Agronomy Research **24**(1), 284–296, 2026
https://doi.org/10.15159/AR.26.015

Bee colony weight dynamics during passive wintering period

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Received: January 29th, 2026; Accepted: March 18th, 2026; Published: April 2nd, 2026

Abstract. Honeybees (*Apis mellifera*) are essential for maintaining ecological balance and enhancing agricultural productivity through their pollination services. Gaining insight into the internal conditions of a honeybee colony is crucial for evaluating its health, productivity, and seasonal dynamics. In the northern countries bee colony activity is divided into two periods: active summer and winter passive periods. Monitoring the weight of honey bee colonies provides valuable insight into their physiological status, food consumption, and survival potential during wintering. This study investigates the weight dynamics of bee colonies throughout the passive wintering period, aiming to better understand colony metabolism and resource utilization under low-activity conditions. Continuous weight measurements were recorded using electronic hive scales. The data were analysed to assess temporal trends in colony mass loss and to identify environmental or management factors influencing these changes. Results showed a gradual decrease in hive weight corresponding to the consumption of stored honey, with the rate of loss varying in response to external temperature fluctuations and colony strength. These findings contribute to improving winter management practices by providing quantitative parameters of weight consumption for assessing colony health and predicting overwintering success.

Key swords: bee colony weight dynamics, honeybee colony monitoring, passive wintering period, precision apiculture, precision beekeeping.

INTRODUCTION

Honey bees (*Apis mellifera*) play a critical role in global ecosystems and agriculture by providing pollination services, sustaining biodiversity, and contributing to food production (Papa et al., 2022). However, honey bee colonies face considerable challenges during the winter season, particularly in temperate and cold climates, where resource scarcity, harsh weather, and stressors such as parasites threaten colony survival

(Minaud et al., 2024). Understanding the internal conditions of a honeybee colony is essential for assessing its health, productivity, and seasonal behaviour (Staszewski, 2025). Recent surveys indicate that winter colony losses remain high across Europe (Gray et al., 2020). In Poland, large-scale data from 2017–2022 show that 12.2% of colonies were lost during winter, with higher losses among small-scale apiaries (Mazur et al., 2025). While overwintering losses are a major concern, the motivation for studying wintering dynamics extends beyond survival alone. Winter processes influence colony energy balance, physiological condition, and the strength of spring population buildup, and therefore have direct implications for colony productivity and management decisions in the following season (Doeke et al., 2015).

Overwintering represents a critical bottleneck in the annual cycle of honey bee colonies (Ying et al., 2026). During winter, bees cease foraging and rely on stored resources (primarily honey) to meet metabolic demands, while ensuring colony integrity (Minaud et al., 2024). Because external environmental conditions, like temperature, light, humidity and internal colony traits, like size, brood presence, insulation, overall health status of the colony jointly influence resource consumption and survival rate of the colonies, continuous monitoring of the hive weight and internal temperature could provide a powerful data into winter colony dynamics (Meikle & Holst, 2015; Serri et al., 2024).

Advancements in sensor-based technologies for bee colony monitoring have laid the foundation for Precision Beekeeping (Zacepins et al., 2015). Smart hive technologies that combine temperature, humidity, and weight sensors now make it possible to monitor colony conditions in real time, enabling beekeepers to intervene promptly and reduce the risk of colony losses (Meikle & Holst, 2015; Marchal et al., 2020; Zaman & Dorin, 2023).

Despite these advances, substantial knowledge gaps remain, especially for passive wintering period which is, the common scenario in which hives are left outdoors under natural climatic conditions, typical for many beekeepers in northern Europe including the Baltic region.

Our study aims to explore hive weight dynamics during the passive wintering period. By deploying an Internet of Things (IoT) based monitoring system for continuous weight and temperature measurements across multiple colonies, authors try to characterize patterns of resource consumption, thermoregulatory behaviour, and their temporal fluctuations over the entire winter period.

MATERIALS AND METHODS

Location and apiary description

Research and measurements were carried in urban apiary (see Fig. 1). The apiary was located at Latvia University of Life Sciences and Technologies (LBTU), Strazdu iela 1, Jelgava, Latvia (GPS coordinates: 56.662937, 23.753923). This apiary was located at the university study centre, where different experimental facilities are located. Five honey bee (*Apis mellifera*) colonies were selected for the monitoring. The main sources of nectar come from vegetation found in public parks and along streets, as well as from plants and crops in private gardens. In addition, bees can access certain forested and agricultural areas.

