Effect of Temperature on the Tensile Strength of Golden Orb Spider Webs

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Honors Research in Biology B1

INTRODUCTION

Since ecosystems were first studied, climate and weather conditions have been known to play a pivotal role in the survival and physical adaptions of wild animals. Temperature, especially, is considered a key factor when explaining fluctuations in metabolic and growth rates in a multitude of animal species. For example, thermal stress can affect the swimming and climbing activity of glass eels, or it may induce defensive and antipredator behavior in certain snake species [1] [2]. Not surprisingly, this phenomenon also applies to spiders.

In previous experiments, there have been research conducted on the effect of temperature on the reproductive rate and hunting performance in female crab spiders [3]. Another study attempted to analyze the toxicity of venom in Black Widow spider when the creatures are exposed to higher levels of temperature [4]. Similarly, one research group decided to determine the heat tolerance of Brown Recluse Spiders to explore possible future improvements in pest control [5]. Unlike its precedent, this study aims to focus on the effect of temperature on spider webs rather than the creature itself.

Commonly, spider webs are known for being the strongest and the most elastic material found in the natural world. On average, web elasticity can range anywhere from a low 20% to an abnormally high 400% [6]. This durable material is surprisingly only composed of a non-sticky scaffolding made of ampullate silk gland fibers and are embedded under web droplets that are secreted by the aggregate glands in the spider. Spiders, who are often territorial creatures, usually stay in one location so they are observed to consume their webs to make space for new ones. This process is known as web recycling and is also a survival technique when the food source is relatively low [7]. The protein and lipid content within the web can be digested by the spider in order to provide it with energy to form a new web. Evidently, the web building process in spiders have evolved to a degree where it has become an advantageous cycle that is optimal to ensure the spider's survival. One species of the orb-web spider family (spiders whose web

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[1] Elizabeth D. Linton, Bjarni Jonsson, and David L. G. Noakes, "Effects of Water Temperature on the Swimming and Climbing Behaviour of Glass Eels, *Anguilla* Spp.,"
[2] Jessyca Michele Citadini and Carlos Arturo Navas, "Inter-Individual Variation and Temperature-Dependent Antipredator Behavior in the Snake *Tomodon Dorsatus* (Dipsadidae),"
[3] Victoria R. Schmalhofer, "Impacts of Temperature, Hunger and Reproductive Condition on Metabolic Rates of Flower-Dwelling Crab Spiders (Araneae: Thomisidae),"
[4] Blerina Vrenozi, "Venomous Spiders of Albania -Does an Increase of Temperature Influence the Toxicity of Spider Venom?,".
[5] Kenneth L. Cramer and Lindsey M. Zagar, "Heat Tolerance of the Brown Recluse Spider (Araneae: Sicariidae): Potential for Pest Control,".
[6] "The Elasticity of Spiders' Webs Is Due to Water-Induced Mobility at a Molecular Level," *Proceedings of the Royal Society of London. Series B: Biological Sciences*.
[7] Mark A. Townley, Edward K. Tillinghast, and Christopher D. Neefus, "Changes in Composition of Spider Orb Web Sticky Droplets with Starvation and Web Removal, and Synthesis of Sticky Droplet Compounds,".

follow an orb pattern) can be found in most climates and continents. They are commonly known as the golden orb-web spider and are scientifically named: *Nephila pilipes*.

Being one of the strongest natural material, spider webs have been proposed as a prospective source of textile fabric. Thus, optimizing the quality of spider webs is the key challenge that must be explored first. As temperature has been observed to be a direct factor that influences the composition and structure of many organic material, this study aims to observe the effect of temperature on the strength of spider webs in order to maximize its potential in replacing other less environmentally friendly or weaker fiber in the textile industry. One common method to examine the strength of fibers in clothing businesses is to conduct a tensile test, an assessment that measure the maximum amount of weight that can be added to a material before its breaking point. Only recently, tensile tests were performed on spider webs using advanced robotic instruments with 75 mg tension weights [8]. Thus, the objective of this experiment is to determine the tensile strength of the webs of *Nephila pilipes* when the temperature is adjusted.

