Die Ergebnisse zur ChillingInjury zeigten eine 100 %ige Mortalität der Larven bei -4 °C und -10 °C bei einer Exposition von 1 und 2 Wochen. Nach einer einwöchigen Exposition bei
-4 °C und bei -10 °C lebten jedoch noch alle Puppen. Nach zwei Wochen bei denselben Temperaturen betrug die Mortalität der Puppen bei -4 °C 26,7 %, bei -10 °C 46,7 %. Es muss jedoch darauf hingewiesen werden, dass 71 % der Puppen bei -10 °C wohl durch Vertrocknung abgestorben waren, was sich durch die Untersuchungsmethode ergab.

Die Überwinterungsfähigkeit von *I. cembrae* im Larvenstadium muss nach den vorliegenden Ergebnissen kritisch betrachtet werden. Untersuchungen an *I. typographus* (Buchdrucker) zeigten, dass neben dem Entwicklungsstadium mehrere Faktoren, wie Diapausemanifestation, Darminhalt oder Kontaktgefrieren an feuchten Oberflächen (Bast) Einfluss auf die Überwinterungsfähigkeit haben. Darüber hinaus müssen Anpassungen hinsichtlich der Physiologie (Gefriervermeidung durch Einlagerung von Zuckern und Alkoholen) und des Verhaltens (Überdauerung des Winters in thermisch günstigen Bereichen, z. B. Boden) als entscheidende Faktoren für eine erfolgreiche Überwinterung von *I. cembrae* betrachtet werden.

Das Thema wurde im Rahmen einer Diplomarbeit bei Univ.-Prof. Dr. Axel SCHOPF erarbeitet.

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Thermoregulation and energetics of heterothermic insects in a variable environment – A heat exchange model of the honeybee

Thermoregulation und Energetik heterothermer Insekten in einer variablen Umwelt - Ein Wärmeaustauschmodell für die Honigbiene

A. STABENTHEINER & H. KOVAC

Heterothermic insects of the small size of honeybees have to cope with an enormous heat loss during foraging because they have to keep their body temperature high to stay ready for immediate flight and to promote fast exploitation of resources. The challenge is high because not only the ambient temperature but also (solar) radiation may vary in a broad range. In order to assess the energetic demand of foraging bees under variable ambient temperatures there have been attempts to measure flight metabolism in the shade. During a foraging trip on many flowers or water sources, however, honeybees are often not airborne for long periods of time (KOVAC & STABENTHEINER 2011). If weather conditions are fine they prefer foraging in sunshine to get additional heat from solar radiation. Depending on the type of reward solar heat may be invested to speed up foraging or to save costs (STABENTHEINER & KOVAC 2009, STABENTHEINER et al. 2012).

The balancing of body temperature regulation during foraging with the own energetic effort and heat gain from the environment to stabilize it is not well known. Simultaneous measurement of all these parameters in bees foraging from artificial flowers uncovered a relationship considerably more complex than expected. Therefore, standard models of heat exchange did not provide satisfying results.

We developed a model which accounts for the fact that in honeybees several parameters of the heat exchange process cannot be determined well enough experimentally. Total convection acting on a foraging bee, for example, is not accessible well enough under field conditions. While it might be possible to measure wind and thermal convection directly, the exact heat loss via respiratory convection seems not easily accessible. The absorption of solar radiation and the heat exchange via long-wave infrared radiation is usually modelled by describing the insect body by standard geometrical shapes. In honeybees, body hairs, wings and variation of visual absorptivity influence radiative heat exchange considerably and make estimation uncertain.

Our comprehensive dataset allowed for the first time the direct verification of the accuracy of such an advanced model. We had measured the energy turnover (calculated from CO_2 production) simultaneously with body surface temperature (measured thermographically), ambient temperature (Ta) and global radiation of honeybees foraging sucrose solution from artificial flowers under very variable environmental conditions and rewards. The mean values (metabolic rate, body temperature, etc.) per foraging trip were compared with the values generated by the model for each stay. In the present stage of development the model allows estimation of energy turnover at about 6-7 mW (1 SD of residuals), at a variation (in measured data) of metabolic heat production ~ 4-85 mW, of Ta ~ 15-36 °C, and of global radiation ~ 5-1100 W m-2.

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Die Untersuchungen wurden im Rahmen der FWF-Projekte P 16584-B06, Body temperature and energetics of foraging bees and wasps; P 20802-B16, Energetics and thermoregulation of foraging wasps and bees; P 25042-B16, Respiration and thermal tolerance of insects durchgeführt. Projektleiter Anton Stabentheiner, Helmut Kovac

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