Bee colonies were placed in BeeBox Hives, which is a polystyrene foam hive system from the Paradise Honey Ltd (https://paradisehoney.fi/eps-beehives/). All components of BeeBox hives are made of food-grade hardened expanded polystyrene (EPS) with a density of more than 100 kg m^{-3}. Hive sizes are equal to Langstroth hive sizes.

Figure 1. Setup of the apiary.

Honey bee colony monitoring system

Weight of the colonies was monitored from 11.12.2024 till 28.02.2025 during the defined time span of 30 minutes between two measurements by the digital bee colony scales. The time interval of 30 minutes was chosen as a compromise to still have fairly frequent measurements and to extend the battery life of the measurement nodes. As well individual bee colony weight changes are not very dynamic in a short time periods during the passive stage. Inside bee colony temperature also was monitored to know the status of the bee colony and to identify the occurrence of the death of the colony.

All honey bee colonies were equipped with a bee colony monitoring system based on the ESP8266 microchip inspired by the monitoring system developed within the SAMS project (Wakjira et al., 2021). The system was equipped with one single-point load cell Bosche H30A and two DS18S20 1-Wire temperature sensors. Each hive was placed on top of a scale platform. Two temperature sensors (Dallas DS18S20) per colony were placed in upper hive body under the pillow for in-hive temperature measurements as suggested by (Stalidzans & Berzonis, 2013). Temperature measurements in this case were used just to verify that the bee colonies are alive. One sensor was.

Data transmission and storage

Data transmission from the bee colonies was performed using one main node. This main node acted as a gateway, by first receiving data from each measurement node, using the ESPNOW protocol (Pasic et al., 2021), serialising (using Protocol Buffers) the received data in one single data packet and further transmitting to Raspberry Pi device. To achieve a more stable connection to the Internet, the ESP32 microchip transmitted the received data to the Raspberry Pi device using asynchronous serial communication. The ability to perform such two parallel data transmissions (receiving data from measurement nodes and transmitting the received data to the Raspberry Pi device) is provided by the ESP32 dual-core microprocessor. Further, Raspberry Pi using the local university network performed data transmission to the remote cloud server using the MQTT messaging protocol. This approach makes it possible to significantly reduce the energy consumption of the measurement nodes, because of the efficiency of the ESP-NOW protocol and faster data exchange.

On the remote side, data was stored in the InfluxDB (https://www.influxdata.com/) database and visualised using the Grafana platform (https://grafana.com/). This solution follows technical implementation approaches described by Kviesis et al. (2023).

For the backup reasons, data was also saved locally in a dedicated SD card. Fig. 2 below demonstrates data transfer approach.

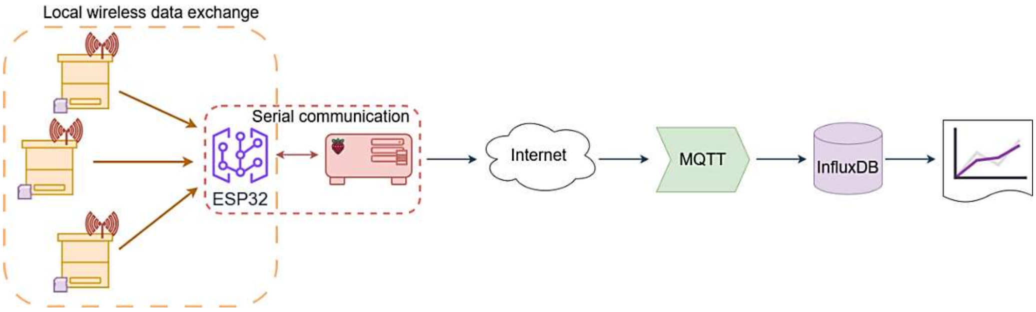


Figure 2. Bee colony data transfer approach.

Description of environmental parameters

The data about the environmental parameters were collected from the nearest LBTU owned weather station. Mentioned weather station was located at the same site near the hives. Meteorological data (hourly) on the following parameters were obtained for analysis: outdoor air temperature (°C), relative humidity (%), wind speed (m s^{-1}), solar radiation (W m^{-2}) and precipitation volume (rain) (mm). Data can be publicly accessed online: https://www.lbtu.lv/lv/meteo.

