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FEMALES' WEB-BUILDING CHARACTERISTICS OF *ACHAEARANEA JAPONICA* (ARACHNIDA: ARANEAE)

Hiroshi Abé[1], Hinako Okuhara[2]

1) Biological laboratory, College of Bioresource Sciences, Nihon University, Kameino 1866, Fujisawa, Kanagawa 252-0880, Japan. E-mail: abe.hiroshi@nihon-u.ac.jp
2) Laboratory of Wildlife Science, Department of Animal Science and Resources, College of Bioresource Sciences, Nihon University, Kameino 1866, Fujisawa, Kanagawa 252-0880, Japan.

Achaearanea japonica is one of the quite common spiders throughout Japan. To understand the biology and ecology of *A. japonica,* we examined the females' web-building characteristics in relating to body size, web volume, and web height above the ground level. The 79 webs of sub-adult and adult females were examined from May to September in 2010 at a hedge of *Photinia glabra* in a ground of Nihon University, Kanagawa, Japan. As a result of the investigation, adult females built a larger web than sub-adult females, and the body sizes of adult females were significantly larger than sub-adult females. The web height was negatively correlated with females' body sizes, and adult females tended to make their webs at lower position than sub-adult females. Therefore, their preferable web-building site is expected to be the lower part of a hedge. However, this tendency was not clear within sub-adult females. During the reproductive period, an adult male searches for a web of a sub-adult or adult female and cohabits with the female for pre-copulation. Although cohabiting sub-adult females were obviously larger than solitary sub-adult females, the web height was not different between solitary and cohabiting sub-adult females. Considering the fecundity, which was clearly correlated with the body size, it is highly probable that the male tries to cohabit with the larger sub-adult female in order to increase his relative fitness irrespective of the sub-adult female's web height.

KEY WORDS: Araneae, Theridiidae, *Achaearanea japonica,* cohabitation, mate choice, web-building behaviour, web-building characteristics.

Х. Абе[1], Х. Окухара[2]. Особенности тенет самок паука *Achaearanea japonica* (Arachnida: Araneae) // Дальневосточный энтомолог. 2013. N 269. С. 1-20.

В Японии *Achaearanea japonica* является одним из самых обычных пауков-тенетников. Для того чтобы лучше понять биологию и экологию этого вида мы изучили тенета самок *A. japonica* в зависимости от размеров самок, величины гнезда и его высоты над уровнем почвы. С мая по сентябрь 2010 г. были обследованы 79 гнезд неполовозрелых и половозрелых самок, расположенных на живой изгороди из кустов *Photinia glabra*, окружающей кампус университета Нихон (Канагава, Япония). Показано, что гнезда взрослых самок больше, чем у молодых, а размеры тела половозрелых самок значительно превосходят размеры неполовозрелых самок. Высота расположения тенет отрицательно скоррелирована с размерами тела: гнезда взрослых самок обычно располагаются на изгороди ниже, чем у неполовозрелых самок. Однако эта тенденция у неполовозрелых самок выражена не столь очевидно. В период размножения взрослые самцы перед спариванием поселяются в гнездах как неполовозрелых, так и взрослых самок. Хотя обитающие совместно с самцами неполовозрелые самки обладают явно большими размерами, чем одиночно живущие молодые самки, высота расположения гнезд у них не различается. Учитывая, что плодовитость самок зависит от их размеров, вполне вероятно, что самцы предпочитают выбирать для совместного проживания более крупных неполовозрелых самок независимо от высоты их тенет над уровнем почвы.

1) Биологическая лаборатория, Колледж биоресурсных наук, Университет Нихон, Канагава, Япония.

2) Лаборатория наук о живой природе, Колледж биоресурсных наук, Университет Нихон, Канагава, Япония.

