Research on the Impact of Temperature on Spiders (Arachnida, Araneae)

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Abstract. Spiders, in the order of Arachnids, play a very important role in nature. As the rapid climate changes nowadays, spiders are likely to be affected by changing weather. There are lots of studies discovering the impact of temperature on animals. However, they left a lacking of knowledge about the potential influence of temperature on spiders. Therefore, this article aims to provide a comprehensive account to better understand the relationship between temperature and spiders throughout their lives. The impact on spiders' breeding was first described that the increasing temperature would increase the frequency of male mating behaviors, but the success rate of female mating was not determined as different results were got from two pieces of research. Secondly, the rising temperature could increase the fecundity and hatching rate of spider eggs. However, if the temperature continues to rise to a critical value, the spider eggs will stop hatching. On the other hand, the impact of temperature on spiderlings' development is not fully proven, but the temperature will cause an impact on spiderlings' behavioral development. The impact on the social structure and population of spiders might not be driven by a single factor, temperature. Further study on more different species is required to expand the discovery across the whole spiders' population. This article gives the reader an overview of the effects of temperature on spiders, especially reproduction, so that people can more easily and intuitively understand these different effects, and provide some perspectives and possible directions for future research.

Keywords: Spiders, temperature, mating process, spiderling development.

1. Introduction

Arachnids, as the most special kind of animals, resemble insects, but they are not insects. As in the classification of Arthropods, they contain more than 54,000 known species [1]. Spider is one of them and they have unique structures that make them one of the most successful animals in the world [2]. Spiders also play a very important role in nature. As a class of insect predators, they are extremely important in balancing the entire ecosystem. Especially in agroecology, spiders are even regarded as a potential way to control pests [3]. As the rapid climate changes nowadays, the changing of temperature and other factors like humidity could have a significant impact on nearly all organisms and their ecosystems. Spiders, under Arachnids, are no exception. In many ways, spiders are likely to be affected by climate change. As a type of creature that cannot regulate body temperature by itself, the temperature change is crucial and might even be life-threatening [4]. This has the potential to affect spider reproduction, spider survival, and even spider silk production.

Much research has been done on the impact of temperature on animals' behaviors. But most of the research was done on insects or fish, and the effects on spiders, especially their reproductive process, remain unstudied [5]. However, the characteristics and behavioral patterns of spiders are worth studying because these studies on spiders could provide more insight into understanding the complex behavior of Arachnida and may even help discover sexual selection [6-8].

This article aims to reveal the impact of temperature change on spiders' different life stages and the further impact on the population. The life stages of spiders could be divided into several parts. This article mainly focused on the impact of temperature on spiders' reproductive process, including changes in mating behavior, spawning and hatching, and early development, and the impact on spiders' adult stage.

2. Spider Breeding Process

2.1. Changes in Mating Behavior

The first and crucial step in the spider reproduction process is attracting mate and mating. Male courtship behavior and subsequent courtship success rate have a decisive impact on spider populations. The research on *Argiope bruennichi* (*A. bruennichi*) provided evidence revealing that courtship in male spiders could have effects on female choice and relate to further mating success [9]. In hence, understanding the influence that temperature could cause on spiders mating behavior is crucial and could provide some empirical evidence.

The research in 2009 on pairs of female and male of another wolf spider, *Pardosa astrigera* (*P. astrigera*) found that with the increasing temperature, copulatory and courtship duration and courtship latency decreased, while the numbers and frequencies of hematodochal expansions and pedipalp insertions increases in the temperature range from 16°C to 32°C. However, the success rate of female mating was not greatly affected by temperature [5]. Another study on another wolf spider species, *Schizocosa floridana* (*S. floridana*), also found some relationship between temperature and spiders mating behavior. In their experiment, the team firstly discovered that there were no courtship behaviors at 11°C or below and the upper mean temperature during *S. floridana* breeding season was 26°C. Therefore, the temperature range was set from the lowest temperature of 11°C to the highest of 38°C to expand the range. The results from their data revealed that higher temperatures have a positive effect on *S. floridana* reproductive behaviors and outcomes. Specifically, the production rate of some behavior increased with the increasing temperature, while other courtship display shows less or stayed unchanged [10].

