BioCombs4Nanofibers

Project BioCombs4Nanofibers

D2.1 Capture strategy of spiders

Reporting period	from	**01.10.2019**	to	**30.09.2020**
Report completed and released		**18.03.2020** **Anna-Christin Joel**		

1. Goals and Detailed Description

Overall goal: D2.1 is a public report on project web-site about capture strategy of cribellate spiders in comparison to other spiders and resulting consequences for the calamistrum.

How spiders catch prey and why their hind leg matters for this

Spiders can be found almost everywhere in the world. They are one of the most species-rich groups in the animal kingdom and important predators in an ecosystem. Though there are occasional reports of spiders feeding on vertebrates, the typical prey of a spider are insects. Most of them are captured by web structures, made out of the famous silk of spider.

Spider silk is produced in the abdomen of the spider and extracted from the spinnerets. The spinnerets are complex movable organs, which can be used to sew silks of different origin together to produce e.g. attachments to fix the web onto the ground or complex threads to capture prey (see for example Grannemann et al. 2019, Joel et al. 2015 or Wolff and Herberstein 2017). In contrast to Spider-Man, spiders typically cannot eject silk, but the silk has to be extracted, e.g. by attaching the silk to one spot and then moving in space. Some spiders can also grip fibers with their feet and thus extract the silk, others even have combs brushing over the spinnerets to extract the silk. Such a process of combing out silk is shown as a schematic in image 1.

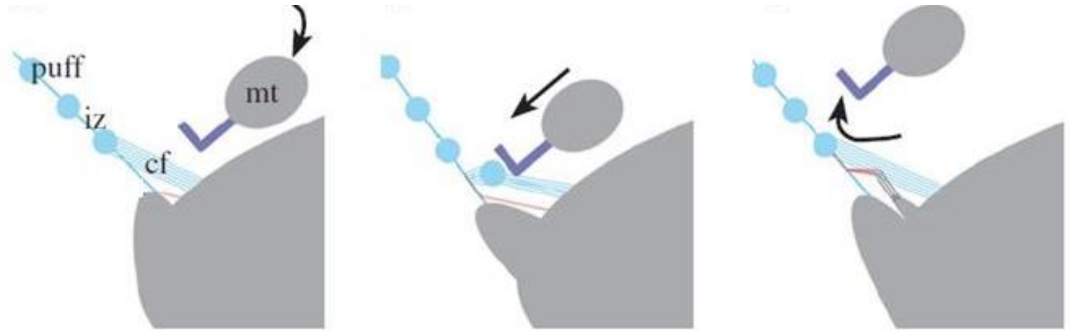

Image 1: Combing the silk by means of the calamistrum (adapted from Joel et al. 2015)

Image 2: Feather-legged lace weaver wrapping prey

Such a comb is found, for example, in cribellate spiders like the feather-legged lace weaver (image 2). Cribellate spiders have a special way to capture prey. In general, there are two main possibilities to produce sticky capture threads (image 3):

- Wet adhesion: So-called ecribellate spiders, which are the majority of the living species, cover their threads with viscoelastic glue droplets.
- Dry adhesion: So-called cribellate spiders, by contrast, use a wool of nanofibers as adhesive.

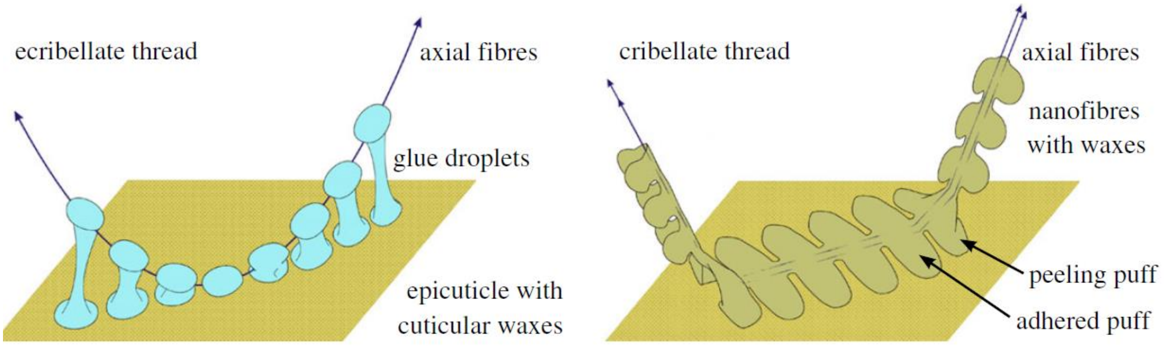

Image 3: Principles of catching mechanisms. Left: ecribellate spiders utilize glue droplets. Right: cribellate spiders use catch wool, i.e. a wool of nanofibres. (adapted from Joel et al. 2015)

In contrast to ecribellate spiders, for example the typical cross spider found in many gardens of Europe, which are using glue to capture prey, cribellate spiders are producing sticky nanofibers. These fibers stick to the prey not only by van der Waals forces, but also by soaking in the viscous waxes covering all insects (see Bott et al. 2017). Thus, the insects bring along their own glue to be captured as shown in image 4.