Data analysis methodology

An 80-day period, from December 11, 2024, to February 28, 2025, inclusive, was selected for analysis. Both hourly and daily hive weight changes were analyzed.

Weather conditions during the observation period are shown in Fig. 3.

The Fig. 3 shows daily weather conditions over a winter period (early December to early March) using five parameters: precipitations, air temperature (min/max/mean), relative humidity, wind speed (min/max/mean), and solar radiation (maximum). Observed conditions reflect a typical Latvian temperate winter: cold temperatures, high humidity, low but episodic precipitation, moderate winds, and gradually increasing solar input toward late winter.

For each hive, the weight change was calculated for each hour of the observation period. Formula 1 was used for the calculation:

$$delta\_w\_h = weight_h - weight_{h-1}, \quad h = 0..23 \qquad (1)$$

where $weight_h$ – hive average weight in current hour from period, $weight_{h-1}$ – hive average weight in previous hour.

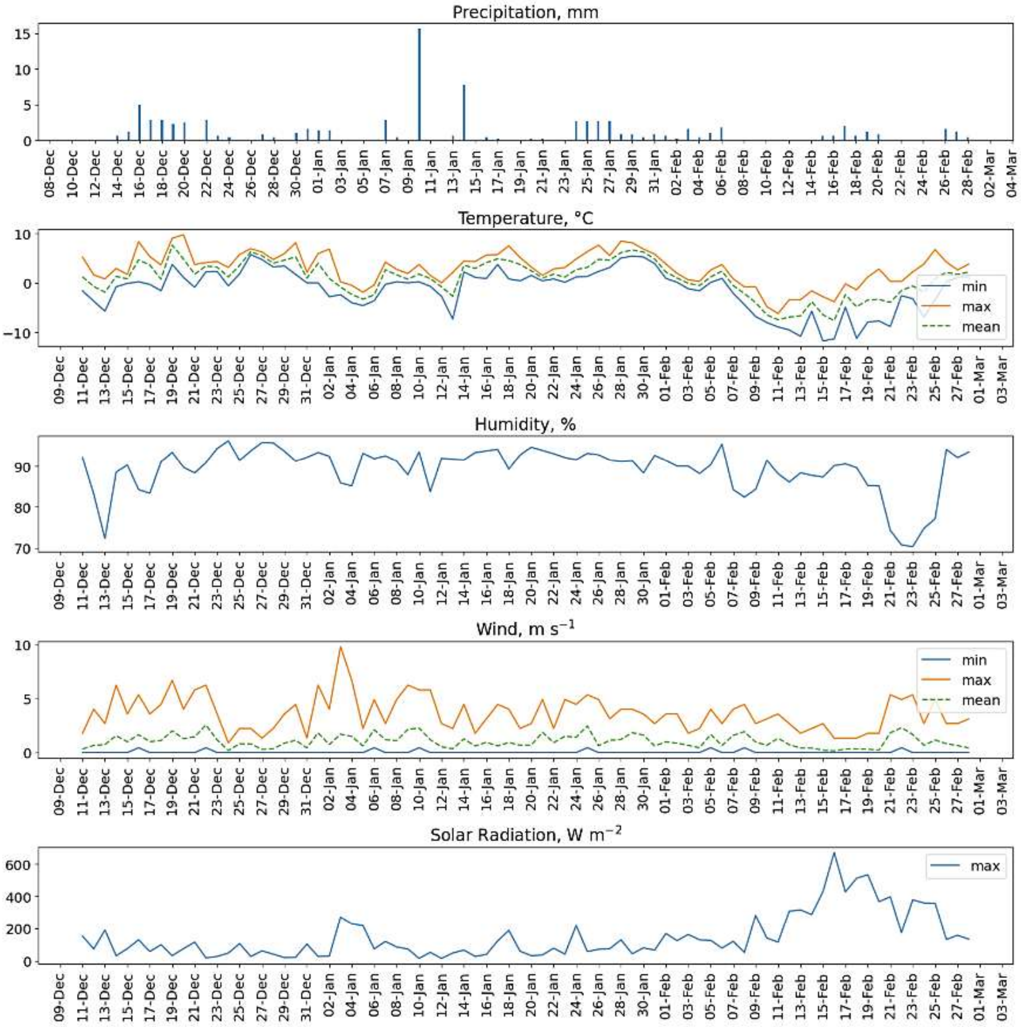


Figure 3. Weather conditions during the observation period.