Methods

The key material of the experiment were the spiders. Although multiple trials were conducted during the experiment, the sample size of spiders needed to be sufficient to be able to represent the population. Furthermore, spiders captured from the wild die at an unpredictable rate due to their inability to adjust to the new environment. Therefore, I purchased a total of 12 golden orb-web (scientific name: *Nephila* pilipes) spiders from Tunghai University, whose team specializing in spider research provided me with. They extracted the spiders from the mountain ranges in Taichung, Taiwan.

The spiders had been placed in individual enclosures (70 cm x 70 cm x 20 cm) made of Styrofoam and see-through nets since capture. They were placed next to each other in a school laboratory that usually maintained a temperature of 23 degrees Celsius. The team from Tunghai University also provided mealworms, a common diet for members of the orb-web spiders. To feed them, I secured one mealworm onto the nets in the spider's enclosure once at the same hour every 2 days.

Their unstable diet and their inability to successfully adapt into the lab environment resulted in the spiders producing inconsistent webs and performing web recycling at irregular intervals. Webs were only extracted after the death and removal of the spiders from the enclosures. I stored the webs from each enclosure in separate petri dishes that were labeled 1 to 6.

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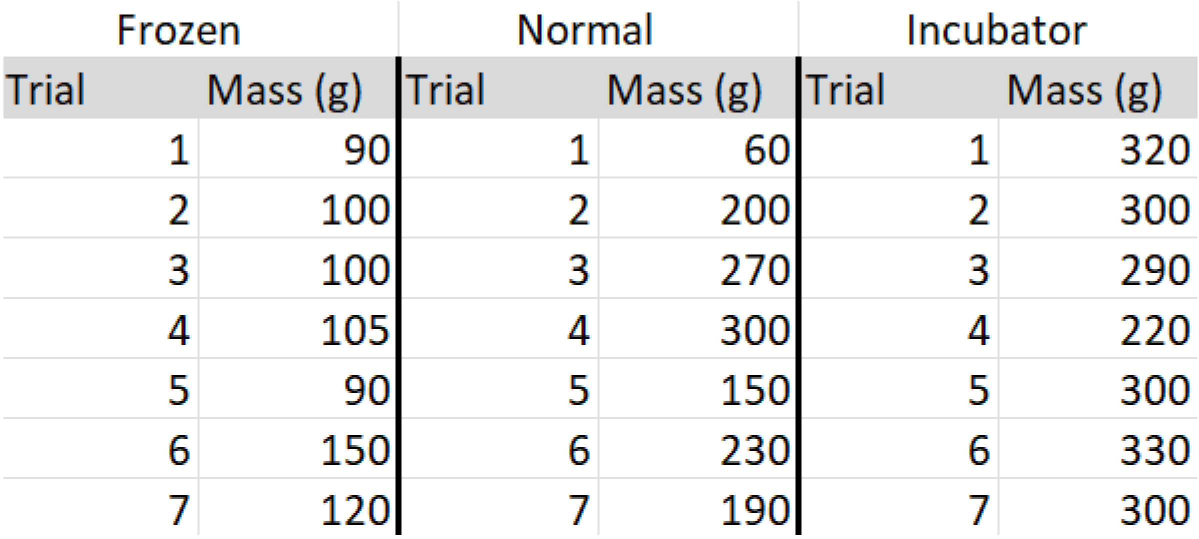
[8] "Intrinsic Tensile Properties of Cocoon Silk Fibres Can Be Estimated by Removing Flaws through Repeated Tensile Tests | Journal of The Royal Society Interface,".

