From Webs to Wires: Unraveling How Humidity Transforms the Electrical Properties of Tarantula and Ghost Spider Silk

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Abstract. Spider silk has long been an evolution spectacle, possessing the tensile of steel and the elasticity of rubber. There are recent studies that show how humidity elicits different electrical resistance from spider silks. In this study, I investigated these different electrical responses from multiple species, the orb-weaver and tarantula spider. By employing self-designed acrylic test chambers and parallel resistance-measurement setups, I measured changes in electrical resistance from 10^{14} Ω down to 10^{6} Ω as relative humidity rose from about 30–40% to 90%. In general, my results revealed that (1)low humidity causes large fluctuations and high resistance values in the spider silks; (2) once the absolute humidity surpasses a certain value (ranging from 10–18 g/m³ depending on the species), then the electrical resistance of the spider and silk worms start to decrease steadily; and (3) the different spider species each showed unique humidity-resistance profiles. In particular, Smeringopus a (ghost spider) silk exhibited high sensitivity, while some species of tarantula spiders displayed different ranges of decline. These varying results hint at the prospect of different spider species having different variations in their silk protein structures and evolutionary adaptations. This study explores the notion of using spider silk as an biodegradable, high-sensitivity humidity-sensing material. Some future prospects could be the focus on expanding spider-silk databases to enhance species identification through their silks, and to develop novel biomaterials for humidity sensors with applications in cultural preservation, cold-chain logistics, and environmental monitoring.

Keywords: spider silk; humidity; electrical resistance; biomaterial; humidity-sensing material.

1. Motivation

From the acrobatic web-swinging feats of Spider-Man to the intricate corner webs we casually brush aside, spider silk has long sparked my imagination. Not only is pop culture interested in the strength of spider silk, actual research increasingly shows that this “secret texture” is no mere fictional marvel. Recent advances have brought the high tensile strength and dynamic electrical responsiveness into the realm of verifiable science (Chang, 1998; Liu et al., 2021). Indeed, the real-world applications of spider silk are expanding: its biomedical sutures, lightweight protective fabrics, and even advanced sensors are yet to be discovered.

In spite of these developments, our knowledge of how the electrical characteristics of spider silk vary with environmental conditions—especially humidity—remains lacking (Eden et al., 2011; Shehata et al., 2018). In this study , I fill up this knowledge gap by comparing spider silks from two ecologically diverse groups—tarantulas and ghost spiders (along with other species of orb-weavers)—to find out if different evolutionary pressures produce distinct humidity-resistance "fingerprints." By doing so, I want to find out if spider silk can live up to its pop-culture promise in a new setting: as a flexible, eco-friendly humidity sensor that can be used in areas like tracking the environment, preserving cultural artifacts, and creating new materials.

2. Literature Review

2.1. Synthetic versus Natural Humidity Sensors

Synthetic polymers, such as polyimide or polyvinyl alcohol (PVA), are common in traditional humidity sensors. Although these materials are efficient, their production can be costly, and their disposal could be ecologically malignant (Chung, 2001).

Research on natural alternatives—such as spider silk—whose protein structure offers both environmental compatibility and acute responses—has therefore become important (Bennett, 2010). In fact, hydrogel-based sensors have faster response times than

many polymer counterparts; however, they can erode and degrade at higher temperatures and in certain chemical environments (Chung, 2001). The potential to replace these synthetic films with spider silk, which is biodegradable and naturally abundant, has sparked a vortex of inquiry into silk's unique humidity-driven electrical properties (Eden et al 2011).

2.2. Composition and Electrostatic Behavior of Spider Silk

Spider silk is primarily made up of repetitive protein blocks that are rich in amino acids—especially glycine and alanine—forming both crystalline and amorphous domains (Lin & Thomas, 2008; Wasserman, 2021). This microstructure contributes to its remarkable mechanical strength and elasticity (Liu et al., 2019). The ability of spider silk to generate and hold an electric charge is less well understood.Studies reveal that spiders may spin electrified nanofibers (Thompson, 2015), a phenomena related with frictional charge or external electric fields. New studies show that humidity can either improve or change these charging characteristics when water molecules help charges to migrate or accumulate along the silk threads (Erica & Daniel, 2018). Such water-induced alterations in electrical conductivity imply that the sensitivity of spider silk to moisture may have both biological purposes—such as assisting to preserve web integrity—and possible uses in technology (Shehata et al 2018).

2.3. Effects of Humidity and "Supercontraction"

Rising humidity is well known to cause "supercontraction" in some spider silks, which results in axial fiber shrinkage of up to 50% of the original length (Liu et al., 2021). By reorganizing protein chains, this supercontraction changes mechanical characteristics as well as electrical resistance (Eden et al., 2011). Orb-weaver silks, often used in prey-capture webs, can help maintain tension or modify web geometry in humid conditions (Chang, 1998). Conversely, the silks of tarantula spiders may be less sensitive to moisture because their ecological demands, such as nest-building and egg-sac protection, differ (Chung, 2001). Recent experiments indicate that some orb-weaver silks experience a drop in electrical resistance by several orders of magnitude once humidity exceeds approximately 50–60% (Liu et al., 2019). Other species stay essentially inactive until higher humidity levels are reached. Knowing the species-specific "fingerprints" in these electrical changes would help to create new sensors based on natural supercontraction systems (Bennett, 2010; Eden et al 2011).

2.4. Linking Applications, Ecology, and Evolution

Scientists have started to investigate how much silk's humidity-responsive activity is impacted by environmenta conditions. For example, orb-weavers—which depend on completely functional webs for prey capture—face more selection pressure to preserve silk integrity in changing climates—perhaps resulting in increased electrical and mechanical reactivity to moisture (Chang, 1998; Jon & Scott, 2014). Tarantula spiders may display mild modifications, which would reflect a reduced reliance on aerial webs (Chung, 2001).