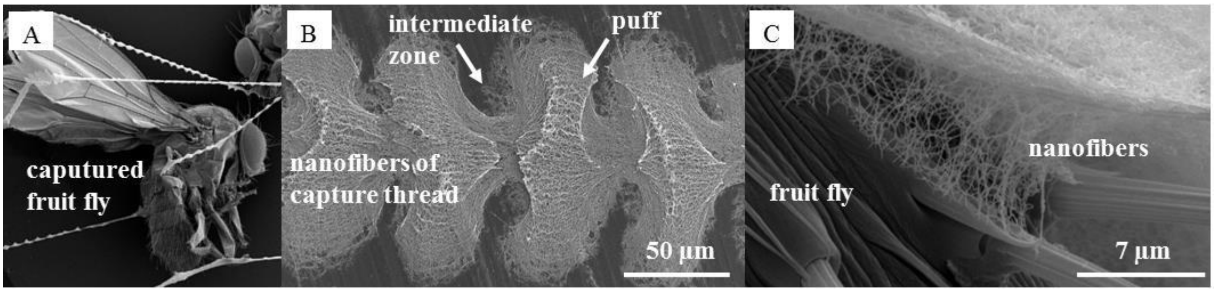

Image 4: Electron microscopy image of a fruit fly captured with nanofibrous capture wool of cribellate spiders (A), detail magnification of the capture threads formed as puffs (B) and the adhesion of the nanofibers, attracted to on the insect surface (C)

Cribellate spiders produce such a nanofibrous capture thread by extracting up to 40.000 10 to 30 nm thick fibers from the eponymous cribellum, a spinning plate close to the spinnerets.

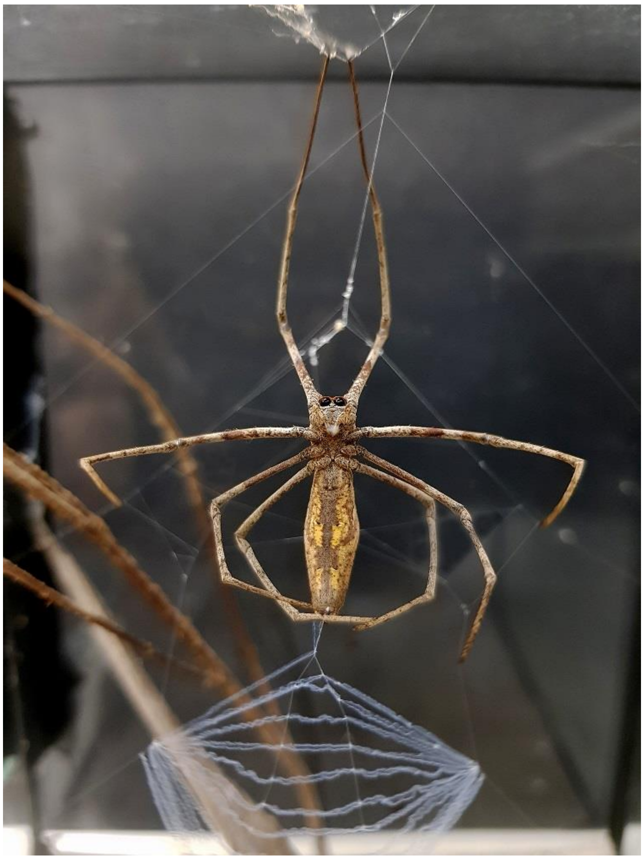

Image 5: Ogre-faced spider combing out silk for its web

To be able to handle such a bunch of extremely fine nanofibers, the spider uses a comb, the calamistrum, on its hindmost legs (image 5, image 6). For a long time, it was assumed, that the calamistrum is mandatory to extract the nanofibers. Recent studies, however, have proven the calamistrum to be more likely a manipulating tool and not necessary to extract the nanofibers (see for example Joel et al. 2015, Joel et al. 2016 or Michalik et al. 2019). The morphology (i.e. form and structure) of the calamistrum can differ between species. Whether these morphological differences result likewise in functional differences is unknown. Only for a teeth-like structure, found on the combs of the ogre-faced spider, it is hypothesized to facilitate a picking up of the fibers (see Joel et al. 2016).

