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Thermal responses of overwintering honey bee colonies to fondant feeding during mild winters and early springs

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Research Article

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Abstract

In the context of climate change, warmer winters and early-spring fluctuations alter overwintering conditions for honey bee colonies (*Apis mellifera*), increasing feed consumption, disrupting the winter cluster and advancing spring development. These changes increase the risk of winter mortality and can compromise spring crop pollination. Beekeepers use winter fondant feeding as an emergency measure, yet changes in hive microclimate in response to such interventions, documented with in-hive and ambient sensor data, remain largely undescribed.

We report reproducible thermal responses to fondant feeding detected by a non-invasive Internet of Things (IoT) hive monitoring system across two winters: a mild winter/early spring in Ukraine (2018–2019) and an anomalously warm winter in Canada (2020). Fondant feedings were timed to winter warm spells and were followed by a sharp rise in in-hive temperature and a gradual decline over several days, accompanied by reduced in-hive relative humidity. We quantified responses as integrated areas of the temperature difference between in-hive and ambient temperature before and after feeding over 5- to 10-day windows. Response amplitude and decay duration were consistent across feeding events and depended on colony strength, suggesting that this integrated temperature difference may serve as a simple, non-invasive indicator of winter colony status, useful for emergency supplementation and preparation for early-spring pollination. To our knowledge, this phenomenon is documented here for the first time using IoT-based hive sensors as a rare but increasingly relevant pattern during warm winters, highlighting the potential of sensor-based monitoring to reduce winter bee mortality.

Introduction

Globally, the western honey bee (*Apis mellifera*) is a key crop pollinator and helps sustain more than US$235 billion of pollinator-dependent crop production each year (FAO, 2018). At the same time, large-scale monitoring shows that substantial proportions of managed colonies are lost each winter. Global COLOSS survey data for winter 2019–2020 documented considerable overwintering losses across 37 countries, with an overall winter loss rate of 18.1% and national values ranging from about 7% to 36% (Gray et al., 2023). A recent example comes from Canada, where national reports for 2023–2024 indicate a winter loss of 34.6% of colonies, with provincial values ranging from 9.8% to 61.3% (Canadian Association of Professional Apiculturists (CAPA), 2024).

Recent studies increasingly demonstrate how altered autumn and winter weather regimes affect the overwintering of honey bee colonies. Using a model driven by measured climatic parameters, Rajagopalan et al. (2024) showed that warmer autumns and winters in the U.S. Pacific Northwest increase the frequency of late-season and winter flights, shorten the period of stable winter populations and reduce spring colony size, thereby raising the risk of winter mortality and loss of pollination services. In a temperate European climate, Switanek et al. (2017) linked warmer and drier conditions in the preceding year with increased winter mortality of colonies, whereas Overturf et al. (2022), at the national scale in the United States, showed that winter losses correlate with winter weather variables, highlighting the value of meteorological data for assessing climatic impacts on honey bee survival.

Anomalously warm periods in winter can trigger an earlier onset of brood rearing, as confirmed by temperature monitoring: in-hive temperature profiles can be used to infer brood presence in overwintering colonies and to predict winter mortality (Minaud et al., 2024). At the same time, such periods may promote breakdown of the winter cluster, accelerate feed consumption and create conditions more favorable for the reproduction of Varroa destructor, which has been identified as a major driver of mortality and reduced populations in overwintered colonies in some regions (Guzmán-Novoa et al., 2010), while phenological shifts in colony seasonal dynamics have been linked to varroa infestation levels (Nürnberger et al., 2019). Against a background of sharp temperature fluctuations, these processes are accompanied by more frequent early-spring flights and characteristic changes in in-hive temperature (Li et al., 2022), and together they can substantially increase the risk of winter losses.

Emergency fondant feeding in late winter is widely recommended in practical guidance for beekeepers as a means to prevent starvation and ensure adequate stores before spring (Honey Bee Health Coalition, 2024; National Bee Unit, 2025). At the same time, field studies that systematically compare the quality and composition of carbohydrate feeds, application methods, environmental conditions and feeding schedules remain relatively scarce. Recent work has begun to address this, showing that different artificial diets and sugar types can affect winter survival, colony population size and food digestibility (Quinlan et al., 2023; Abdella et al., 2024), yet internal hive microclimate responses to such feeding under field conditions—particularly during mild winters—remain largely undocumented.

Meanwhile, as previously anticipated (Marchal et al., 2020; McMinn-Sauder et al., 2024), wireless technologies and continuous measurements of hive weight and temperature have made long-term field studies of honey bee colonies possible. In recent years, this has resulted in the emergence of multi-sensor, standardized datasets and smart hive networks that provide homogeneous time series of in-hive microclimate and weight across different regions (Zhu et al., 2024; Kurdin and Kurdina, 2025).