Cataloging these species-specific variations helps to create a "fingerprint library" of spider silks, which simplifies the identification of spider types through simple electrical testing at different humidity levels. Beyond taxonomy, using the environmentally motivated conductivity of spider silk could generate sustainable sensors for agricultural monitoring, biomedical tools, and preservation of cultural artifacts—areas that call for exact humidity control and environmentally friendly materials (Bennett 2010).

3. Hypothesis

Based on previous research and my knowledge on spider silk proteins, I posited that higher humidity would cause a major drop in silk resistance. Once relative humidity (RH) goes past a key threshold (~50-60%), the resistance of the biological filaments (spider silks) would start to drop significantly, a phenomenon likely tied to structural features and hydrophilic amino acid content. In addition, I hypothesized that different spider species would have distinct resistance sensitives and profiles. Each species may have their individual species-dependent threshold, the point at which their resistance starts dropping rapidly. This reflects differences in the different silks' molecular composition and their different evolutionary adaptations.

4. Materials and Methods

4.1. Spider Silk Samples

- Tarantula Silk: Sourced from nest/egg-sac silk of tarantula spiders (*Augacephalus breyeri*, *Chilobrachys fimbriatus*, etc.).
- Ghost Spider Silk: Harvested from web frame threads ofthe orb-weaver *Smeringopus pallidus*.
- Other Web-Building (Orb Weaver) Silks: This includes spiders such as Npehila pilipes, Leuauge magnifica, and more. All silks were collected with minimal handling and then sealed in containers to avoid early moisture exposure.

Working with specialists who can identify the different spider species, we collected spider silk from multiple spider species, such as the ghost spider, orb-weavers, and the tarantula spiders. For the Tarantula Spiders, I collected the likes of Augacephalus breyeri (Mozambique gold baboon tarantula), Chilobrachys fimbriatus (Indian cherry tarantula), Ephebopus murinus (Skeleton tarantula), and Ornithoctoninae sp. (various species) from outdoors and indoors.

For the Web-Building (Orb-Weaver Spiders), we collected the likes of Smeringopus pallidus (Ghost spider) (Figure 1), Nephila pilipes (Human-faced spider) (Figure 2), Trichonephila clavata (Horizontal-banded spider), Cyrtophora moluccensis (Spring clouded spider), Leucauge magnifica (Silver-bellied spider), Gasteracantha sauteri (Sauter's spiny spider), and Tetragnatha maxillosa (Japanese long-legged spider).

For the web-building spiders, we sampled the "frame silk", the silk used to anchor or form the main structural elements of the web. For the tarantula spiders, I collected the nest and/or egg sac silk. I collected the silks using a custom spider-silk collector, put them under the microscope (Figure 3) to observe the details, and then placed them on an acrylic carrier I designed for the experiment (Figure 4).

Figure 1. Smeringopus pallidus (Ghost Spider)

Figure 2. Nephila pilipes (Human-faced Spider)

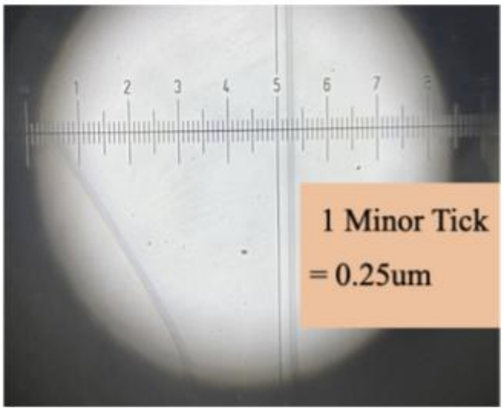

Figure 3. Ghost Spider Silk Under the Microscope

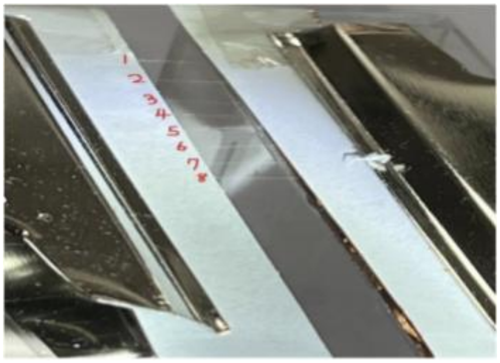

Figure 4. Eight Spider Silks on the Acrylic Spider Silk Carrier

Then,I decided on the research process(Figure 5).