The original dataset of hourly hive data for the period under review consisted of 9,114 records. Data related to colonies after colony deaths were removed from the dataset. Data outliers for each hive *delta_w_h* values were detected and removed from the dataset by applying the interquartile range (*IQR*) based filtering. Only rows in dataset that have values within *1.5*IQR* of quartiles *Q1* and *Q3* was kept. After *IQR* filtering, 9.4% of records were excluded and the final data set amounted to 7,452 records.

For each hive, the daily weight change was calculated for each day of the period under consideration. Formula 2 was used for the calculation.

$$delta\_w\_d = weight_d - weight_{d-1} \qquad (2)$$

where $weight_d$ – hive average weight in current date from period, $weight_{d\text{-}1}$ – hive average weight in previous date.

RESULTS AND DISCUSSION

Temperature changes inside the hives were analyzed. The diagram of average daily temperature changes is shown in Fig. 4; the average outer temperature is shown by the gray dash-dotted line (t_out). The first number in the legend indicates the colony identifier, while the second denotes the sensor (sensor 1 or sensor 2).

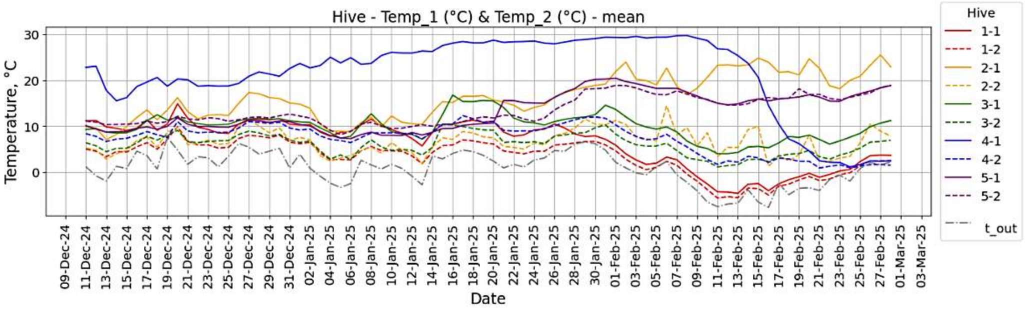


Figure 4. Temperature changes in hives and average environmental temperature values.

The figure shows that the temperature in hive 1 on January 28, 2025, almost equalled the ambient temperature and subsequently remained virtually the same, indicating the death of the bee colony, which was subsequently confirmed by beekeeper. A similar situation can be seen with hive 4, beginning on February 24, 2025. Our results are consistent with those reported by (Li et al. 2022), showing comparable patterns and supporting the robustness of the observed winter colony dynamics.

Data from hives 1 and 4 were included in the analysis only up to the time of colony death.

After the data cleaning, resulted histogram of *delta_w_h* values for all hives is shown in Fig. 5.

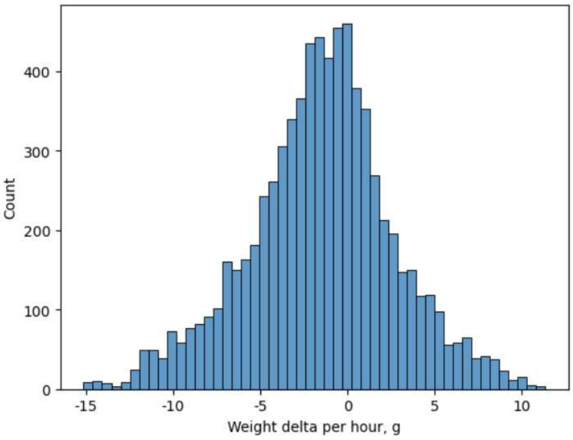


Figure 5. Histogram of *delta_w_h* values.

The Fig. 5 shows a histogram of hourly hive weight change (delta_w_h) values, with the y-axis representing observation count and the x-axis showing weight change magnitude. The distribution is approximately normal (bell-shaped) and centered close to zero. Most observations fall within a narrow interval around −0.005 kg to + 0.005 kg (weight change per hour). The distribution appears fairly symmetric, with a mild skew toward negative values.