Similarly, another study that has been done on the species *Rabidosa punctulate* (*R. punctulate*) also discovered a decreasing mating behavior under a colder environment. Lower temperatures would lead to less activity in males. The experiment showed that more than 58% of the males did not express any tactic under the cold trial. In the rest of the males, they took much shorter to express tactics in warmer trials than in colder trials and the number of individuals that showed mating behaviors like courtship and direct mount was significantly different from the two temperature sites. To be specific, 3 males showed courtship and 12 males showed direct mount in 4°C trial, whiles 11 ones showed courtship and 16 ones showed direct mount in 27°C trial. Moreover, in low-temperature trials, the mating success rate significantly dropped [11].

These three pieces of research utilized different analyses to discover the impact of temperature change on spider (*S. floridana, P. astrigera,* and *R. punctulate*) mating behavior. All these three pieces of research found that the behaviors were significantly influenced by different temperatures. On the other hand, a common result of decreased mating success was found in lower temperature situations than in warmer situations. An interesting finding was that all research showed different levels of adaptations of different wolf spider species to the changing temperatures. The spiders were showing their flexibility in different behaviors when facing different temperatures. These similar results showed the importance of temperature affecting spiders' behaviors. However, there are some differences between these three pieces of research. Firstly, the spiders are different species of wolf spiders. Therefore, there was a possibility that the specific responses of the spiders to different temperatures were due to species-specific characteristics. Moreover, as these experiments set different temperature ranges and treatments for different species, they highlighted the complexity of the effects of temperature on these creatures. Further research on the influence of specific temperature could cause on spiders could be done.

2.2. Changes in Spawning and Hatching

The production of female spiders and the hatching of spider eggs are also extremely important in the entire spider reproduction process, because this may be the weakest and most susceptible stage to external factors. It is clear that egg sacs provide protection for eggs' development from predation and other factors (Fig. 1) [12]. Several studies have proved that temperature would have great impact on

the survival rate of spider eggs and female fecundity. The increasing temperature could cause a higher proportion of egg sacs to be produced by females, but if the temperature continued increasing, the survival rate and hatching rate of the eggs would decrease to some certain level even to zero even with the protection of the silk egg sacs [13-15].

Figure 1. The egg sac silk as a defense layer of Cyclosa sp. https://www-tandfonline-com.ezproxy.library.sydney.edu.au/doi/full/10.1080/15440478.2022.2025986#

The research on *P. astrigera* was done by Chen, Z. et al. The experiment utilized a similar design as the one that investigated the effect of temperature on male mating behaviors, but in this case, Chen, Z. et al. focused on discovering the impact of rising temperatures on the output of female reproduction and the egg sacs. The results showed that the number of egg sacs that had been produced could be significantly affected by temperature and the results showed that the relationship between temperature and female fecundity. It was clearly showed that as the temperature was increasing, the number of egg sacs being laid increased and reached a peak at 28°C (Fig. 2) [13]. Also, female fecundity was positively affected by the rising temperature. The fecundity was much higher under 24°C, 28°C, and 32°C than 16°C and 20°C, which indicate that females tend to produce more egg sacs in warmer situations [13].

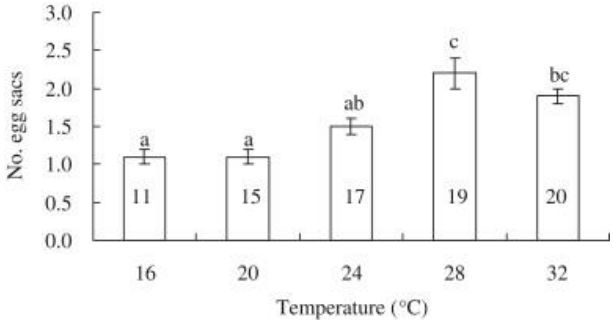

Figure 2. The number of egg sacs been produced with the increasing temperature. https://ars-els-cdn-com.ezproxy.library.sydney.edu.au/content/image/1-s2.0-S0306456510000033-gr1.jpg

Another research on *Nephila clavipes* (*N. clavipes*) also came to similar conclusions. The study suggests that with the rising temperature, female spiders tend to produce more egg sacs. However, if the temperature continues to grow, the eggs will be in the life-threatening situation that the survival and hatching rate will decrease and even touch the bottom of zero hatching rate. This conclusion provides more evidence for the influence of temperature on the productivity of female spiders.