Climate projections for temperate regions suggest that warm winter anomalies and unstable spring conditions will become more frequent and persistent over the coming decades. This creates a dual need: to develop approaches that reduce winter losses of honey bee colonies under mild-winter conditions, for example by using sensor data to guide fondant feeding, and to track year-to-year thermal responses of colonies as bioindicators of changing overwintering conditions.

Accordingly, we hypothesized that winter fondant feeding—usually recommended as an emergency measure—can, when guided by in-hive sensor data, be used in mild winters and early spring as a planned intervention. At the same time, the thermal response of colonies to feeding may serve as a non-invasive indicator of their current winter status and as a tool to support management of colony population dynamics in winter and early spring, potentially enabling more timely reduction of winter losses and better planning of the summer season. Here, we present reproducible overwintering thermal responses of *Apis mellifera* colonies to fondant feeding, detected by non-invasive IoT hive sensors at two temperate sites (Ukraine and Canada). By spanning two geographically distant but climatically similar mild-winter regimes, this study provides a compact example of how hive-level microclimate data can complement traditional meteorological records. The design also illustrates how standardized IoT hives can form the basis of distributed environmental monitoring networks centered on pollinator health.

Materials and methods

All measurements were performed non-invasively using AmoHive smart hives equipped with in-hive temperature sensors, in-hive and ambient relative humidity sensors, and electronic hive scales, with LTE connectivity and a solar-powered IoT architecture that enabled year-round operation, including in remote and snowy locations. Each AmoHive unit was treated as an integrated multi-sensor platform, continuously recording variables directly shaped by colony metabolism and external weather forcing. An example of an AmoHive unit used in this study (hive 003 in Ukraine) is shown in Fig. 1.

Measurements were taken at regular intervals determined by the charge state of the solar-powered battery: typically, every 1 h during the spring–summer period and every 2 h during the autumn–winter period. Occasional gaps in the time series, caused by prolonged absence of solar radiation and consequent full battery discharge, were rare and were imputed according to predefined rules described in the publicly available dataset (see Data availability). A detailed description of the AmoHive hardware and software is provided in Kurdin and Kurdina (2025), and the underlying hive-level diagnostic system is described in a related patent (Kurdin, 2019).

Colonies were housed in Langstroth hives made of expanded polystyrene (EPS) with gravitational ventilation via an open, adjustable bottom board.

The in-hive temperature and humidity sensor position was standardized to the fourth frame from the side wall, approximately 5 cm below the top bar of the lower brood box, on the inner face of the rear wall; this location was chosen to ensure sensitivity to the microclimate of the winter cluster and, subsequently, early spring brood. In autumn, colonies were treated against Varroa destructor with Bayvarol strips (Bayer, Germany).

We analyzed two overwintering cases monitored by this IoT system. The first consisted of a single fondant feeding in one colony during a mild winter/early spring in 2018–2019 at an apiary in the Kyiv region, Ukraine (approx. 50.45° N, 30.52° E). The second consisted of four sequential fondant feedings in three colonies during an anomalously warm winter in 2020 at an apiary in the Toronto region, Canada (approx. 43.39° N, 79.23° W). The 2019–2020 winter in the Toronto region was anomalously mild compared with the 1961–1990 climate normals for mean monthly temperatures (Environment and Climate Change Canada, n.d.), providing a suitable case study for sensor-based monitoring of overwintering responses under warm-winter conditions.

At the Ukrainian site, the fondant feeding took place on 31 December 2018 at 12:06 in hive 003; a 690 g portion of commercial fondant was placed on the top bars directly above the winter cluster, with the perforated side facing down, using a quick “open–place–close” procedure without dismantling the brood nest. At the Canadian site, four fondant feedings were performed during naturally occurring short winter warm spells in 2020, when ambient temperature exceeded 10°C and conditions were suitable for cleansing flights. Approximately 1 kg of fondant was placed in each hive on 24 February and subsequently on 8–9 March, 1 April and

28 April 2020, always on the top of the hive frames above the cluster; all feedings in the Canadian apiary were carried out synchronously in the three monitored colonies.

For each hive and each feeding event, we analyzed continuous time series of in-hive air temperature (T_in), ambient air temperature (T_out), in-hive and ambient relative humidity, and hive weight. These variables were analyzed over multi-day windows before and after each feeding event to characterize the thermal response of colonies to fondant under field conditions.