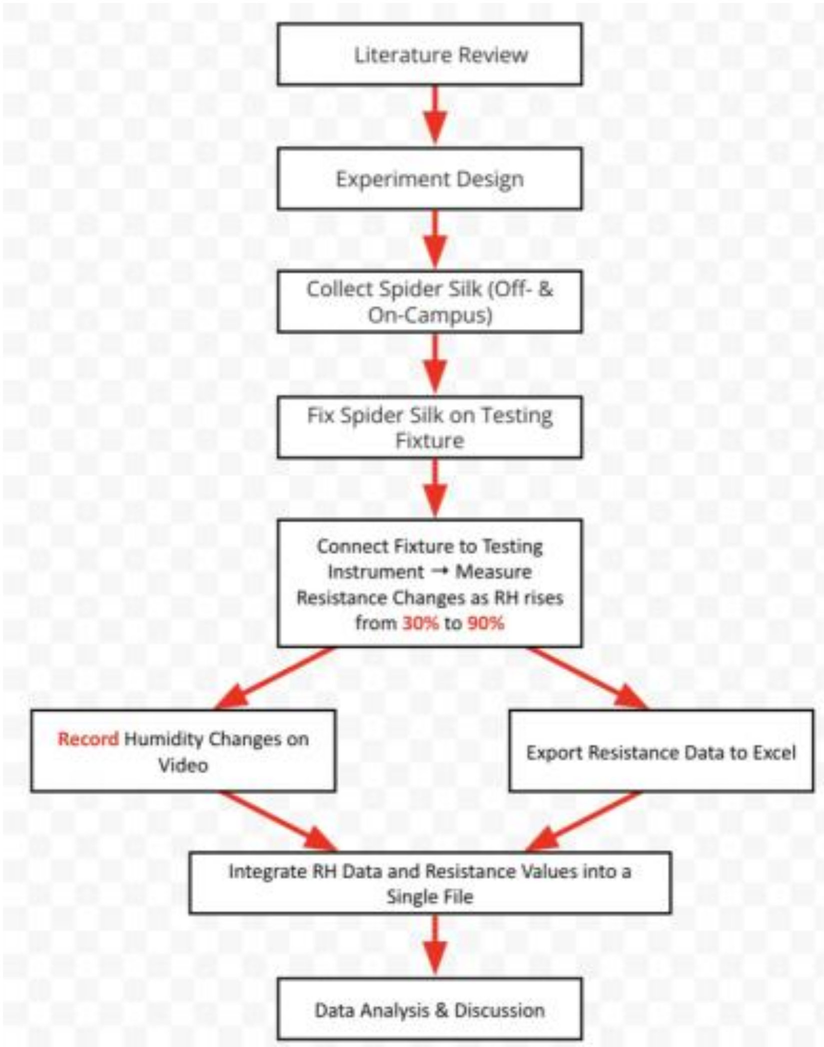

Figure 5. Experimental Flow

4.2. Experimental Setup

Acrylic test chambers (45 × 45 × 45 cm) were prepared and initially dehumidified (to ~30%) using commercial desiccants. A spray humidifier then gradually increased RH toward ~90%. A Hioki IM3523 LCR meter recorded resistance at one-second intervals, while a thermo-hygrometer (TES1260) monitored RH and temperature (kept above 20 °C). Each sample was clamped in parallel (4- or 8-strand arrays) on a custom acrylic holder lined with copper foil electrodes. The strands were around 4 cm each. However, the length of the strand between the copper foils was only 1 cm each. The copper foils were folded back on themselves to sandwich the filaments, allowing for the best electric conductivity.

To set up the experiment, I designed two acrylic devices, a humidity test chamber and the spider silk acrylic carrier. The first acrylic device is the humidity test chamber, where the testing box was 45 × 45 × 45 cm. I used the boxes to conduct humidity control (Figure 6). In order to do so, there were (1) spray humidifiers, which raised the humidity from ~30–40% to ~90%; (2) a desiccant to reduce the humidity to ~30–40% before each test; and (3) a heating bulb and air conditioning to keep the temperature above 20 °C.

In addition, I designed a spider silk acrylic carrier, as illustrated in Figures 6 and 7, that would hold eight filaments in parallel. Each filament was secured on each side by two copper-foil strips, which were secured by dovetail clamps as seen in the aerial view of the carrier in Figure 8. The parallel alignment was deliberate, as it reduces overall electrical resistance to a more measurable range.

For the testing and measuring process, I created an elaborate arrangement of the testing chamber, spider silk carrier, and the measuring devices as illustrated in Figure 9. To ensure the most accurate measurements, I utilized (1) a resistance test device (Hioki IM3523 LCR), which allowed a continuous resistance data collection; (2) a thermo hygrometer (TES1260), which measured the temperature and humidity; (3) a humidifier to enhance humidity; and (4) the spider silk carrier as the Figures 7 and 8 have shown. One data point was recorded every second for 30 minutes at a time.