Fig. 6 shows the change in average hive weight during the observation period.

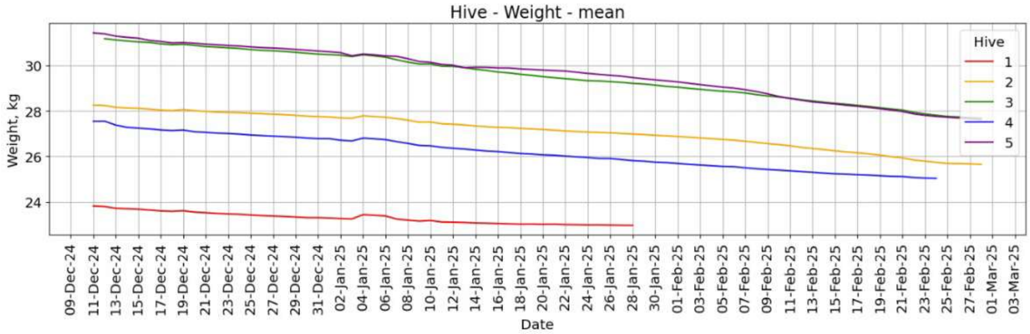


Figure 6. Change in average hive weight during the observation period.

Fig. 6 illustrates the temporal evolution of the hive weight for each monitored colony over the observation period from early December to early March. All colonies exhibit a gradual and predominantly monotonic decrease in average weight, reflecting continuous consumption of stored resources during wintering. The decline is relatively smooth, with only minor short-term fluctuations, indicating stable winter conditions without abrupt feeding or disturbance events.

Clear differences in absolute weight levels and loss rates are visible among hives. Hives 3 and 5 maintained the highest average weights throughout the period, whereas hives 1 and 4 showed lower initial weights and steeper declines. Data for hives 1 and 4 terminate earlier than for the other colonies, corresponding to the timing of colony loss. Toward late February, the remaining colonies show a slight convergence in weight, suggesting comparable cumulative resource use by the end of the winter period.

Overall, the figure highlights both the common seasonal trend of winter weight loss and inter-colony variability in resource depletion dynamics during passive overwintering.

The average delta value (per hour) for each hive by month is shown in Fig. 7.

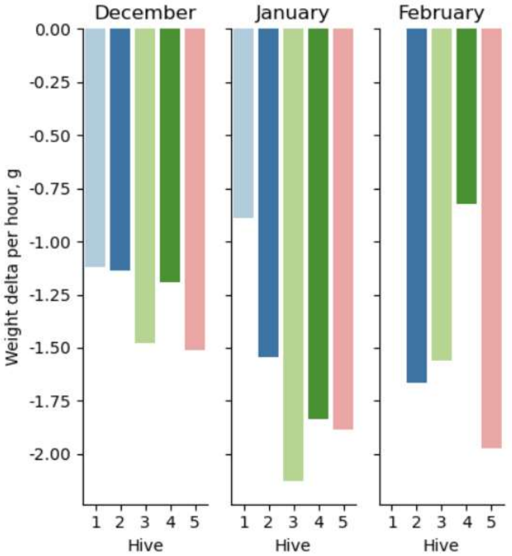


Figure 7. Average *delta_w_h* value for each hive in each month of the observation period.

The change in *delta_w_h* depending on the hour of day was also analysed and shown in Fig. 8.

The figure presents the relationship between hour of day (0–23) and hourly hive weight change (delta_w_h). Individual observations are shown as scattered points, while the red line represents the smoothed mean trend across hours. A weak diurnal pattern is visible: the mean trend shows slightly more negative values during the late morning to early afternoon (around 10–15 h), suggesting marginally higher average weight loss during this period.

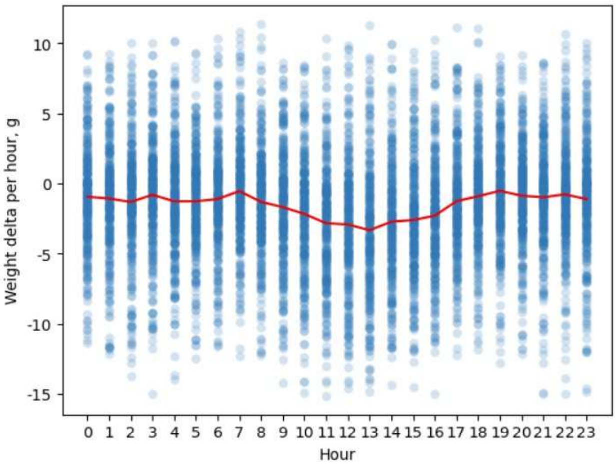


Figure 8. *delta_w_h* change depending on the hour of the day.

