Female	6	7	8	5	26
Total	62	54	23	15	154

Discussion

The present study provides further evidence that *V. destructor* remains one of the principal threats affecting honey bee colony health and productivity. The overall pattern of responses is consistent with previous studies identifying this ectoparasitic mite as a major factor contributing to colony weakening, viral transmission and increased colony mortality (Rosenkranz et al. 2010; Genersch 2010; Ryabov et al. 2014).

One of the most important findings of the present study was the significant relationship between monitoring frequency and infestation level. Respondents who monitored their colonies regularly more frequently reported lower infestation levels than beekeepers performing only occasional or no monitoring. These findings support previous conclusions that regular monitoring represents a fundamental component of effective varroosis management (Dietemann et al. 2013; Nazzi & Le Conte 2016). However, the present questionnaire evaluated primarily the reported frequency of monitoring and did not distinguish between the effectiveness of different diagnostic approaches. Consequently, the present study cannot assess whether monitoring methods differ in their ability to detect increasing mite populations or

Sex and monitoring frequency

The relationship between reported beekeeper sex and reported monitoring frequency is presented in Table 7. Male respondents more frequently reported regular monitoring, whereas female respondents were proportionally more represented in less frequent monitoring categories. The chi-square test revealed a statistically significant association between sex and monitoring frequency ($\chi^2 = 11.03$, $df = 3$, $P = 0.0116$, Cramér's $V = 0.27$). However, this finding should be interpreted cautiously because the analysed sample was strongly male-biased, which may have influenced the observed association.

reduce colony losses. Early detection of increasing mite populations allows timely intervention and may reduce the probability of severe infestation and colony decline.

A similarly important result was the significant association between reported treatment frequency and colony losses. Respondents reporting regular treatment more frequently reported lower annual colony losses, whereas irregular treatment or absence of treatment was associated with higher mortality. Although these findings are consistent with current knowledge of varroosis management, the questionnaire did not record the seasonal timing of treatment. Consequently, no conclusions can be drawn regarding the influence of treatment timing, which is considered an important determinant of successful Varroa control (Rosenkranz et al. 2010; Jack et al. 2023).

Although professional beekeepers more frequently reported high or sufficient knowledge levels than hobby beekeepers, the relationship between beekeeper type and knowledge level was not statistically significant. This suggests that practical experience and individual interest in bee health management may influence knowledge acquisition independently of beekeeper category. Nevertheless, the descriptive pattern observed in the present study generally supports previous findings emphasising the importance of beekeeper education and management experience for successful disease control (Jacques et al. 2017).

The relationship between locality and infestation level was also not statistically significant. Although respondents from rural and mountainous areas more frequently reported medium or high infestation levels, the observed variation among localities was insufficient to support a clear geographic effect. These results suggest that colony

management practices may exert stronger effects on infestation dynamics than locality alone within the studied region. Another factor that may contribute to infestation dynamics is the density of neighbouring apiaries and the associated risk of mite reinvasion. This variable was not included in the questionnaire and therefore could not be evaluated, although it may represent a more direct determinant of infestation pressure than the general classification of apiary locality. Similar conclusions were reported by Smoliński et al. (2021), who emphasised that environmental and climatic factors interact with management practices, colony condition and local environmental characteristics.

The significant association between infestation level and perceived reduction in honey production further supports the importance of *V. destructor* as a major economic and biological threat in apiculture. Respondents reporting higher infestation levels more frequently indicated moderate or severe decreases in honey production. Previous studies similarly demonstrated that mite infestation negatively affects colony vitality, worker longevity and foraging efficiency, which may ultimately reduce colony productivity (Medina-Flores et al. 2011).

No statistically significant relationship was detected between perceived mite resistance and treatment type. This may reflect the multifactorial nature of treatment efficacy, which depends not only on resistance development, but also on treatment timing, dosage, rotation of active substances and overall colony condition. In addition, the questionnaire did not distinguish between individual biotechnical practices, such as drone brood removal, brood interruption or queen replacement, which may also influence treatment effectiveness. Nevertheless, resistance to acaricides remains an important concern in modern apiculture, particularly under repeated use of identical active compounds (Elzen et al. 1999). The present findings therefore support recommendations favouring integrated and rotational treatment strategies.

The significant relationship detected between beekeeper sex and monitoring frequency should be interpreted cautiously because the analysed sample was strongly male-biased. Consequently, the observed pattern may partly reflect unequal sample structure rather than biologically meaningful behavioural differences. Additional studies using more balanced respondent samples would be necessary to evaluate this relationship more reliably.

Several limitations of the present study should also be acknowledged. The analyses were based on self-reported questionnaire data rather than direct field measurements, and several evaluated variables reflected respondent perception rather than objectively quantified infestation or production parameters. Infestation level was based on respondents' own assessment, and no standardized quantitative thresholds were applied. Furthermore, although the questionnaire included information on monitoring methods, the present study focused primarily on monitoring frequency and therefore did not evaluate

differences among individual monitoring methods. In addition, the questionnaire did not record the seasonal timing of treatment or specific biotechnical management practices. Finally, the study was geographically restricted to Eastern Slovakia, and variables such as apiary density or the risk of mite reinvasion from neighbouring colonies were not assessed. Despite these limitations, the study provides useful information on beekeeper behaviour, management practices and perceived impacts of *V. destructor* under regional apicultural conditions.

Conclusion

The present study showed that beekeeper practices were significantly associated with several important aspects of *Varroa destructor* management and colony health in Eastern Slovakia. Regular monitoring was associated with lower reported infestation levels, whereas regular treatment was associated with lower annual colony losses. In addition, higher reported infestation levels were significantly associated with a perceived reduction in honey production.

In contrast, no statistically significant relationships were detected between beekeeper type and knowledge level, locality and infestation level, or perceived resistance and treatment type. These findings suggest that colony management practices, particularly regular monitoring and treatment, may represent more important determinants of infestation dynamics than beekeeper category or locality alone.

The results emphasise the importance of regular monitoring, regular treatment and continued beekeeper education for effective varroosis management. Despite the limitations associated with questionnaire-based and self-reported data, the study provides useful insight into beekeeper behaviour and management strategies under regional apicultural conditions in Eastern Slovakia.

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