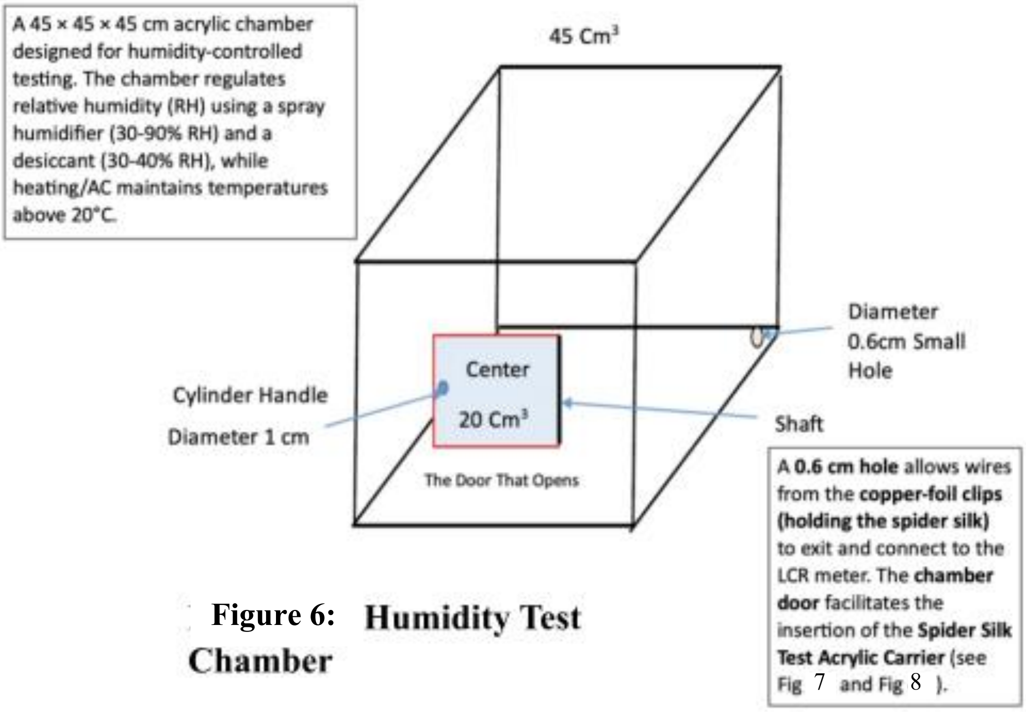

Figure 6. Humidity Test Chamber

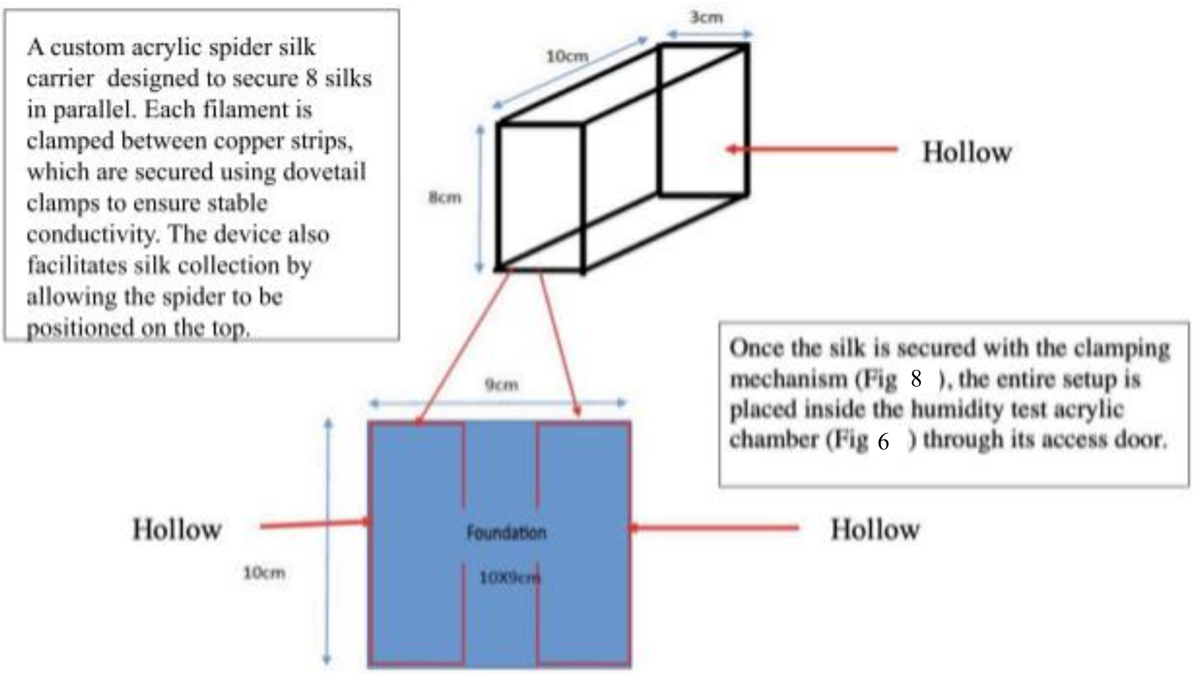

Figure 7. Spider Skill Acrylic Carrier

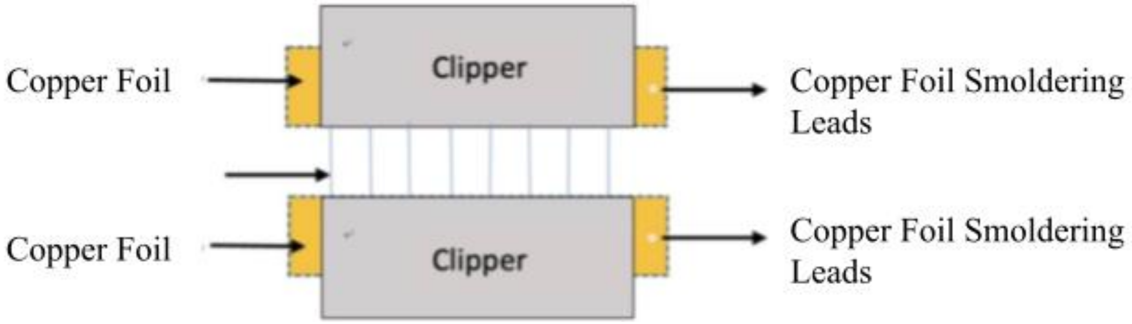

Figure 8. pider Skill Acrylic Carrier (Aerial View)

