Self-adhesive ghosts

Kiel researchers publish comprehensive evolutionary biology study on attachment structures of stick and leaf insects

They live between leaves almost everywhere on earth, grow to between one and 60 centimetres in size, and are considered to be masters of camouflage: we are talking about stick insects and leaf insects (Phasmatodea). Their specialities include not only camouflage, but also the attachment pads on their feet, with special microstructures which enable them to grip a wide variety of surfaces. A research duo at Kiel University (CAU), with international support from Russia and Switzerland, has discovered that these attachment microstructures (AMS) are as diverse as the creatures themselves. The scientists have published the results of their evolutionary biology study in the Journal of the Royal Society Interface in London.

The first fossils of stick insects and leaf insects are dated from the Cretaceous period, approximately 126 million years ago. To date, approximately 3,000 species have been described, occurring on almost all continents – except for a few cold or temperate climate zones. In addition to their camouflage abilities, these herbivores have a remarkable grip on many surfaces, including leaves, bark, sand, soil, stones and even on glass. This is made
possible by the nature of their feet (tarsi): on each of the first four segments, which Thies H. Büscher from the CAU’s Zoological Institute examined more closely, there is a heel attachment pad. The fifth element has a toe attachment pad and two claws.

© Bruno Kneubühler

Stick and leaf insects use their tarsal attachment pads to adhere to different surfaces, even glass, as can be seen here with the Malaysian phasmid *Calvisia leopoldi*.

© Thies Büscher, Kiel University

The foot of stick and leaf insects consists of five segments (ta1-ta5). On the first four, there are the heel attachment pads (euplantulæ; eu), whose microstructures were investigated here. The fifth element has a toe attachment pad, the arolium (ar), and two claws (cl), which assist attachment. The image shows a tarsus of *Lamachodes brocki*.
Research results from the early 2000s only revealed smooth, plateau-type or big nub structures on the attachment pads of this order of insects. Through his comprehensive study, Büscher has expanded this repertoire to eight: “In addition to the three previously-known types, there are also flat, undulating, small nubs, maze-type and ridge-type structures. This diversity within an insect order is unusual – in flies, for example, the structures are quite similar, although this order includes many more species.” Thies Büscher is a doctoral researcher in the “Functional Morphology and Biomechanics” group led by Professor Stanislav N. Gorb. Insects – and especially phasmids – have always fascinated Büscher. Through Gorb’s expertise in nature’s adhesion mechanisms and Büscher’s fascination with phasmids, the biologists came up with the idea of investigating the attachment ability of these six-legged creatures within the framework of a doctoral thesis.

The tarsal attachment pads (euplantulae) of stick and leaf insects are known to possess a high diversity of attachment microstructures. In total, eight different principal patterns could be identified and incorporated in the mathematical simulation, such as the big nubs of Sungaya inexpectata, shown here greatly enlarged.

Büscher examined samples of over 130 species, sourced from museums and breeders. For this purpose, living specimens, those preserved in alcohol as well as dried stick and leaf insects were made available. In order to make the microstructures on the tarsi visible, Büscher took scanning electron microscope images of each sample in a dried state. Then Mikhail Kryuchkov (Department of Pharmacology and Toxicology at the University of Lausanne, Switzerland) developed a mathematical simulation of all patterns, supervised by Professor
Vladimir L. Katanaev (Department of Pharmacology and Toxicology at the University of Lausanne, Switzerland, and the School of Biomedicine at the Far Eastern Federal University in Vladivostok, Russia), with the help of Alan Turing’s reaction-diffusion model. The model served to theoretically explain the development of all attachment microstructure patterns found in phasmids. In this way, the researchers showed that the different structures can be formed by self-organisation, and can be transformed very easily in the course of evolution.

Evolution of the structures

“The results were very surprising to all of us. We had assumed that with the global prevalence of stick and leaf insects, there must be a phylogenetic context in the development of their attachment pads, so that closely-related species must have similar microstructures,” said Büscher. “However, we were able to demonstrate that the same structures in different species must have developed independently of each other. In doing so, we were able to identify a recurring pattern: specific attachment structures exist in specific phasmids, which occur in specific habitats. Phasmids which live on the ground often have nubby attachment structures. These are adapted to a wide range of rough surfaces.” In the case of smooth attachment structures, the properties are different: “Smooth attachment structures grip the best on smooth surfaces, such as those of leaves. The possibility of forming other structures through relatively simple mechanisms, namely the change in concentration of a chemical ingredient during the development of the attachment pad, could be a great advantage. In this way, the attachment structures could adapt quickly to the respective habitat,” summarised Büscher.

The team can only speculate about the exact properties and functions of some structures. Further research is aimed at clarifying which attachment microstructures are best suited for which surfaces, and what other properties (e.g. self-cleaning) they have.

PhD supervisor Gorb sees great potential in the research on adhesive pads of stick and leaf insects: “With the help of evolutionary research and biomechanics, we can better understand functional principles in nature in order to derive benefits for society in the future.” Büscher stressed the valuable advantages for business and industry: “By decoding the attachment principles of the phasmids and better understanding exactly how they work, we create new inspirations for developing surfaces with adhesive or anti-slip functions. These are useful for example in robotics, for constructing the arms of a robot in such a way that it can grip components by means of physical adhesion and release them again, without the component itself requiring an appropriate coating – just like with the stick and leaf insects do in their environment.”
Different attachment microstructures (top row) provide specific grip advantages in different ecological environments. For the mathematical model depicted here, the structures were simulated (second row). Using the reaction-diffusion model proposed by Alan Turing, the development of these patterns can be calculated based on the concentrations of two chemicals (bottom section) and the transition between the patterns can be simulated.
Contact:

Thies H. Büscher
Functional Morphology and Biomechanics, Gorb group
Zoological Institute at Kiel University (Special Zoology)
Telephone: +49 (0)431/880-4144
tbuescher@zoologie.uni-kiel.de

Professor Dr. Stanislav N. Gorb
Head of the Functional Morphology and Biomechanics, Gorb group
Zoological Institute at Kiel University (Special Zoology)
Telephone: +49 (0)431/880-4513
sgorb@zoologie.uni-kiel.de

More information:

Zoological Institute at Kiel University:
www.uni-kiel.de/zoologie/gorb

University of Lausanne, Switzerland:
www.unil.ch

Far Eastern Federal University in Vladivostok, Russia:
www.dvfu.ru/en

Farah Claußen
Press, Digital and Science Communication
fclausen@uv.uni-kiel.de
+49 (0)431/880-2148
Details