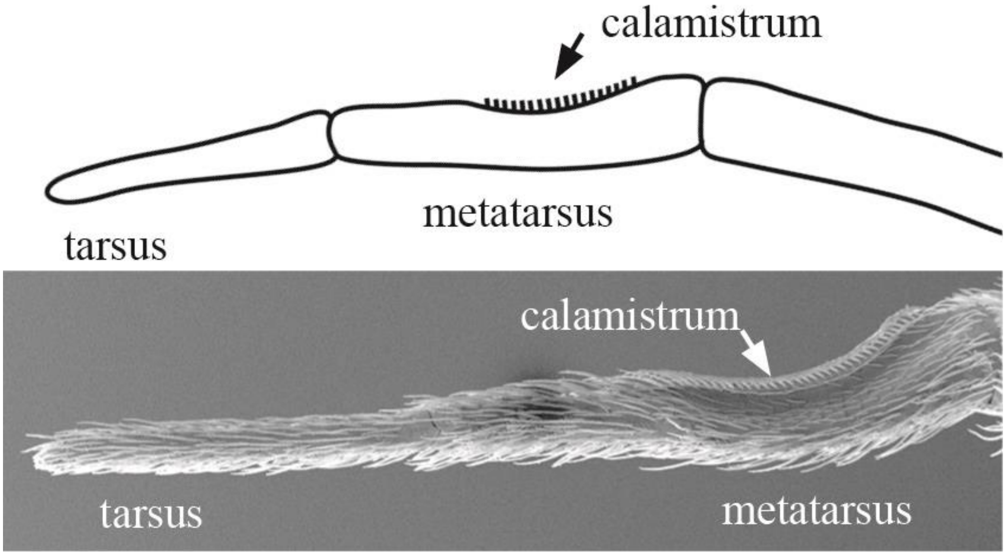

Image 6: Schematic drawing and SEM image of the hindmost (4th) leg of a cribellate spider.

Though the specific function of the calamistrum is still elusive, it has to have some special features. For example, it is non-adhesive towards the nanofibers. Thus, cribellate spiders can add their sticky capture spiral out of nanofibers to their nets, which interacts and captures the prey very effectively, without sticking to the spider itself. This non-adhesiveness cannot only depend on an adaption of the cuticle composition, avoiding the soaking in of viscous waxes, but also by a reduction of van der Waals forces.

The van der Waals forces (van der Waals interactions), named after the Dutch physicist Johannes Diderik van der Waals, are the relatively weak non-covalent interactions between atoms or molecules, whose interaction energy for spherical particles drops to about the sixth power of distance. Thus, according to current understanding, the van der Waals forces can be divided into three components:

- Keesome interaction between two dipoles (dipole-dipole forces).
- Debye interaction between a dipole and a polarizable molecule (dipole-induced dipole forces)
- London dispersion interaction (London forces) between two polarizable molecules (induced dipole-induced dipole forces). The London forces are often referred to as Van der Waals forces in the narrower sense.

All van der Waals forces are weak forces compared to covalent bonding and ionic bonding, with the dispersion interaction generally being the dominant of the three. The London dispersion interaction also occurs between non-polar microparticles (noble gas atoms, molecules), if they are polarizable, and leads to a weak attraction of these microparticles.

The principle is as follows: Electrons in a microparticle (atom) can only move within certain limits, which leads to a constantly changing charge distribution in the microparticle. As soon as the center of gravity of the positive charges is spatially separated from the center of gravity of the negative charges, one can speak of a dipole, because there are two (di-, from the Greek δίς "twice") electric poles. Single non-polar molecules can only be called temporary dipoles, because their polarity depends on the distribution of electrons, which changes constantly. (In polar molecules, on the other hand, the dipole property is permanent due to the electronegativities of the atoms and the spatial structure, which is why they are called permanent dipoles or dipoles in the narrower sense).

If two non-polar molecules come close to each other long enough (i.e. at low relative speed), they will interact electrostatically with each other. For example, if particle A shows its neighbor B a distinctly negatively charged side, the electrons of neighbor B (from the side facing it) are repelled. In this way, the dipoles align themselves with each other. Such a charge shift caused by an electric field is called an influence. This means that the negative pole of a temporary dipole inflates a positive pole opposite the neighboring molecule. In this way, particle B becomes an "influenced" dipole. In the technical literature this is called "induced dipole" (lat. inducere: (to) introduce). Between the original, temporary dipole and the induced dipole Van-der-Waals forces occur. From now on, the dipoles influence each other, their electron displacement synchronizes.

Hence, if two atoms or molecules get close enough, one of the following situations can occur.

- Two temporary dipoles meet: The particles attract each other.
- A temporary dipole meets a particle without a dipole moment: the dipole induces a rectified dipole moment in the non-dipole, which again creates an attractive force between the two particles.