INTRODUCTION

The design of spider webs has been well studied especially in orb-web spiders. For instance, the web area size (Watanabe, 2001; etc.), the number of web radii (Eberhard, 1990, etc.), the mesh size (Herberstein & Heiling, 1998; etc.). In addition, web location and habitat selection are major subjects of biology of spiders (Janetos, 1986). Various aspects of habitat selection have been well studied in web-building spiders as reviewed by Wise (1993), Uetz (1991), and Riechert & Gillespie (1986). Site selection of spiders has been sometimes taken up for discussion in ecological surveys relating to a prey capture rate (Bilde *et al*., 2002; etc.), a prey type selection (Olive, 1980, etc.), an inter- or intraspecific competition (Suwa 1986, etc.), an escape from predators (Rypstra *et al*., 2007; etc.), architectural attributes of habitats (Lubin *et al*. 1993; etc.), abiotic characteristics of environment (Voss *et al*., 2007; etc.) and so on. These studies have linked web-building site selection to individual fitness through effects on growth, survival, and reproductive success in the course of spider evolution.

Achaearanea japonica (Bösenberg et Strand, 1906) in the family Theridiidae is one of the quite common spiders throughout Japan. Although a significant amount of information on its life cycle and phenology (Ikeda 1990; Ikeda, 1993; Ishimoto *et al*., 2005, 2008), brood-care behaviour (Ito, 1985; Ishimoto *et al*., 2005), and mating behaviour (Ikeda, 1989, 2010) has been obtained, studies addressing the site preference of the spider for web-building are quite limited (Ikeda, 2010). To obtain fundamental knowledge of the biology and ecology of *A. japonica,* we examined the adult and sub-adult females' body sizes, fecundities, and web-building characteristics in relation to web volumes and site preferences. In addition, we also mentioned males' preferences for mate choice in order to get further information on mating system of this spider.

MATERIALS AND METHODS

Study animal

Achaearanea japonica is a small spherical spider which is less than 5mm in body size with reddish brown color (Fig. 1). Both male and female are similar in appearance. This spider is quite common throughout Japan and is usually found in urban and sub-urban areas as well as open woodland in mountainous areas. The web is held in place by silk lines connected to branches of a tree and consists of upper tangle web and under horizontal sheet web. In the study area, the juvenile builds a web from late April and molts into the sub-adult (penultimate instar) in June. The spider's reproductive process takes place from early June to late August. The adult female rarely changes the web position comparing with the sub-adult female (Ikeda, 1990). During this period, an adult male searches for a web of a sub-adult or adult female and cohabits with the female in the web. Cohabitation is caused for pre-copulation and also is considered to be a form of the male's mate-guarding (Ikeda, 1989). If an adult male finds a sub-adult female in a web, copulation occurs in the web soon after the female's final molt. If a male finds an adult female in a web, copulation occurs there at once. The male sometimes continues to stay on the female's web even after mating and tries to mate her over and over again. The male usually guards his mate against other invasive males by showing a threating behaviour (Ikeda, 2010). During the reproductive period, an adult or rarely sub-adult female hangs a small leaf in the center of the web and lays her eggs on the down side of the leaf. Juveniles hatch out and almost disperse before November.

Fig. 1. An adult female placed behind a leaflet in the center of a web and an adult male cohabiting with the female in the web. Scale bar = 1cm.

Study area and study period

This study was conducted at a hedge of *Photinia glabra* (220 cm high, 1620 cm wide) in a ground of Nihon University College of Bioresource Sciences (35°20'N, 139°29'E), Fujisawa City, Kanagawa, Japan. The 79 webs of sub-adult and adult females of *Achaearanea japonica* (Arachnida: Araneae: Theridiidae) were examined to reveal female's web-building characteristics from June to September in 2010.

Study items

To examine biological and web-building characteristics of sub-adult and adult females, and those of solitary and cohabiting females, the following four items were measured. The adult female was distinguished from the sub-adult female by the developmental condition of epigynum. To avoid multiple measuring for the same individual, specific tag was given to each female's web.