Following this period of preparation, spider webs were dissected into individual strands, each 500 μm wide, using a sharp dissecting probe then stored in separate petri dishes in a way where the strands were not in contact with any surface of the plastic dishes. Each dish was kept in either the freezer (17°C), the room (23°C), or the incubator (30°C). After being treated at different temperatures for 48 hours, the dishes were removed and tested for their tensile strength. I added alloy hanging masses to the center of the strand in 5-gram increments until the strand snapped, at which the total mass applied was recorded as the tensile strength of that strand of web in grams. I conducted a total of 7 trials for each temperature treatment, indicating 21 total trials in total.

To further analyze the precision of the results, I also conducted tensile tests on webs with altered widths. Using the dissecting probe, webs were split into strands that were 50 μm , 100 μm, 275 μm, and 500 μm wide under a microscope. I then performed tensile tests on each strand, keeping them at room temperature (23°C) throughout this portion of the procedures. 5 trials were conducted for each width, and 20 trials were administered in total.

RESULTS

Temperature



Frozen		Normal		Incubator	
Trial	Mass (g)	Trial	Mass (g)	Trial	Mass (g)
1	90	1	60	1	320
2	100	2	200	2	300
3	100	3	270	3	290
4	105	4	300	4	220
5	90	5	150	5	300
6	150	6	230	6	330
7	120	7	190	7	300

Table 1: Data Table of Measured Tensile Strengths of Webs Treated at Different Temperatures

In Table 1, masses were added to webs treated at three different temperatures until breaking point (n=7). The mass in grams at which this occurred was recorded as the tensile strength for that trial.

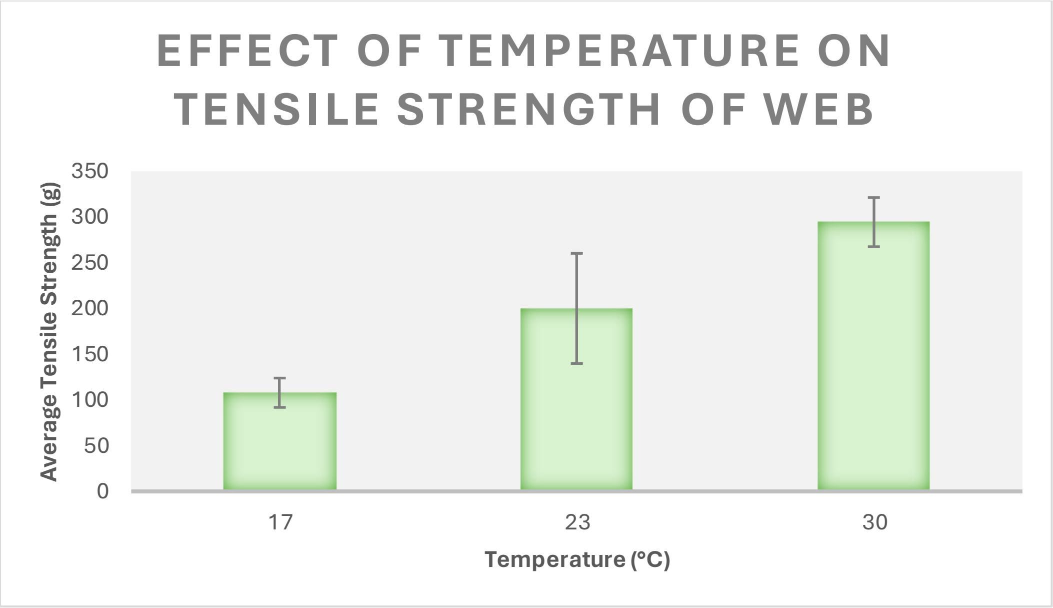


Figure 1: Graph of Average Tensile Strengths of Webs Treated at Different Temperatures

Data from each temperature treatment in Table 1 was averaged and visualized in Figure 1. The percent error of the trials can be observed on each bar in the graph.