Hayasaka, D. et al. did research discovering the lethal temperature of the invasive widow spider Latrodectus. The research aimed to find the proper way to control the species population to limit the negative effect of the invasive species on the local ecosystem and environment. However, by studying this experiment, we can still have an insight and more evidence for the effect of high temperatures on spider eggs under the protection of silk sacs. *Latrodectus hasseltii* (*L. hasseltii*) and *Latridectus geometricus* (*L. geometricus*), which are the two invasive species in Japan, were studied in this

research. In the experiment, the lethal temperature (LT) was recorded as the temperature when all the spider eggs stopped hatching. The egg sacs of both of the two species showed a complete failure in hatching after being exposed to a high temperature of 55°C for more than 10 minutes. In the meantime, 90% of *L. hasseltii* eggs failed to hatch at the temperature of 50.9°C and 90% of *L. geometricus* eggs failed to hatch at 52.8°C [14].

All these three pieces of research revealed a significant impact of temperature on female mating outcomes and the development and hatching of the eggs. Two common types of spider species, widow spiders and wolf spiders, were studied in two pieces of research and they emphasized different stages of spiders' eggs. The research on the specific impact of the development of spider eggs is crucial and essential for a better understanding of the mechanism behind it.

2.3. Changes in Early Development

The next step in spiders' reproduction process is the growth and development of spiderlings and juveniles. It is proved that rising temperature will cause influence on juveniles' development and behaviors. It is revealed that early behaviors like attacking behavior, cannibalism, and springing tend to develop earlier and faster under higher but suitable temperature. However, the impact of increasing temperature on juveniles' weight gain is skeptical as there were different results from different experiments. Moreover, the impact of other factors like the living density of the juveniles cannot be neglected as the changes in the development of spiderlings could be driven by the combination of several factors [16-19].

The research on *Latrodectus Hesperus* (*L. Hesperus*) focused on whether urban heat island conditions could have effects on spiders' development. The part for the family development could provide some insights into the impact of temperature on spiderling or juvenile development. By comparing the body mass that the spiders gained under two temperature treatments (27°C and 33°C), 76uj on day 105, a decreased mass gain in juveniles at higher temperature was found. This indicated that there was a slowed development of spiderlings under higher temperature conditions. The research also recorded an accelerated penultimate molt and reduced body mass at 33°C in males. On the other hand, the results also showed an earlier and faster appearance of attacking behavior to prey in males in 33°C conditions [16].

Another research done by de Tranaltes, C. et al. were also on *L. hesperus*. However, they mostly put their emphasis on the siblicide behavior of spiderlings that have been affected by temperature. The research method and measurement were similar to what Johnson, J.C. et al. did. However, other factors like the density of the spiderlings were also taken into consideration. Interestingly, they found out that there might even be some correlations between each factor that had a combined effect on cannibalism. There was significant evidence showing that spiderlings had cannibalism behaviors faster at 33°C than at 27°C at the densities of four, three, and two siblings in one box. This indicated that temperature did have effects on cannibalism, but it was hard to determine whether the impact had been greatly affected or even mediated by other factors [17].

The first research emphasized more on a broader view, which provided insights about the effects of temperature on spiderling growth or development, while the second research emphasized a more specific point that reflected the impact of temperature and other factors on spiderling cannibalism. Both of these two pieces of research revealed a wide effect of temperature on spiderlings. However, as the main aim of this research was to discover the influence that the urban heat island effect could do on spiders, the team for this experiment only set two temperature sites to record and measure the difference. The results actually did not provide strong evidence revealing the relationship between temperature and spiderlings, because there were so few different levels of temperature that the current results can only indicate a rough possibility. Moreover, the studies were limited to only one species of spider. Whether the results revealed a species-specific situation or a common trend between spiders' species is unknown.