1. Body sizes of solitary sub-adult and adult females, and cohabiting sub-adult and adult females: Body size was measured as a combined length of patella and tibia of the first leg, 'tibpat' in Lubin *et al*. (1993). This length is positively correlated with a carapace width and regarded as an indicator of body size (Ikeda, 2010). The spider was gently removed from the web and anesthetized by using CO^2 gas. Thereafter, the lengths of patella and tibia of the right or left first leg was measured under a binocular microscope with an aid of an ocular micrometer.

2. Fecundity of adult female: Egg sacs were removed from a female's web and torn open with tweezers under a binocular microscope. The number of eggs in each egg sac was fully counted. Thereafter, the total number of eggs laid in a female's web was calculated.

3. Web volume of solitary and cohabiting sub-adult female, and solitary and cohabiting adult female: A web of the spider consists of horizontal basal sheet and supporting thread. The maximum length and maximum width of a basal sheet of the web, and maximum depth of a part of supporting threads of the web were measured. The form of the web is almost identical with an elliptic cone. Therefore, the web volume was calculated following the equation of an elliptic cone:

web volume = $\pi \times$ maximum length $\times$ maximum width $\times$ maximum depth $\times$ 1/3,

where maximum length and maximum width are regarded as the major and minor axis of a basal elliptic sheet, respectively.

4. Web height of solitary and cohabiting sub-adult female, and solitary and cohabiting adult female: An elevation of a basal sheet of the web above the ground level was measured by using a measuring rod.

Statistics

The relationship between the body size and the web height as well as the fecundity was examined using Spearman's rank correlation (ρ). Interaction between date and web height was examined by the one-way ANOVA test. Interactions among sub-adult female, adult female, solitary female, and cohabiting female on web height, web volume, and body size were examined by the Wilcoxon rank-sum test. Statistical analyses were conducted using JMP 4J (SAS Institute Inc.).

RESULTS

Biological characteristics of sub-adult and adult females

The temporal fluctuation in the total number of sub-adult and adult females in the research area from June to September in 2010 was shown in Fig. 2. Sub-adult females emerged in the early summer and the population size was largest in the middle June. Thereafter, the number of sub-adult females gradually decreased with minor fluctuations until autumn arrived in early September. On the other hand, adult females emerged in the middle of June. And the population of adult females increased until early July and the population size was roughly maintained until September. Although the sub-adult females were predominant over adult females until late July, thereafter the relationship was reversed. Such a negative relationship between sub-adult and adult populations well expressed the demography in an isolated area.

As the result of an examination of body size for 38 sub-adult and 41 adult females from 3 July 2010 to 2 September 2010, adult females were significantly larger than sub-adult females (Wilcoxon rank-sum test, $p<0.01$) (Fig. 3A). In 16 adult females, the fecundity was clearly correlated with the female's body size (Spearman's ρ: 0.66, $p<0.01$) (Fig. 4A). It indicates that the egg production increases as the female's body size becomes larger.