The average hourly weight change is –1.520 ± 4.203 grams.

The daily weight change for each hive over the entire observation period is shown in Fig. 9.

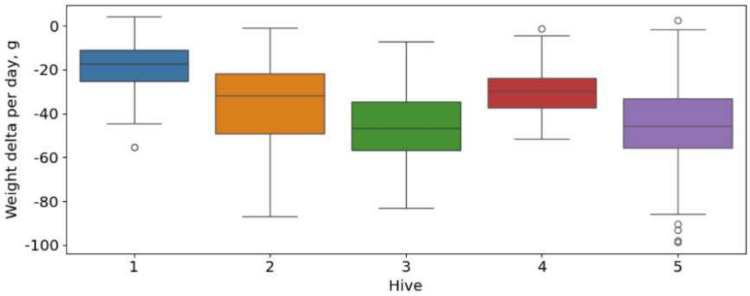


Figure 9. Daily weight change for each hive over the entire period under consideration.

The daily weight change for each hive by month of the period under consideration is shown in Fig. 10.

The Fig. 10 presents daily weight change (g per day, negative values indicating loss) for five honeybee colonies (“Hive 1–5”) during the passive wintering period, shown across three months (December, January and February). All honey bee colonies exhibit net weight loss during passive wintering, which is expected due to the absence of foraging and the reliance on stored honey reserves to sustain thermoregulation and metabolism (Norrström et al., 2021; Abi-Akar et al., 2020). Hive 1 generally shows the smallest losses particularly in the January, what can be explained by the fact, that this colony died in January. Hive 2 and Hive 4 fall in an intermediate range, with Hive 2 showing notably higher loss in the February compared with other months.

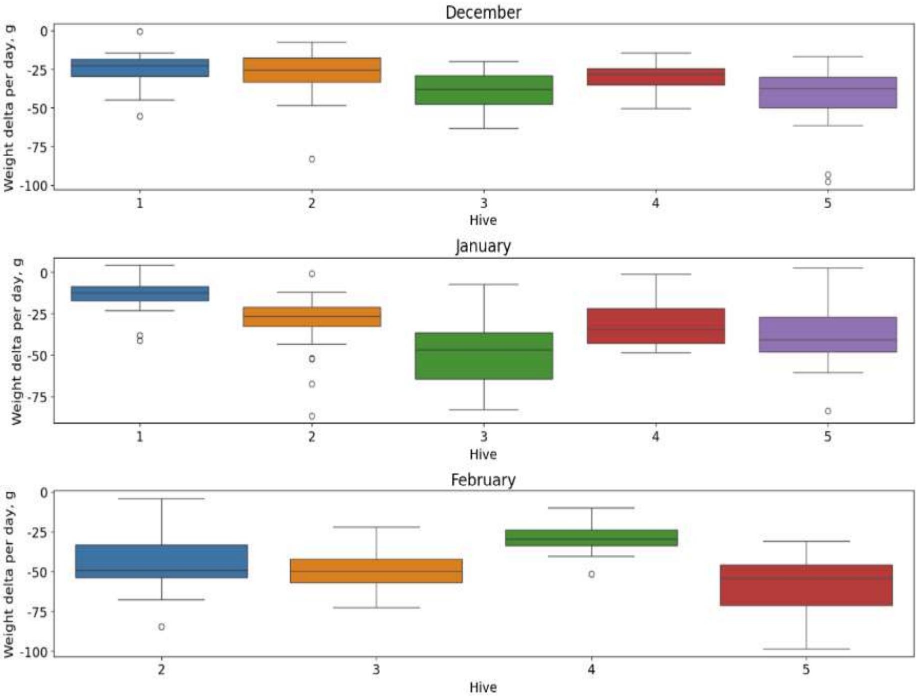
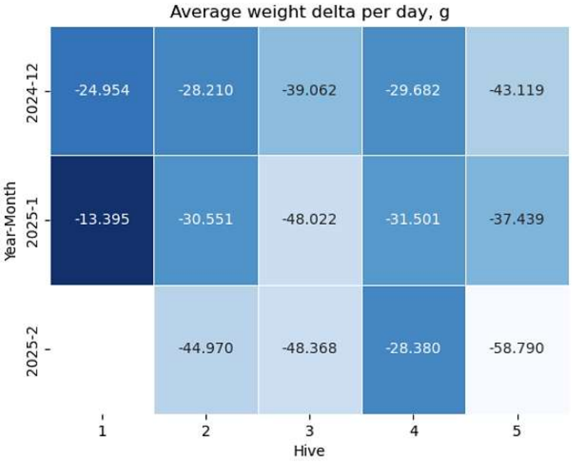