Anthony, S.E. et al. did research discussing the thermal tolerance and thermal performance of different wolf spiders (Araneae: Lycosidae) under different temperature conditions. The part for the

changes in body mass between spiders acclimated in warm and cold conditions showed a significant difference. The mean body mass of the juveniles under cold acclimation was 12.8±2.1 mg while the mean body mass under warm acclimation was 28.7±5.3 mg, which was a huge size range [18]. This might indicate that the cold condition would decrease the juveniles' growth.

Another study put attention on one rare mygalomorph spider, *Grammostola vachoni*. The team tried to reveal the relationship between the juveniles' locomotor performance and temperature and thermal preferences. The result showed that all juveniles and females preferred staying in the 25 to 29°C area and there was little difference between the preference of juveniles and adult females. However, the locomotor performances in juveniles and adult females were greatly affected by temperature, especially juveniles. The sprint speeds reached a peak at around 25 and 30°C, while the speeds were relatively low at around 5, 10, and 40°C. These results indicated higher temperatures could promote the locomotor performances of juveniles but medicated the behavior when the temperature reached too high [19].

According to these studies, it is clear that the effect of temperature changes during the spiderlings is significant. Not only the physical condition of the juvenile spiders like body mass could be affected, but also, behavior development could be greatly influenced. However, two different results about body mass were got from two research. Johnson, J.C. et al. got the result that body mass was lower in higher temperatures, while Anthony, S.E. et al. got the result that juveniles in higher temperatures would get more body weight. The reason for different results might be the difference in temperature range and different species chosen for the experiment. Therefore, it is worth doing further research comparing different species and controlling the variables to reveal the different or common effects on spiders on a larger scale.

3. Other Influences

The temperature has an effect not only on the reproduction cycle of spiders but also on the whole population. A two-year study done by Meineke, E.K. et al. focused on the impact of urban warming on spiders in North Carolina. They found that the spider abundance was not greatly affected by urban warming overall, instead, spider community structure was greatly influenced in 2013. A decline in the spider group was discovered. Therefore, the research team assumed that the reason for the influence in 2013 was that 2013 had a higher temperature and drier conditions. However, whether this is the consequence that directly affects the spiders' population is unsure [20].

Another study used Habronattus jumping spiders as experimental subjects to understand the relationship between temperature and their thermal biology and distribution. Species distribution was suggested to be related to some biotic factors like courtship or mating choice. However, a higher warming tolerance ability was found in the jumping spiders, which provided insight that they could adapt to climate change well [21].

These two pieces of research highlighted the importance of temperature change in spider groups. However, these two studies focused on two aspects and the lack of horizontal contrast of different species make the results not representative enough for studying the impact of temperature on spiders. Macroscopically speaking, these two studies may be limited by geographical influences. The environment of the areas they selected may be extremely influential, and it is difficult to obtain results that are very correlated with temperature changes.

4. Conclusion

It is proved by several studies that there is a large impact of temperature on spiders' different life stages. The impact on spiders' reproduction process was mainly focused on the mating behavior. The changes in behaviors during the mating process were greatly influenced by temperature. The frequency of male mating behaviors like mounting frequency was positively correlated with increasing temperature. However, two studies got two opposite results on female mating success rates.

Moreover, the flexibility of spiders adapting to temperature change was found. For the spawning and hatching stage, the increasing temperature could lead to increasing egg sacs that have been produced by the female. Also, the hatching rate of the eggs was influenced by the temperature. Extremely high temperatures would stop the development of the eggs. After the eggs were hatched, the development of juveniles could also be influenced. The changes in juveniles' body mass were not proved as the different results. But the studies found that early development of behaviors like cannibalism and sprinting were advanced with the rising temperature. The specific impact of temperature on spider distribution and population was not identified, but there were still some correlations or combined effects of several factors. As concluded, the impact of temperature on spiders is undoubted. However, there are still some limitations according to these studies. First of all, the selection of subjects is relatively simple, and there are not many other species of spiders involved in the experiment. On the other hand, some opposite results were gotten from different experiments. This could have resulted from different experimental designs and species being chosen. Therefore, some cross-sectional comparisons between multiple species and multiple temperature ranges are necessary. Future studies could focus on more different types of spiders and make comparisons. It is worth studying the effect of a particular temperature on spiders, or species-specific correlation.

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