As a quantitative measure of the thermal response, we used a response index I (Eq. 1) based on the integrated difference between in-hive and ambient temperature before and after feeding. For each event, we computed

$$I = \sum_{d=1}^{D_{\mathrm{post}}} \Delta T_{\mathrm{after},d} - \sum_{d=1}^{D_{\mathrm{pre}}} \Delta T_{\mathrm{before},d}$$

1

where $\Delta T = T_{\mathrm{in}} - T_{\mathrm{out}}$ at daily resolution, and $D_{\mathrm{pre}}, D_{\mathrm{post}}$ correspond to 5-, 7-, or 10-day windows before and after feeding, respectively. Thus, I is expressed in degree-days (°C·day) and reflects both the amplitude and the duration of the thermal response to fondant; positive values of I indicate a sustained elevation of in-hive temperature relative to ambient conditions after feeding.

Results and discussion

Recurrent thermal response to fondant feeding

The time series of in-hive temperature are consistent with an enhanced thermoregulatory response of the winter cluster following access to easily assimilated carbohydrates (Fig. 2a).

When warm fondant is placed above the cluster, bees consume this high-calorie feed and produce heat: in-hive temperature rises sharply and subsequently declines in an almost exponential manner. At the same time, the level of in-hive relative humidity gradually decreases, subject to the degree of ventilation and air exchange with the outside. This decline lasts for several days—up to 10–14—and depends on colony condition, hive ventilation design and ambient temperature.

The thermal response of the colony to fondant was recurrent: under otherwise similar conditions between hives (weather, ventilation), the shape of the response reflected the individual condition of the colony and the dynamics of early spring development (Fig. 2b,c).

Thermal response index of the colony

As a quantitative measure of the thermal response to fondant feeding, we used the difference in integrated areas of ΔT = (T_in − T_out) before and after feeding over 5/7/10-day windows, formally described by the response index I in the Materials and methods section. For each feeding event, we calculated I and compared its values between colonies and between successive fondant feeding events (Fig. 2d,e). This approach enabled us to interpret individual responses under comparable conditions and to compare the overwintering status of colonies, based on the assumption that the intensity and dynamics of the thermal response reflect colony strength.

In practice, the strongest colony exhibited a larger response amplitude and a longer decay period (up to ~ 14 days), resulting in larger integrated ΔT areas and higher I values (Fig. 2d), which were consistent with an independent invasive assessment of colony strength during the first spring inspection. Conversely, the smallest ΔT areas and lowest I values corresponded to the weakest colony (Fig. 2e). In the strong colony (Fig. 2d), post-feeding values of the response index I were typically about 30–100% higher than pre-feeding values across 5-, 7- and 10-day windows, with the largest relative increases occurring after the first and third feedings (up to ~ 100% increase). In contrast, the weak colony (Fig. 2e) initially showed only modest increases of about 20–60%, but by late April its post-feeding I values were approximately 1.5–2.0 times higher than pre-feeding values (up to ~ 195% increase), consistent with progressive recovery after avoiding winter mortality.

Although the amplitude of the initial “impulse” is informative, it is a less reliable metric because it strongly depends on hive ventilation parameters and construction. In contrast, a sustained elevation of ΔT and its maintenance over several days after feeding is a more robust indicator of overwintering strength.

Thus, the thermal response to fondant can be viewed both as an individual characteristic of a colony and as a comparative indicator that allows beekeepers and researchers to (i) assess colony condition already during winter, and (ii) respond in a timely manner across a wide range of management goals, from reducing winter mortality to planned strengthening of colonies to ensure maximum efficiency of spring pollination services.

These case studies indicate that the thermal response index to fondant feeding could serve as a practical, non-invasive marker of the current status of overwintering colonies, and fondant feeding itself a tool not only for emergency or rescue feeding, but also potentially for planned and controlled interventions in winter apiary management under global warming, which is altering the classical course of honey bee overwintering. The absence of such a response, or its marked weakening, may signal problems with feed reserves, ventilation, or a critical condition of the colony.

An additional effect of fondant feeding is the heat released by the colony and partially stored in the internal hive elements (such as combs with feed), which act as a passive thermal buffer and smooth out nocturnal drops in temperature.

Limitations

This observational study involves a small number of colonies and feeding events at only two sites. In winter, hive weight is a slow and weather-sensitive proxy for feed consumption (e.g. affected by wetting and drying of the roof and hive body) rather than a precise marker. Brood status was inferred indirectly from temperature profiles because invasive inspections were avoided. Consequently, our findings should be regarded as exploratory and require confirmation on larger, more diverse datasets, with further work to refine dose, timing and composition criteria for winter feeding under different local conditions.

Mild winters favor earlier brood rearing; therefore, timely, planned fondant feeding during warm periods supports the natural course of colony development under mild winter conditions. A potential increase in the reproduction of Varroa destructor under such conditions requires further investigation and must be considered during the first spring inspection in order to limit its negative impact on the subsequent summer–autumn development of colonies.