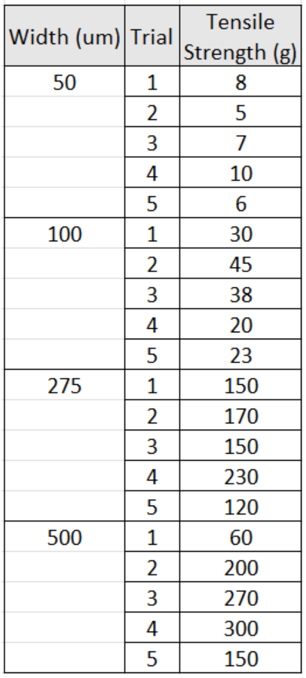
From both Table 1 and Figure 1, it could be observed that the spider webs stored in the incubator, which was at the higher temperature level of 30°C, performed best on average on the tensile tests. The average mass required to break each strand of this treatment group was 295 grams. According to Table 1, the data of the 7 trials in the incubator have tensile strengths ranging from 220 grams to 320 grams. This results in a standard deviation of 35 grams and a percent error of ± 13.4%.

At a room temperature of 23°C, the web strands had an average tensile strength of 200 grams. Of the 7 trials performed at this temperature treatment, the highest tensile strength recorded was 300 grams whereas the lowest was 60 grams. This large disparity between the data resulted in a standard deviation of 80 grams and a high percent error of ± 30.1%.

Finally, web strands retrieved from inside a freezer with a set temperature of 17°C performed worst with an average tensile strength of 105 grams. However, the data set for this treatment group was the most precise, with the maximum being 150 grams and the lowest being 90 grams. I calculated a standard deviation of only 20 grams and a percent error of ± 8.01%.

After completing my experiment on the effects of temperature, I also investigated the impacts of the width of the web strand. Each strand in the first experiment was approximately 500 μm wide, but I wondered whether variations would affect the precision and accuracy of the data, leading me to conduct a second experiment that focused on width.

Width



Width (um)	Trial	Tensile Strength (g)
50	1	8
	2	5
	3	7
	4	10
	5	6
100	1	30
	2	45
	3	38
	4	20
	5	23
275	1	150
	2	170
	3	150
	4	230
	5	120
500	1	60
	2	200
	3	270
	4	300
	5	150

Table 2: Data Table of Measured Tensile Strengths of Webs with Different Widths

In Table 2, masses were added to webs 50 μm wide, 100 μm wide, 275 μm wide, 500 μm wide until breaking point (n=5). The mass in grams at which this occurred was recorded as the tensile strength for that trial.