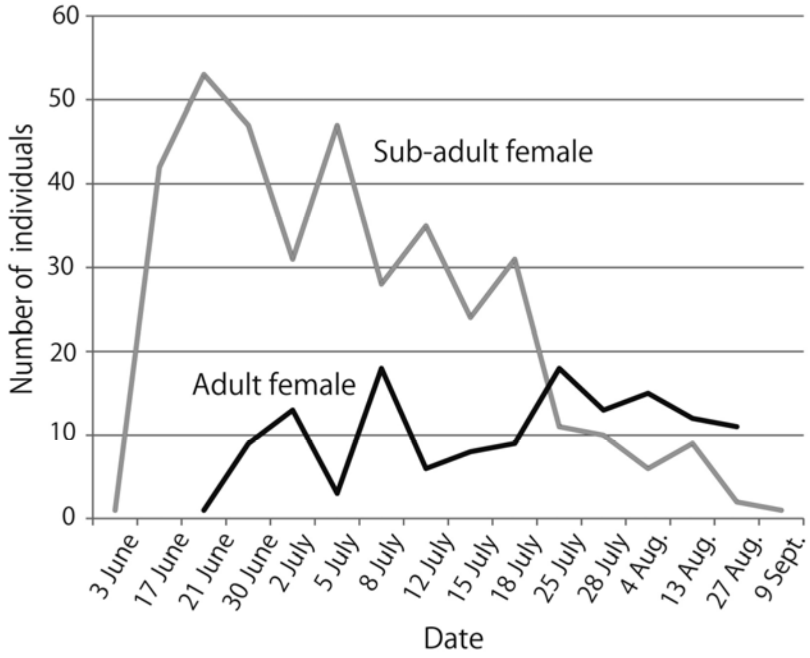


Fig. 2. The temporal fluctuation in the total number of sub-adult and adult females observed on a hedge of *Photinia glabra* in a ground of Nihon University from June to September in 2010.

Web-building characteristics of sub-adult and adult females

As for the web volume, 65 webs of sub-adult females and 18 webs of adult females were examined from 17 June 2010 to 13 August 2010. In result, the webs of adult females were significantly larger than those of sub-adult females (Wilcoxon rank-sum test, $p<0.01$) (Fig. 3B). The web height above the ground was also measured for 38 webs of sub-adult females and 41 webs of adult females from 3 July 2010 to 2 September 2010. As a result, although there was no clear relationship between the web height and the body size in sub-adult (Spearman's ρ: -0.21, $p=0.21$) and adult (Spearman's ρ: 0.13, $p=0.40$) females, a significant negative correlation between the web height and the body size was detected for 79 females as a whole (Spearman's ρ: -0.25, $p<0.05$) (Fig. 4B). It suggests that the web height generally decreases as the female's body size becomes larger. Further, the web heights of 38 sub-adult females were compared with those of 41 adult females. It resulted that the adult female tended to make her web at lower position than the sub-adult female (Wilcoxon rank-sum test, $p<0.05$) (Fig. 3C). On the other hand, concerning the relationship between the dates and 79 female's web heights, there was no significant relationship between them (one-way ANOVA, $F=1.26$, $p=0.29$).

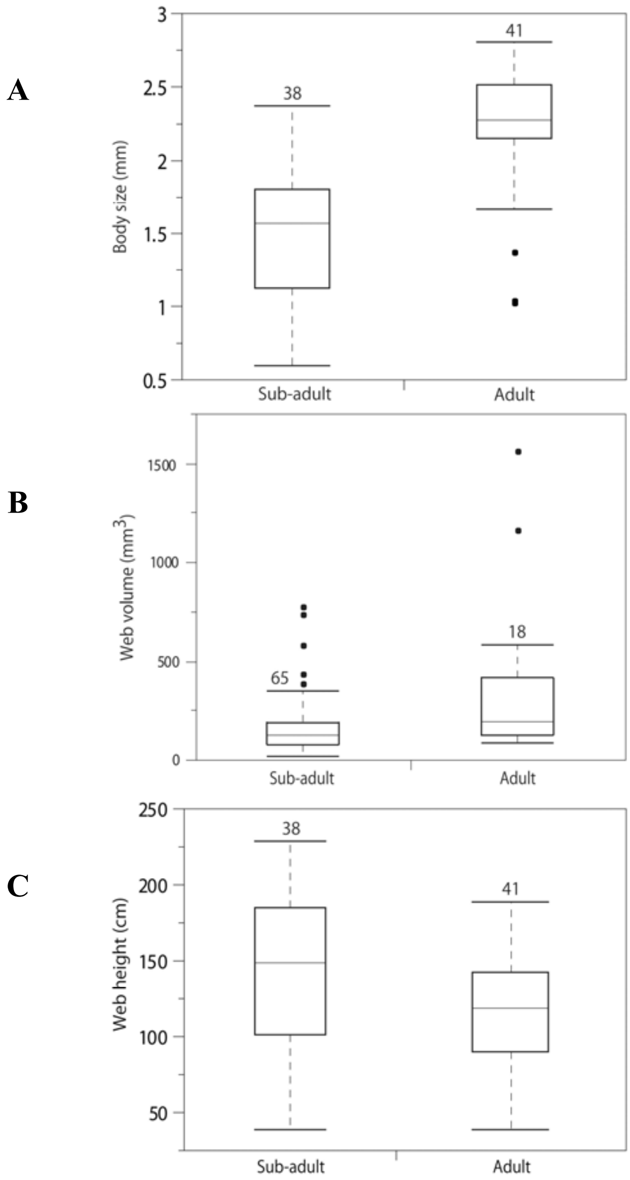
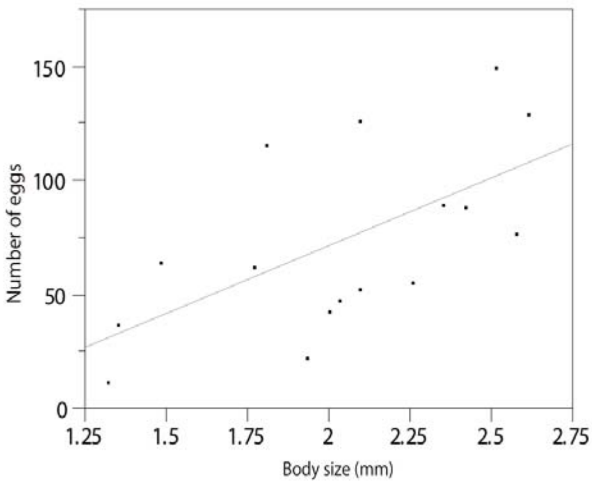