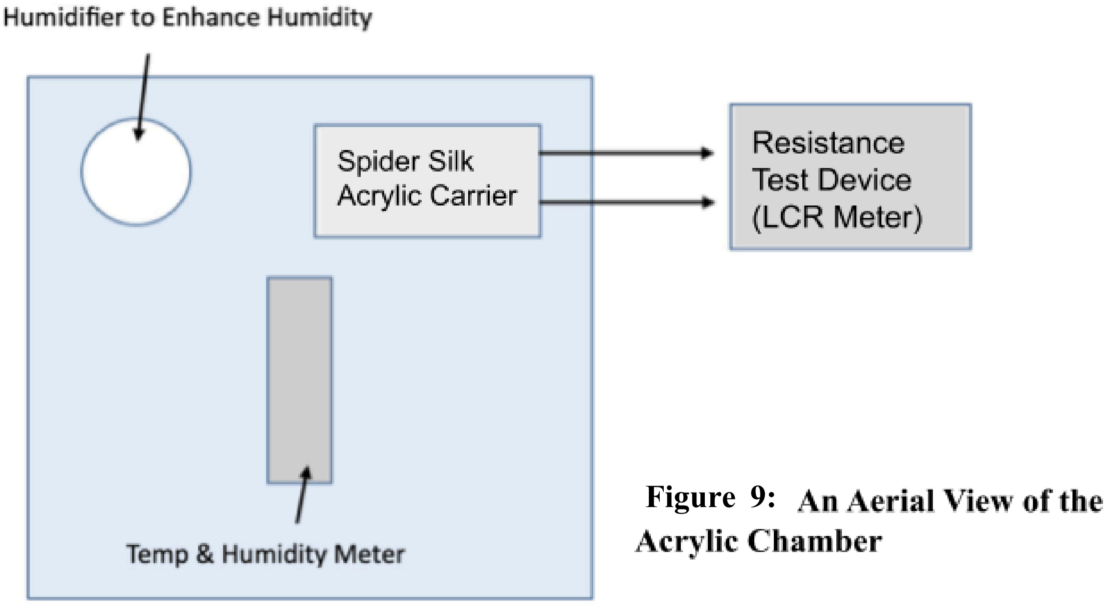

Figure 9. An Aerial View of the Acrylic Chamber

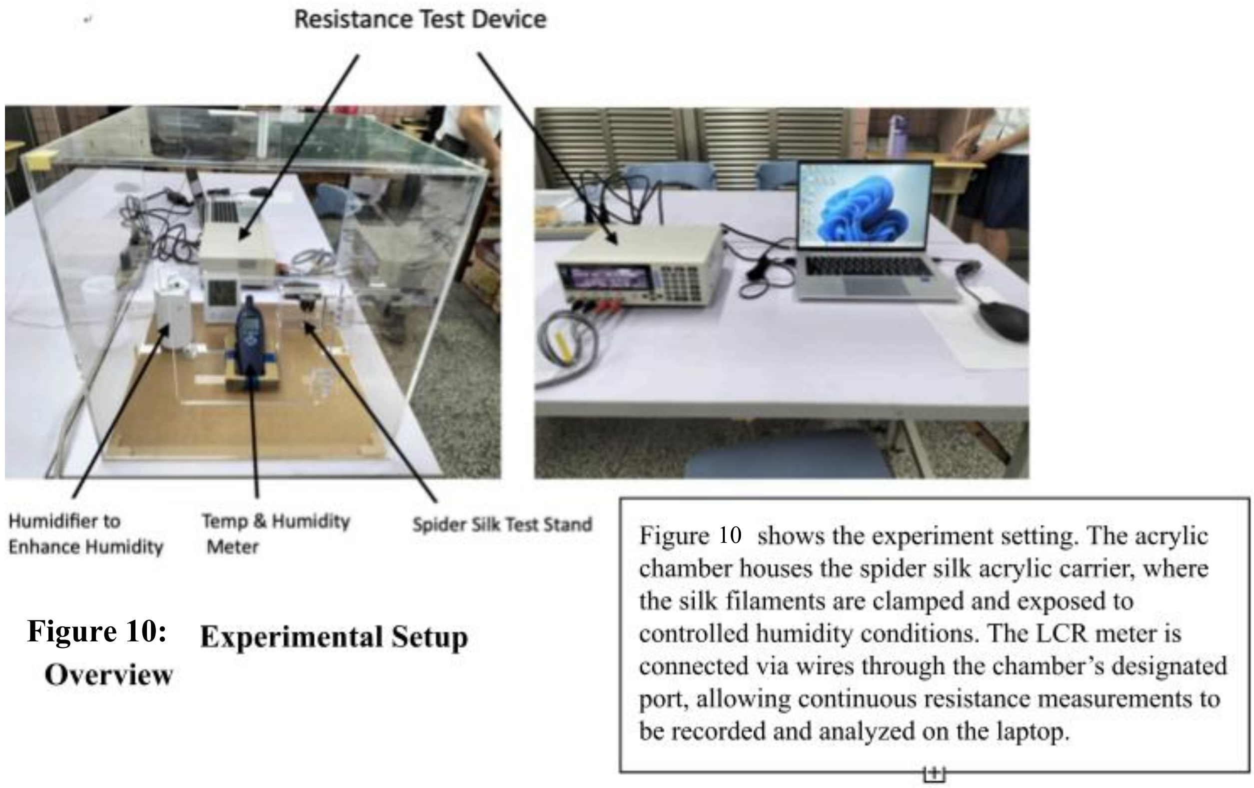

Figure 10. Experimental Setup Overview

4.3. Data Collection and Analysis

1. Low-Humidity Baseline: Chamber dried to ~30% RH.
2. Humidification: A humidifier steadily raised RH toward 90%.
3. Data Processing: The logged resistance values (Ω) were analyzed in spreadsheet software; raw data were converted to log-scale (log R).
4. Comparisons: The onset humidity for a stable decline in resistance and the magnitude of final drops (~90% RH) were compared between tarantula and ghost spider silks.

First, I collected the biological filaments needed for the experiment. To do so, (1)I collected the silks for the respective spider species and cut the silks to 8 strands; (2) affixed them parallelly onto the acrylic test carrier with copper foil and secured all the materials together with a clip; and (3) placed the carrier inside the acrylic test chamber and sealed the chamber.

Then, I controlled the humidity in the chamber by (1) inserting the desiccant to lower the RH to ~30-40% and (2) maintaining the temperature at > 20 °C by utilizing AC or light bulbs. After finishing the setup for the experiment, I proceeded to set up the laptop for data logging and the chamber for humidity control.

To control the relative humidity levels, I sprayed the humidifier until the RH increased from ~40% to ~90%. During this time, a video camera was set up for simultaneous humidity readings. Moreover, I connected the test carrier to the LCR meter and the laptop, where the data for resistance was logged at 1 point per second. Once the relative humidity reached 90%, I stopped the humidifier and data logging.

From thereon, the resistance data was exported to a spreadsheet, where the respective humidity levels for each data point was added. In addition, the filaments were immediately removed to test the diameter change.

The last step was to process all the data acquired from the trials. To do this, (1) I converted the raw resistance (Ω) to logarithmic form (log R); (2) I plotted log R against %RH (relative humidity) or absolute humidity (g/m^3) to control for temperature fluctuations; (3) I compared the humidity thresholds at which the silk's resistance began to decrease steadily; and (4) I identified the final minimal resistance near 90% RH (or ~25 g/m^3 absolute humidity).

5. Results

I conducted around 50 experiments (multiple individuals in each species), observing several key patterns in resistance changes under varying humidity conditions.