Conclusions

Taken together, this study links three components that are rarely integrated in current practice: (i) a changing climatic background that increasingly challenges conventional overwintering of honey bee colonies under mild winters and unstable spring weather; (ii) a practical intervention – emergency winter feeding in the form of pure honey or fondant – for which existing recommendations are largely based on beekeepers' experience, blogs and gray literature rather than on quantitative evidence; and (iii) systematic documentation in the form of homogeneous, non-invasive time series of in-hive microclimate and correlated feed consumption recorded by embedded IoT sensors, which can be used to construct predictive models of overwintering adapted to local climatic conditions and current sensor readings.

First, fondant feeding induces a predictable metabolic thermal response of the honey bee colony inside the hive. The parameters of this response, measured non-invasively by in-hive sensors and compared with ambient sensor readings, illustrate how the integrated temperature response can serve as a non-invasive indicator of colony strength. The amplitude and duration of the thermal response, expressed through the response index I, are likely to depend on the individual strength of the colony.

Second, winter colony strength can be quantitatively assessed by comparing sensor-derived parameters before and after fondant feeding. Our results suggest that a weak thermal response is associated with a weakened colony and an elevated probability of poor overwintering, whereas a strong response is characteristic of a stronger colony. Changes in the dynamics of the response following periodic fondant feedings may reflect changes in colony strength, either towards further weakening or towards recovery, and may serve as an early indicator of overwintering success or risk.

Third, whereas fondant has traditionally been used mainly as an emergency winter feed, the availability of in-hive IoT sensors and simple methods for assessing colony strength and tracking the dynamics of the thermal response suggests that fondant feeding can also be considered as a planned intervention aimed at optimally preparing colonies for spring crop pollination. Such a sensor-based approach has the potential not only to reduce winter colony mortality under climate change, but also to enhance the overall pollination service provided by honey bees.

The relationship between fondant, heat production, feed consumption, humidity and brood emergence is complex and dynamic. It requires larger sample sizes, observations over multiple winter seasons in different climatic regions and, where possible, additional sensors placed closer to the winter cluster with higher temporal resolution. We encourage other researchers and beekeepers to further develop this line of work to create new, effective overwintering practices based on sensor data and biological colony responses, which are increasingly needed under changing climatic conditions.

Declarations

Competing interests:

I. Kurdin is the inventor of a patented honey bee diagnostic system in hives (Patent UA133650), which is cited in this article. The authors declare that they have no other relevant financial or non-financial interests to disclose.

Ethics approval:

No approval of research ethics committees was required for this study because it involved an unregulated invertebrate species (*Apis mellifera*) and non-invasive procedures that did not cause pain, suffering, distress or lasting harm. This article does not contain any studies with human participants or vertebrate animals performed by any of the authors.

Consent to participate:

Not applicable.

Consent to publish:

Not applicable.

Compliance with ethical standards:

All authors have read, understood, and have complied, as applicable, with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors.

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Author Contribution

IK and AK conceived and designed the study. Material preparation, data collection and analysis were performed by IK. IK and AK jointly interpreted the results and revised the manuscript. Both authors read and approved the final manuscript.

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Data Availability

The time-series dataset (raw data, cleaning and imputation notes) and all scripts used for data processing and analysis are available on Zenodo (https:/doi.org/10.5281/zenodo.17371886).

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Figures



Figure 1

AmoHive smart hive 003 used in this study. This solar-powered unit, equipped with in-hive temperature and humidity sensors, ambient temperature and humidity sensors, and electronic hive scales, provided the hourly time series used to characterize the colony's thermal response to fondant feeding; Kyiv region, Ukraine, 2018–2019.



Figure 2

Thermal responses of *Apis mellifera* colonies to fondant during overwintering. ΔT = (T_in − T_out), where T_in is in-hive and T_out ambient temperature; "−5/+10 days" windows are relative to the feeding day.

(a) 31 Dec 2018 feeding elicited an immediate rise in T_in followed by gradual decay (~10–14 days) and a concomitant decrease in in-hive relative humidity; hive 003, Kyiv region, Ukraine, 2018–2019.

(b) 24 Feb 2020 feeding (first fondant feeding) produced a similar increase in T_in followed by a decline; hive 465, Toronto region, Canada, 2020.

(c) 1 Apr 2020 feeding (third fondant feeding) produced a similar rapid increase in T_in and gradual decline; hive 465, Toronto region, Canada, 2020.

(d) Strong colony (hive 465): difference between integrated ΔT areas before and after fondant feeding.

(e) Weak colony (hive 750): difference between integrated ΔT areas before and after fondant feeding.