Figure 10. Daily weight change for each hive by month during the period under review.

This can be explained by the fact that honey bee colonies become progressively more active toward the end of winter as brood rearing resumes and colony activity increases in preparation for spring development (Doeke et al., 2015). December appears more moderate overall, consistent with earlier winter when reserves are still abundant and bee cluster activity may be lower.

The average daily weight change is –37.037 ± 19.284 grams (see Fig. 11).

During the analysis, the dependence of hourly weight change on weather conditions was examined, Pearson correlation coefficients were calculated, and it was found that solar radiation has the greatest impact on the delta value. The Pearson correlation coefficient is –0.147.



Year-Month	1	2	3	4	5
2024-12	-24.954	-28.210	-39.062	-29.682	-43.119
2025-1	-13.395	-30.551	-48.022	-31.501	-37.439
2025-2		-44.970	-48.368	-28.380	-58.790

Figure 11. Average daily weight change for each hive by every month during the period.

A diagram displaying average solar radiation values depending on the hour of day and the average weight change in all hives over the entire period is shown in Fig. 12.

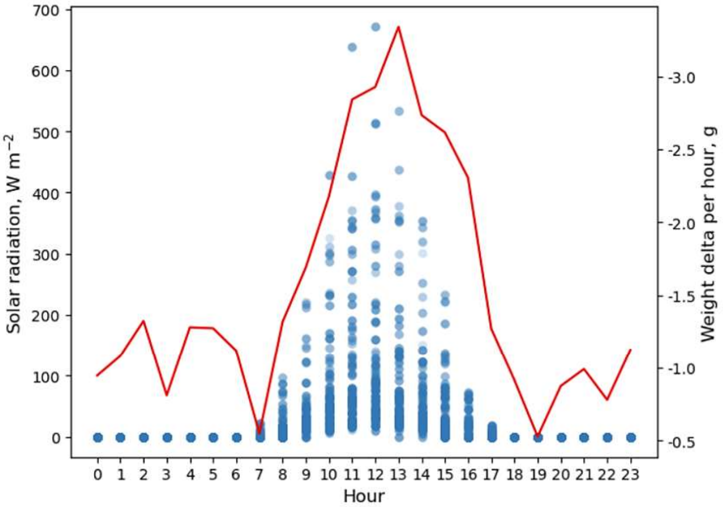


Figure 12. The diagram of the average weight change in all hives versus the hourly average solar radiation values for the entire period.

With red line is shown average value of the delta_w_h for each of date hours during all period.

The chart overlays hourly solar radiation with concurrent hive weight change dynamics, highlighting a clear diurnal structure and a strong temporal association between the two variables.

Solar radiation increases after early morning, forming a midday peak between roughly 10:00 and 15:00, with maximum values approaching 600–700 W·m^{-2}. The scatter shows substantial variability around midday, consistent with changing cloud cover or day-to-day variation.

The red line shows averaged hourly hive weight change, remaining close to zero or slightly negative during nighttime and early morning. As solar radiation increases, the weight change becomes more negative, reaching its strongest magnitude around midday (approximately −0.003 to −0.0035 kg). After mid-afternoon, the magnitude of weight loss decreases again, returning toward baseline levels by evening.

The figure demonstrates a clear diurnal cycle in both environmental forcing (solar radiation) and colony behavior (weight dynamics) even during the passive wintering period of the honeybee colony. Before, this effect was observed during the food collection by the bees (Czekońska et al., 2023; Gounari et al., 2022).