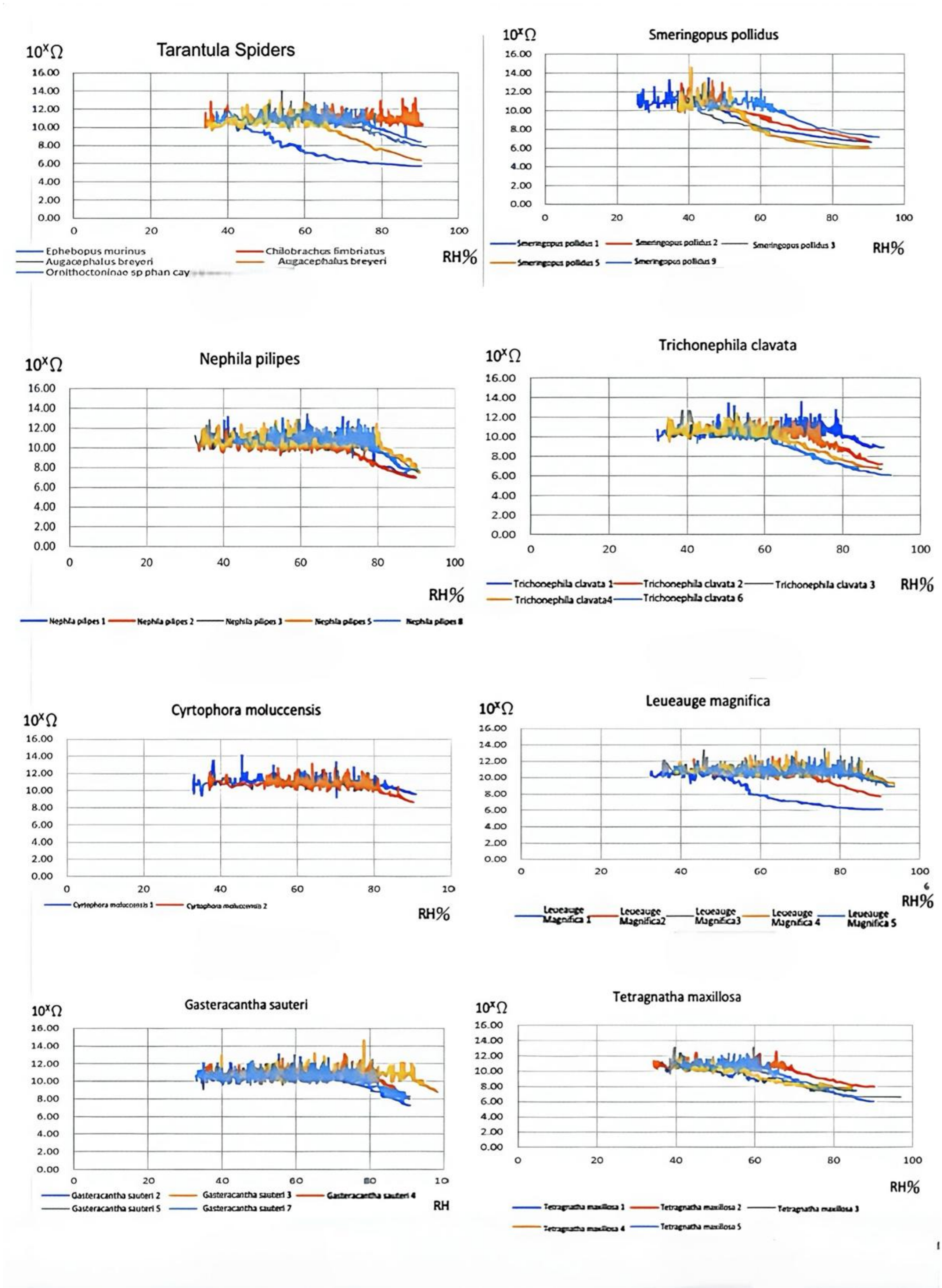

Figure 11. Experimental results of different spiders under various humidity conditions (a)