Fig. 3. Body size (A), web volume (B), and web height above the ground (C) of sub-adult and adult females presented as box plots. The number above the box indicates the number of examined individuals. The black line in the box shows the median and the whiskers show the range except for the outlier (black dot).

A



B

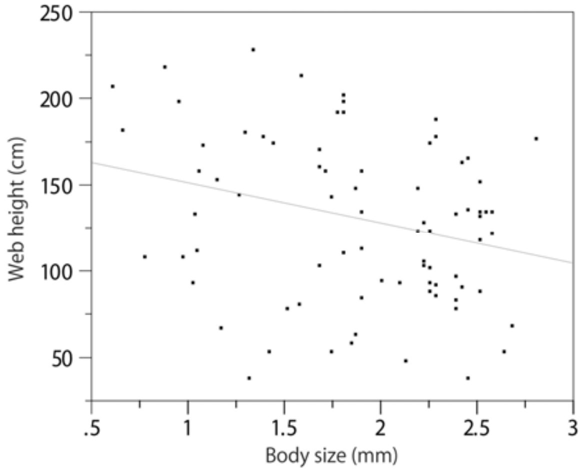


Fig. 4. Correlations between number of eggs and body size of adult females (A) (n = 16, R^2 = 0.37), and web height above the ground and body size of sub-adult and adult females (B) (n = 79, R^2 = 0.07).

Biological characteristics of solitary and cohabiting females

The ratio of the number of cohabit to solitary individuals observed from 3 July 2010 to 2 September 2010 is 0.65 (15 cohabit, 23 solitary) in sub-adult and 0.37 (11 cohabit, 30 solitary) in adult females. Namely, males were more likely to be found in association with sub-adult females. The body size was examined for 23 solitary and 15 cohabiting sub-adult females. In result, cohabiting sub-adult females were significantly larger than the solitary sub-adult females (Wilcoxon rank-sum test, $p<0.05$) (Fig. 5). On the other hand, as the result of an examination of body size for 30 solitary and 11 cohabiting adult females, there was no significant difference between them (Wilcoxon rank-sum test, $p=0.62$).

Web-building characteristics of solitary and cohabiting females

As the result of an examination of the web volume for 13 solitary and 7 cohabiting adult females from 21 June 2010 to 2 July 2010, we observed no clear difference between them (Wilcoxon rank-sum test, $p=0.20$). Unfortunately, the statistical comparison of the web volume for solitary with cohabiting sub-adult females was not conducted because of the scarcity of the cohabiting sub-adult females during this period. The web heights of 23 solitary sub-adult females were compared with those of 15 cohabiting sub-adult females from 3 July 2010 to 2 September 2010. In result, there was no clear difference between them (Wilcoxon rank-sum test, $p=0.62$). In addition, the web heights of 30 solitary adult females were compared with those of 11 cohabiting adult females. However, the significant difference was not detected between them (Wilcoxon rank-sum test, $p=0.18$).