The diagram of the average solar radiation values depending on the hour of day and the average weight change in all hives for each month of the observation period is shown in Fig. 13. With red line is shown average value of the *delta_w_h* for each of date hours during each month of the period.

Prior work has demonstrated the value of continuous monitoring of bee colonies. In a field study of 32 colonies in southwestern Sweden over winter 2019–2020, researchers recorded nearly continuous hive weight and weather data, and found that daily weight loss averaged only ~0.039 ± 0.013 kg per colony, even under northern-climate conditions. The study further showed that increases in ambient temperature and light intensity triggered greater resource consumption, suggesting that even mild winters or episodic warm spells can accelerate the depletion of honey stores (Norrström, Niklasson & Leidenberger, 2021). Authors results are in line with Norrström study.

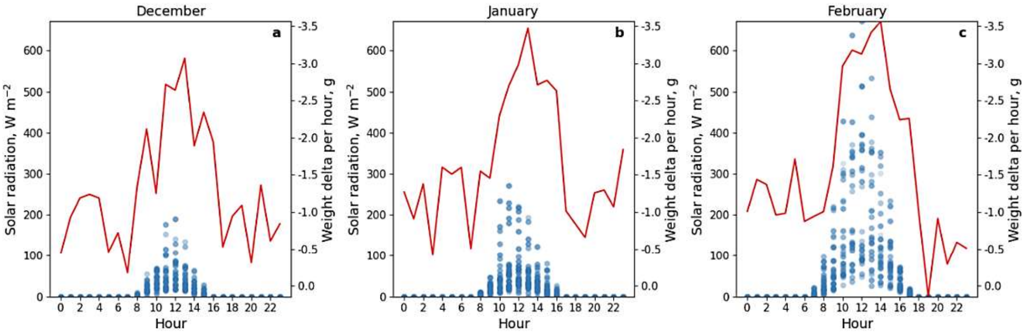


Figure 13. The graph of the average weight change in all hives versus the hourly average solar radiation values for each month of the period.

Authors acknowledge one limitation of the study, which is related to the relatively small number of monitored colonies (n = 5), which reflects the exploratory nature of a pilot field investigation conducted under real wintering conditions. While the dataset was sufficient to identify consistent patterns in colony weight dynamics and to test the feasibility of continuous monitoring, the limited sample size constrains statistical power and may reduce the representativeness of the observed responses across different apiaries, management practices, and environmental contexts. Consequently, caution is warranted when generalizing these findings to broader populations of honey bee colonies. Future studies involving larger sample sizes, multiple locations, and multi-winter observations are needed to validate the detected trends and to better capture inter-colony variability under passive wintering conditions.

As well in-hive temperature measurements were included primarily as a supporting indicator of colony viability and overwintering status, rather than as a primary variable for quantitative analysis. The present study was designed specifically to characterize colony weight dynamics during the passive wintering period, and the analytical framework, data resolution, and sample size were optimized for that purpose. A more detailed assessment of temperature patterns and their relationship with weight loss are planned for future studies, where temperature will be examined as a primary explanatory variable in relation to colony energy consumption and wintering success.

CONCLUSIONS

This research underlines the important role of the automated monitoring of bee colony temperature and weight as essential indicators of colony activity. This study demonstrates that continuous monitoring of hive weight during the passive wintering period provides valuable insights into colony resource consumption, stability, and behavioural transitions.

The results show that winter weight loss is generally gradual but punctuated by distinct episodes of increased consumption corresponding to external environmental shifts, particularly temperature variations and solar radiation. The integration of continuous weight monitoring with supplementary colony and environmental data illustrates the significant potential of IoT-based hive systems for detecting colony behavioural changes. These systems enable the identification of critical periods when colonies may be more vulnerable due to accelerated resource depletion or instability within the winter cluster.

ACKNOWLEDGEMENTS. This study was partially conducted within the framework of the 'Evaluation and determination of the most effective methods of controlling major pests of legumes and identification of factors affecting the viability of the most important pollinators for agriculture' project funded by the Ministry of Agriculture of the Republic of Latvia. This research was partially supported by the ERA-Net project Top4HoneyChains.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS. During the preparation of this work authors used ChatGPT-5 in order to improve the readability and language of the manuscript. After using this service, authors reviewed and edited the content, and take full responsibility for the content of the published article.

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