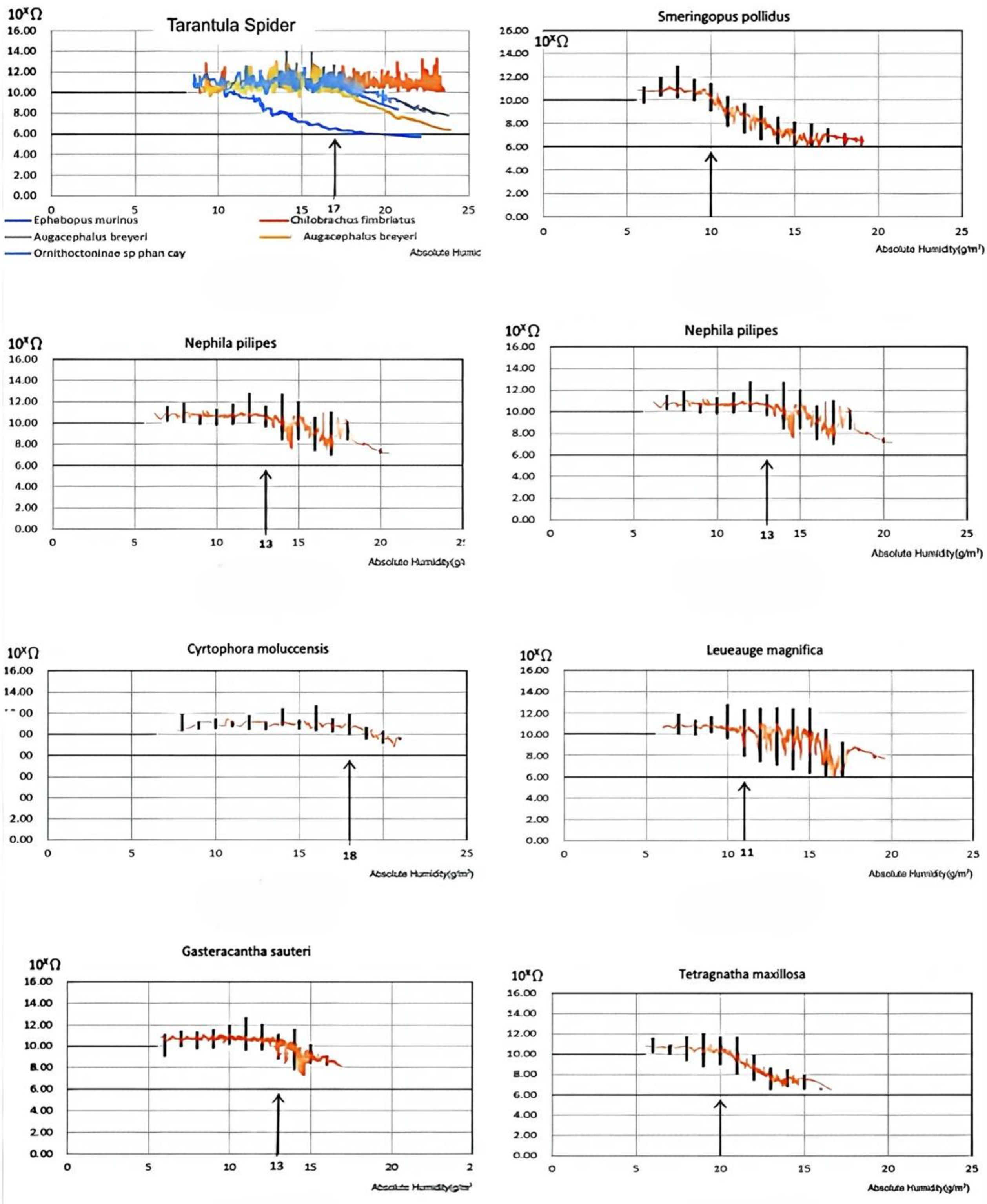

Figure 12. Experimental results of different spiders under various humidity conditions (b)

Fluctuations at Low Humidity

The resistance fluctuated significantly at low humidity levels (<50% RH). Across all tested filaments, at ~30–40% RH (<10 g/m³ absolute humidity), measured resistances remained extremely high (10^11 ~ 10^14 Ω) and showed large fluctuations. This suggests that protein-based fibers in dry conditions inherently exhibit electrical instability. Figure 12 illustrates how most spider silks retained resistance values above 10^10 Ω until RH exceeded 30-40% (absolute humidity >10 g/m³). Notably, *Chilobrachys fimbriatus* displayed no resistance drop, remaining stable even at higher humidity.

Species-Specific Thresholds for Resistance Drop

As humidity increased, the resistance began decreasing at species-specific thresholds. The following patterns were observed:

- *Smeringopus pallidus* (Ghost spider) typically exhibited a resistance drop at 45–50% RH (~10 g/m^3 absolute humidity). Figure 11 and Figure 12 highlight this behavior, showing a sharp decline in resistance at these thresholds.
- *Nephilapilipes* (Human-faced spider) required ~65% RH (~13 g/m^3 absolute humidity) before a stable decline occurred.Figure 11 and Figure 12 illustrate the resistance drop of *Nephilapilipes* after surpassing this humidity level. *Nephilapilipes* required ~65% RH (~13 g/m^3 absolute humidity) before a stable decline occurred.
- *Cyrtophora moluccensis* (Spring clouded spider) required an even higher threshold, an RH exceeding 75% (>18 g/m^3 absolute humidity), before resistance dropped significantly. Figure 11 and Figure 12 display this species' delayed response to humidity increases.
- The tarantula spider silks showed greater variation in their resistance drop, with some decreasing at 45% RH and others at 70% RH.
- *Smeringopus pallidus* (Ghost spider) and *Tetragnatha maxillosa* (Japanese long-legged spider) showed the widest resistance drop range, from 10^10 Ω to 10^6 Ω .
- Some tarantula silks, especially *Chilobrachys fimbriatus*, showed minimal response to humidity changes and maintained high resistance throughout.
- Different spider silks reached distinct final resistance levels, with some stabilizing at 10^6 Ω while others remained higher at 10^8 Ω, despite reaching 90% RH. Figures 11 and 12 collectively compare these variations in final resistance values across multiple species.
- Absolute humidity thresholds also varied among species. Some orb-weaver spiders exhibited stable resistance until absolute humidity exceeded 11–13 g/m^3 (e.g., *Nephilapilipes* and *Gasteracantha sauteri*). However, *Smeringopus pallidus* and *Tetragnatha maxillosa* exhibited the earliest resistance drop below 10 g/m^3 absolute humidity.

Effects of Filament Arrangement

The alignment of 8 parallel filaments had a significant impact on measured resistance. This arrangement lowered overall resistance, making it easier to track changes within the 10^6 ~ 10^9 Ω range. Conversely, silk samples with fewer parallel strands exhibited higher final resistances, highlighting the importance of configuration in these experiments. Figure 12 provides a real experimental setup image, showing the acrylic humidity chamber, LCR meter, and laptop used for data recording.

6. Discussion

Ecological and Biological Implications

The stark difference in resistance behavior between tarantula and ghost spider silk highlights species-specific adaptations. Ghost spider silk exhibits robust, early responses to rising humidity—a trait beneficial for ensuring web function under wet or humid conditions. Some tarantula and other orb-weaver species, by contrast, appear relatively inert until higher humidity is reached, reflecting different ecological needs and possibly different protein compositions (Spider Silk Chemical Structure, n.d..).

Prospects for Humidity Sensing

Spider silk's large, predictable drop in resistance within mid-range humidity offers promising avenues for environmentally friendly sensors. Synthetic sensors often rely on polymers requiring specialized fabrication and disposal (Chung, 2001). Spider silk is biodegradable, and orb-weaver silks in particular demonstrate reproducible, high-sensitivity responses—features that could be advantageous in museums (Bennett, 2010), greenhouses, and industrial humidity monitoring.