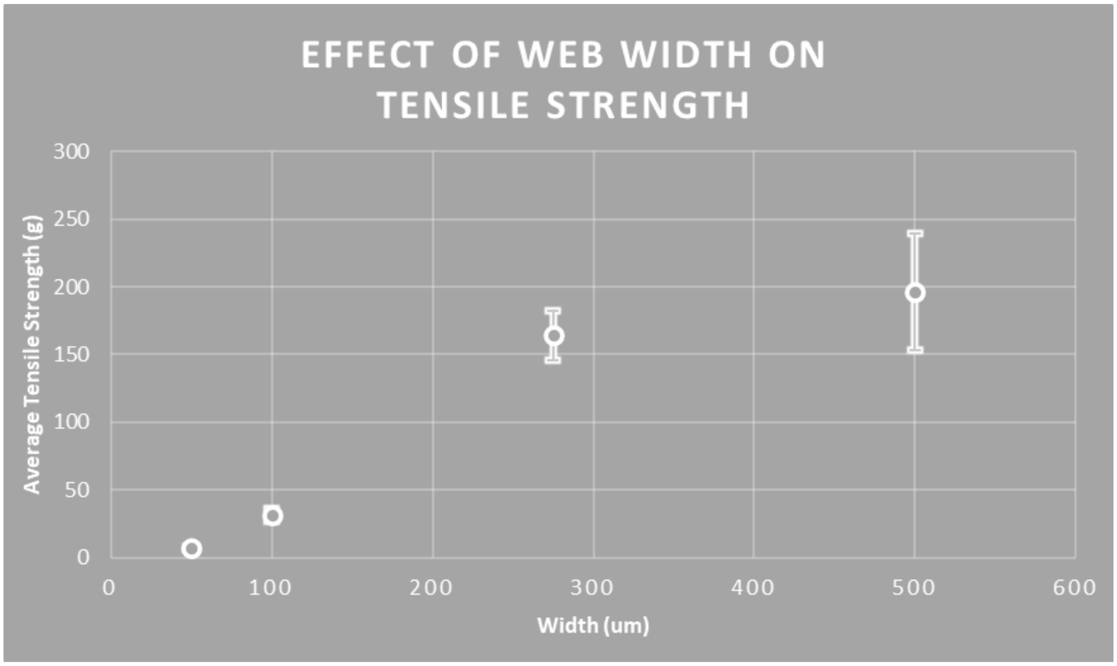


Figure 2: Graph of Average Tensile Strengths of Webs at Various Width

The average of each group extracted from the data in Table 2 is graphed in Figure 2 with their percent error bars.

As the width of the strands of spider webs increased, so did the average tensile strength.

The average mass required to break the 50 μm web strands was 7 grams. These 5 trials displayed a close range from 5 grams to 10 grams, with a standard deviation of 1 gram and a percent error of ± 0.86%. It should also be noted that at 50 μm, masses were added on at 1-gram increments rather than 5-gram ones.

At 100 μm, strands had an average tensile strength of 30 grams. The best tensile test in this treatment group recorded 45 grams while the worst recorded 20 grams. This could explain the standard deviation of 10 grams and the percentage error of ± 4.6%.

The average tensile strength of spider webs that were 275 μm wide was 165 grams. The standard deviation here is 40 grams and percentage error is ± 37%.

Finally, 500 μm wide spider web strands required an average of 195 grams to break with a standard deviation of 95 grams. There is a high percent error of ± 43%.