Why the calamistrum is non-adhesive, i.e. why van der Waals forces are so small on this surface in contrast to other natural surfaces towards these fine nanofibers is still elusive and the clarification of these properties, as well as its technical abstraction for technical nanofiber processing, is the aim of the project **BioCombs4Nanofibers** (image 7).

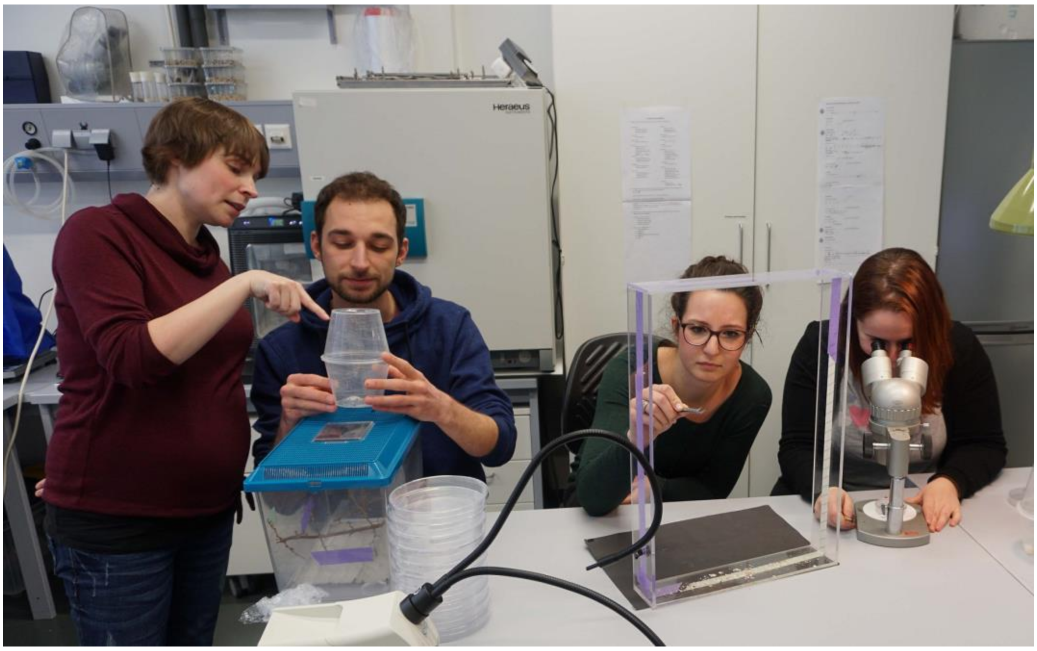

*Image 7: Junior Research Group “Spider Silk” at **RWTH** investigating spiders within the project **BioComb4Nanofibers**.*

Literature hints:

- Bott, R. A.; Baumgartner, W.; Bräunig, P.; Menzel, F.; Joel, A.-C., Adhesion enhancement of cribellate capture threads by epicuticular waxes of the insect prey sheds new light on spider web evolution. Proceedings of the Royal Society B: Biological Sciences 2017, 284 (1855), 20170363.
- Grannemann, C. C. F.; Meyer, M.; Reinhardt, M.; Ramírez, M. J.; Herberstein, M. E.; Joel, A.-C., Small behavioral adaptations enable more effective prey capture by producing 3D-structured spider threads. Scientific Reports 2019, 9 (1), 17273.
- Joel, A.-C.; Kappel, P.; Adamova, H.; Baumgartner, W.; Scholz, I., Cribellate thread production in spiders: Complex processing of nano-fibers into a functional capture thread. Arthropod structure & development 2015, 44 (6 Pt A), 568-573.
- Joel, A.-C.; Scholz, I.; Orth, L.; Kappel, P.; Baumgartner, W., Morphological adaptation of the calamistrum to the cribellate spinning process in Deinopoidae (Uloboridae, Deinopidae). Royal Society Open Science 2016, 3 (2), 150617.
- Michalik, P.; Piorkowski, D.; Blackledge, T. A.; Ramírez, M. J., Functional trade-offs in cribellate silk mediated by spinning behavior. Scientific Reports 2019, 9 (1), 9092.
- Wolff, J. O.; Herberstein, M. E., Three-dimensional printing spiders: back-and-forth glue application yields silk anchorages with high pull-off resistance under varying loading situations. Journal of the Royal Society Interface 2017, 14 (127), 1-11.

2. Evaluation of Goals and Resulting Actions

This report has been published as a public report in a long (PDF) and short version on the web-site of the **BioComb4Nanofibers** project (http://biocombs4nanofibers.eu). Additionally, a short version will be published on twitter and research gate as project update for our followers.

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Public Reports

Capture strategy of spiders (1,3 MB)

*Image 8: Screenshot of the Dissemination section of the **BioCombs4Nanofibers** web-site.*