Future Directions

1. Expanded Species Pool: Testing other orb-weaver and tarantula spiders could validate the generality of these humidity-resistance patterns.
2. Protein-Level Investigations: Amino-acid sequencing or proteomic analysis may pinpoint the molecular basis of these divergent electrical responses (Shehata et al., 2018).
3. Hysteresis Studies: Determining whether silk exhibits a different response when humidity decreases may refine sensor calibration for real-world applications.

These experiments have shown us a few things.

(1) The species' individuality species-dependent threshold may be a result of evolutionary adaptations. Spiders in humid tropical areas may develop moisture-tolerant silk proteins, while arid-region spiders may have different protein structures for their silks. This reinforces the idea that each species' silk's amino acid composition (especially the hydrophilic sequences) vary significantly;

(2) Narrower silks (e.g., ghost spider) did not always show higher resistance. Ghost spider silks often reached lower resistance values at high humidity than thicker filaments (e.g., *Nephila* silks). This indicates that protein composite and molecular arrangement (e.g., primary structure, crystalline β-pleated sheets, hydrophobic vs. hydrophilic domains) may influence electrical resistance more than geometry alone;

(3) The filaments exhibited instability at low humidity. In general, all of the spider silks tested had sharp fluctuation in the 30–50% RH range. Additional experiments where humidity decreases rather than increases (from 90% to 30%) might confirm whether hysteresis or supercontraction significantly affects the measured values. However, due to logistical constraints, as hours of desiccation are needed for RH to return from 90% to 30%, I was limited to "increasing humidity" tests;

(4) The results show that the silks have the potential for species identification. By plotting logR vs. absolute humidity for multiple individuals from each species, we drive basic profiles or "fingerprints" based on the humidity-resistance transitions. With more data and an established database, identifying spider species from a stray silk sample could manifest into reality – an approach that could help biodiversity surveys or even in forensic contexts.

7. Conclusion

Comparative tests of tarantula versus ghost spider silk reveal that:

- Ghost spider silk begins a pronounced resistance drop around 50% RH and stabilizes near 10^6–10^7 Ω at 90% RH.
- Tarantula silk frequently remains above 10^10 Ω until higher humidity (~65%), showing less drastic reductions even at 90% RH.

These findings underscore the ecological underpinnings of spider-silk humidity responses and highlight the potential for orb-weaver silk to serve as a biodegradable, highly responsive humidity sensor. Continued research could map further spider species into a "humidity-resistance database," advancing both ecological insight and green sensor development. This research opens up a new direction of investigation into the composition of spider silk that could unlock deeper insights into how molecular structures govern humidity-induced conductivity changes. By sequencing and analyzing spider silk DNA, scientists can identify key amino acid sequences responsible for moisture sensitivity and supercontraction. This knowledge could pave the way for bioengineered silk with enhanced conductivity and tailored humidity responses, revolutionizing the development of natural, high-performance materials.

In essence, (1) the biological filaments have high sensitivity to humidity. From ~30–90% RH (or 10–25 g/m^3 absolute humidity), spider silk resistance can drop by up to 10^8 Ω; (2) each spider species show a distinct species-dependent threshold, as the species all have different "onset humidity" for a steady resistance decline. This difference is reflected in the varying amino acid composition and morphological structures of the spider silk; (3) these biological filaments hold promise for eco-friendly sensors. Spider silk's natural abundance, biodegradability, hypoallergenicity, and antimicrobial property makes it a strong candidate as a sustainable sensor, outclassing many synthetic polymers in sensitivity; and (4) this study shows the vast prospective impact that spider silks possess. Future technology could utilize spider silk for humidity detection for (1) cultural heritage preservation, as monitoring humidity (keeping it between 45-64%) is crucial to protect artifacts; (2) cold-chain logistics, as a stable humidity and temperature is important for perishable goods; (3) biomedical devices, since the spider silks may conduct real-time monitoring and actuation for humidity-sensitive biomaterials; and (4) environmental monitoring and forensics, as being able to rapidly classify spider species protect the ecosystem and the silks can serve as local climate indicators as well. By advancing my understanding of how and why spider silks differ in electrical properties across humidity conditions, this work paves the way for new biomaterials research and potentially transformative sensing technologies.

8. Future Prospects

From the data and analysis I have collected from this experiment, there seems to be a couple of different future prospects that can come from spider silks. (1) These biological filaments (like spider silks) can be used in the context of species identification and forensics. Once more spider species and their silks samples are compiled in an established and vast database, then a comprehensive library of humidity-resistance curves could be derived to refine spider-silk and species classification; (2) the database could be used to conduct protein analysis. Through biochemical assays (e.g., amino-acid sequencing, proteomic analysis), specific molecular structures could be linked to observed electrical behaviors; (3) the spider silks could be used to investigate the effects of alternating humidity (either increasing or decreasing) to understanding potential hysteresis and supercontraction recoverability; (4) there is vast potential for industrial prototypes. The spider silks could be used to develop humidity sensors, which could then be used in real world conditions (e.g., museum displays, greenhouse agriculture) to assess its reliability, durability, cost-efficiency, and environmental friendliness; and (5) there are potential genetic and synthetic approaches. The results from the study could allow scientists and engineers to explore either genetically engineered or artificially spun spider silks to tailor to conductivity, mechanical strength, or response speed. This could amplify and improve the already-impressive performance and characteristics of natural spider silk and provide new pathways for commercial-scale production. Through these results, spider silk (or other protein-based filaments) could transform into the cornerstone of future eco-friendly sensor solutions, combining nature's genius and its potential to advance human technologies.

Advancements in genetic engineering could enable the creation of bioengineered spider silk with optimized properties for diverse applications. By deciphering the genetic blueprint of spider silk, researchers could selectively modify its protein structure to enhance its electrical response to humidity. This could lead to the development of sustainable, biodegradable electronics, reducing reliance on synthetic polymers. As these bioengineered materials evolve, spider silk could redefine the future of eco-friendly conductive materials, offering scalable solutions for flexible sensors, electronic textiles, and next-generation biomaterials.

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