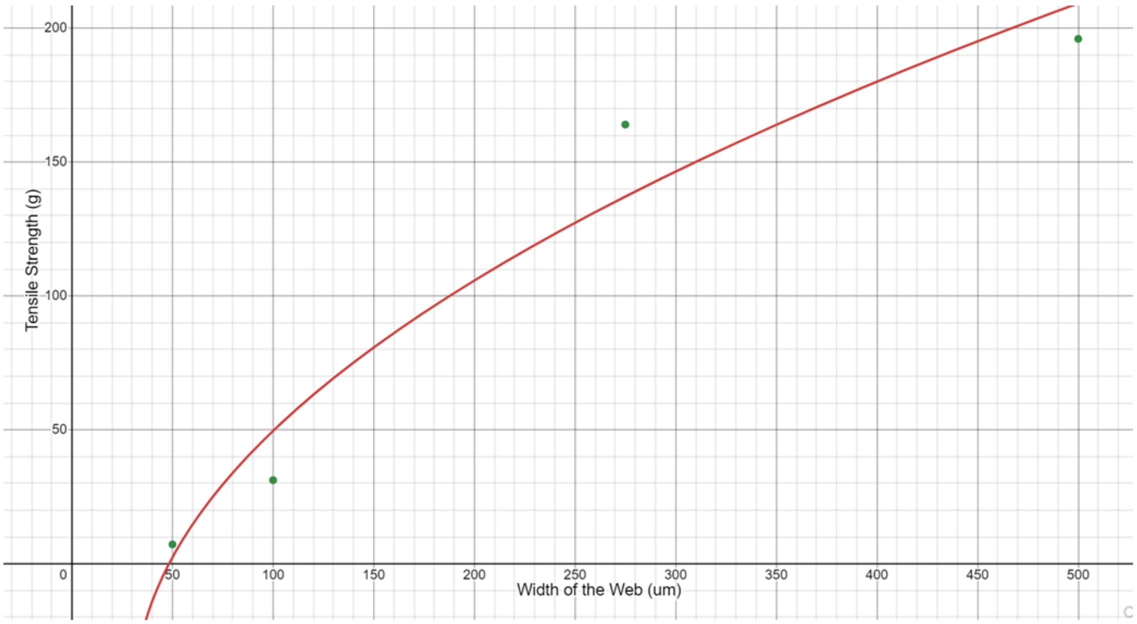


Figure 3: Correlation between Tensile Strengths and Width of Webs

Figure 3 is a graph produced on Desmos that displays the relationship between the measured tensile strength averages and the width of the spider webs according to the data collected in Table 2 that is also charted in Figure 2. The red line is the square root regression of the green plotted data points.

As illustrated in Figure 3, even though tensile strength does increase as width increases, the correlation between these two variables is not linear. In fact, the square root regression of the data points indicates that the equation between width, x, and tensile strength, y, can be described as $y = 7.06\sqrt{2.87x - 89.1} - 49.7$ with a R^2 value of 0.953.

Discussion

Optimal temperatures to cultivate *Nephila pilipes* spider webs are around 30 degrees or possibly higher.

Originally, I predicted that spider web tensile strengths would deteriorate at both higher and lower temperatures in comparison to room temperature. I assumed that the components of the web, such as the proteins within the web droplets that enable its sticky and stretchy nature, would denature at unnatural environments. However, the results instead demonstrate that the average tensile strengths of webs increase as the temperature increases according to Table 1 and Figure 1. Thus, this must imply that either spider web strength is enhanced at higher temperatures, or the natural environment of the spider is higher than room temperature.

Interestingly, at elevated temperatures, webs made from webworms (another insect that weaves webs) are more insulated and allow the creature to capture environmental heat in order to conserve its body heat [9]. Spiders may utilize their webs at warmer times in a similar fashion. If so, one explanation for the increase in tensile strength may be that the higher temperature induces fundamental modifications in the composition of the web for the purposes of allowing it to retain more heat while, at the same time, resulting in the web feeling more elastic and stronger.

For the latter theory, the Golden Orb Web spiders used in this experiment are extracted from mountains in Taichung, Taiwan, so any explanations deriving from the concept of natural environments must be corroborated with the climate conditions in that area. The average temperature at an elevated altitude in Taichung is around 18°C, but the temperatures can peak to the high-20 degrees range in the summer [10]. Since the experiments were carried out in November, this suggests a slight possibility that the spider web tensile strength may have optimized at around 30°C because it matched the climate in its natural habitat when the spiders were extracted.

As the width of the spider web increases, the tensile strength also increases, but at a nonlinear rate. Thus, width is a critical factor that may have affected the accuracy of the temperature experiment.

The scale at which the web widths are measured is so minute, it is easy to have fluctuations in the width of the web strands in the first experiment. Although it is assumed that all of the web strands in the temperature experiment are 500 μm wide, it is likely that there are many variations in the actual number. This may influence the accuracy of the first experiment, as the width variable is not completely held

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[9] B. G. Rehnberg, "Temperature Profiles inside Webs of the Fall Webworm, *Hyphantria Cunea* (Lepidoptera: Arctiidae):: Influence of Weather, Compass Orientation, and Time of Day,".

[10] Bruno A. Walther et al., "The Effects of Rainfall, Temperature, and Wind on a Community of Montane Birds in Shei-Pa National Park, Taiwan,".

control. Thus, to observe the quantitative effect width has on tensile strength, I determined the relationship between the two through regression on Desmos. The calculated equation indicates that even a deviation of 1 μm from 500 μm strands in the temperature experiment may have resulted in a 13-gram difference in the measured tensile strength. Thus, the precision of the first experiment may not be as accurate as initially thought.

In upcoming studies, other factors that play a role in determining the tensile strength of spider webs may be identified. Ultimately, optimizing every identifiable factor may be able to maximize spider webs' potential as a strong organic fiber. Integrating spider webs as a source of clothing, though, is another question altogether that may be possible only in the future.

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