DISCUSSION

The web height of females was negatively correlated with females' body sizes (Fig. 4B). Consequently, the web height becomes lower as the female's body size gets larger. Adult females were significantly larger than sub-adult females (Fig. 3A). Furthermore, adult females tend to make their webs at lower position than those of sub-adult females (Fig. 3C). Life-history stages of spiders influence their habitat selections (Blamires *et al*., 2007). Heiling & Herberstein (1999) examined intraspecific competition of orb-web spiders and reported that adult females frequently occupied prime habitat. If the females of *A. japonica* go up the tree from the ground for web-buildings, their preferable web-building site is expected to be the lower part of a hedge. Abiotic habitat features like temperature, humidity, and substrate architecture act as predictors of spider distributions in the field (Rypstra, 1986; Voss *et al*., 2007; Lubin *et al*., 1993), and environmental stability would be important to maintain certain web condition for spiders. The site preference of adult females of *A. japonica* for lower part of a hedge probably allow protection of the webs from over exposure to solar radiation, wind, rain, and so on.

Although the correlation between the web volume and the female's body size was not recognized, adult females built larger web than sub-adult females (Fig. 3B). During a mating period of this spider, a male usually searches for a web of sub-adult female and mate with her after her final molt. Therefore, the web size will increase after the female mates with a male, probably because the female must build a certain-sized egg-laying ground by hanging a leaf in the web regardless of her body size.

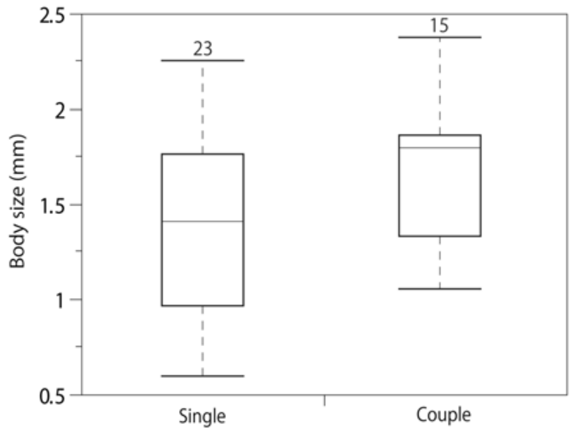


Fig. 5. Body size of solitary (single) and cohabiting (couple) sub-adult females presented as box plots. The number above the box indicates the number of examined individuals. The black line in the box shows the median and the whiskers show the range.

In various crustaceans, insects, and arachnids, males are sometimes known to cohabit with young females and mate with them after they moult into mature. If the first mate sperm precedence exists in the spider (Watson, 1991; Austad, 1982; Jones & Parker, 2008), it is quite important for males to select females' webs for cohabitation. In fact, the male of the desert, funnel-web spider is known to exhibit clear mate choice (Riechert & Singer, 1995) and it suggests that the male recognizes the preferable female and her web for cohabitation and copulation. In case of *A. japonica,* the web height was not different between solitary and cohabiting sub-adult females. Therefore, the male does not select the female for pre-copulation based on the female's web height. On the other hand, the cohabiting sub-adult females were significantly larger than solitary sub-adult females (Fig. 5). It suggests that the male cohabits with larger female for pre-copulation. The larger body size of the sub-adult female should exhibit an approach to the final moult and/or represent her higher fecundity. The egg production increased as the female's body size becomes larger (Fig. 4A). Male mate choice will be adaptive when an increase in reproductive success can be expected by choosing highly fecund females in species where fecundity and female size is correlated (Olsson, 1993). Focusing on such a male's adaptive significance, it is highly probable that the male tries to cohabit with the larger sub-adult female for pre-copulation to increase his relative fitness.

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