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SHORT COMMUNICATION

Field observations on consumption of fermented tree sap by spiders in deciduous forests in Japan

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Abstract. Accumulated studies have revealed that spiders, which are believed to be true predators, also feed on various plant materials such as pollen, nectar, and stigmatic exudate. Hereby, we report observational cases of fermented tree sap feeding by four spider species, namely *Sinopoda forcipata* (Karsch, 1881) (Sparassidae), *Otacilia komurai* (Yaginuma, 1952) (Phrurolithidae), *Weintrauboa contortipes* (Karsch, 1881) (Pimoidae), and *Doenitzius* cf. *peniculus* Oi, 1960 (Linyphiidae), in deciduous forests in Japan. This is the first report of spiders feeding on fermented sap, and also the first report of plant material consumption in the families Sparassidae, Phrurolithidae, and Pimoidae.

Keywords: Alternative food resource, *Castanea crenata*, phenology, plant-eating, *Quercus serrata*

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Accumulated studies have reported that spiders, recognized as true predators (i.e., capturing and eating live prey), also utilize plant-derived materials as food. Plant-eating occurs in at least 10 families: Anyphaenidae, Araneidae, Clubionidae, Cheiracanthiidae (=formerly Eutichuridae), Linyphiidae, Oxyopidae, Salticidae, Theridiidae, Thomisidae, and Trachelidae (Nyffeler et al. 2016). Remarkably, most cases have been found in cursorial spiders, such as salticids (Nyffeler 2016; Nyffeler et al. 2016). Plant materials consumed by spiders are diverse, such as pollen (e.g., Eggs & Sanders 2013), nectar (e.g., Taylor & Foster 1996; Jackson et al. 2001), honeydew (e.g., Jackson et al. 2008), stigmatic exudate (e.g., Marquinez et al. 2010), and leaf-associated organs that are rich in proteins and lipids (known as Beltian bodies; Meehan et al. 2009). Although plant-eating is widespread among spiders, most spiders are not exclusive plant feeders as they cannot molt to the next instar under a plant-dominant diet (e.g., Smith & Mommsen 1984; Vogelei & Greissl 1989). Even though *Bagheera kiplingi* Peckham & Peckham, 1896 (Salticidae), the jumping spider that mainly eats Beltian bodies of acacia trees under natural conditions, also forages for larvae and pupae of ants to obtain protein (Meehan et al. 2009).

Plant sap, or vascular fluid, is also a plant-derived food resource foraged by herbivorous invertebrates. Sap feeders are mainly found in hemipterans, such as whiteflies and aphids, which rely on phloem sap (Douglas 2006), and cicadas, which feed on the xylem of trees throughout their life (Cheung & Marshall 1973). Compared to consumption of nectar and pollen, plant sap feeding by spiders has rarely been reported: *Anelosimus* sp. (Theridiidae) biting mango leaves in the field (Stejskal 1976), and three jumping spider species biting leaves of *Rubus* sp. and *Prunus* sp. in the laboratory (Nyffeler 2016; Nyffeler et al. 2016). Thus, the consumption of plant sap by spiders under natural conditions remained a somewhat unsettled issue.

In this study, we focused on fermented tree sap as a food resource. In the temperate secondary forests of Japan, sap often exudes through the bark of oak trees (Fagaceae) as a result of the boring behavior of carpenter worms (Lepidoptera: Cossidae; Yoshimoto & Nishida 2007). The sap is fermented by microorganisms and the resulting odor attracts many insects, including beetles (Coleoptera), hornets and ants (Hymenoptera), butterflies and moths (Lepidoptera), and flies (Diptera; Yoshimoto et al. 2005). Notably, the chemical composition of the fermented sap of oak trees has been described for *Quercus acutissima* Siebold et Zucc.: it is rich in protein (4.5–4.7%) and sugar (0.24–2.37% fructose; 0.20–1.78% glucose), and also contains ethyl alcohol (1.04–2.55%), acetic acid (0.18–0.71%), and lactic acid (0.11–0.24%; Yajima 2005). Although fermented sap is a reliable food for many insects, none of the previous studies have reported fermented sap feeding in spiders.

In order to reveal the consumption of fermented tree sap by spiders, we conducted field observations in deciduous forests in Japan. Continuous field observations were conducted in the forest at Uenohara (35° 38′ 44.178″ N, 139° 6′ 31.2906″ E), Yamanashi Prefecture, Japan, between November 20, 2019, and March 21, 2020. We recorded spiders over the fermented sap of a *Quercus serrata* (Fagales: Fagaceae) tree using interval photography (40 s intervals; Panasonic GX7MK2, Japan). Then, we converted the interval photographs into time-lapse movies to examine the presence and behavior of spiders. We also conducted nocturnal observations in the forest in Watagashima (34° 52′ 1″N, 137° 47′ 44″E), Hamamatsu City, Shizuoka Prefecture, Japan, every July between the years 2015 and 2019. We walked throughout the forest with a flashlight at night and directly observed a spider on the fermented sap of *Castanea crenata* (Fagales: Fagaceae) trees. We filmed their behaviors with a digital camera (Olympus TG-4, Japan). We considered spiders to be feeding on sap when their mouthparts were directly in contact with exudates and showed feeding movements, that is quivering of the chelicerae and pedipalps. Notably, we did not collect any spiders and, instead, identified them through the photographs. Spider nomenclature is based on the World Spider Catalog (2020).

During five winter months (Nov 2019 to Mar 2020), we made 24 nocturnal observations of spiders apparently feeding on the fermented sap of the same individual oak *Quercus serrata* in a forest at Uenohara. Twenty-two of the observations (= 88% of all recorded incidents) were of the same species: *Weintrauboa contortipes* (Karsch, 1881) (Pimoidae), 13 females and 9 males. One observation was of *Otacilia komurai* (Yaginuma, 1952) (Phrurolithidae) and one of *Doenitzius* cf. *peniculus* Oi, 1960 (Linyphiidae). In *W. contortipes*, both sexes consumed fermented sap (Figs. 1A, B; video in Sano 2020) and the frequency of consumption was not significantly different between sexes (binomial test, $P = 0.52$). Overall, the presence and feeding on sap took place between the evening and early morning (18:05–05:45). In addition, over the course of four summers (July) of nocturnal observations at Watagashima we only observed a single male of the sparassid, *Sinopoda forcipata* (Karsch, 1881) feeding on the fermented sap of the oak *Castanea crenata*.

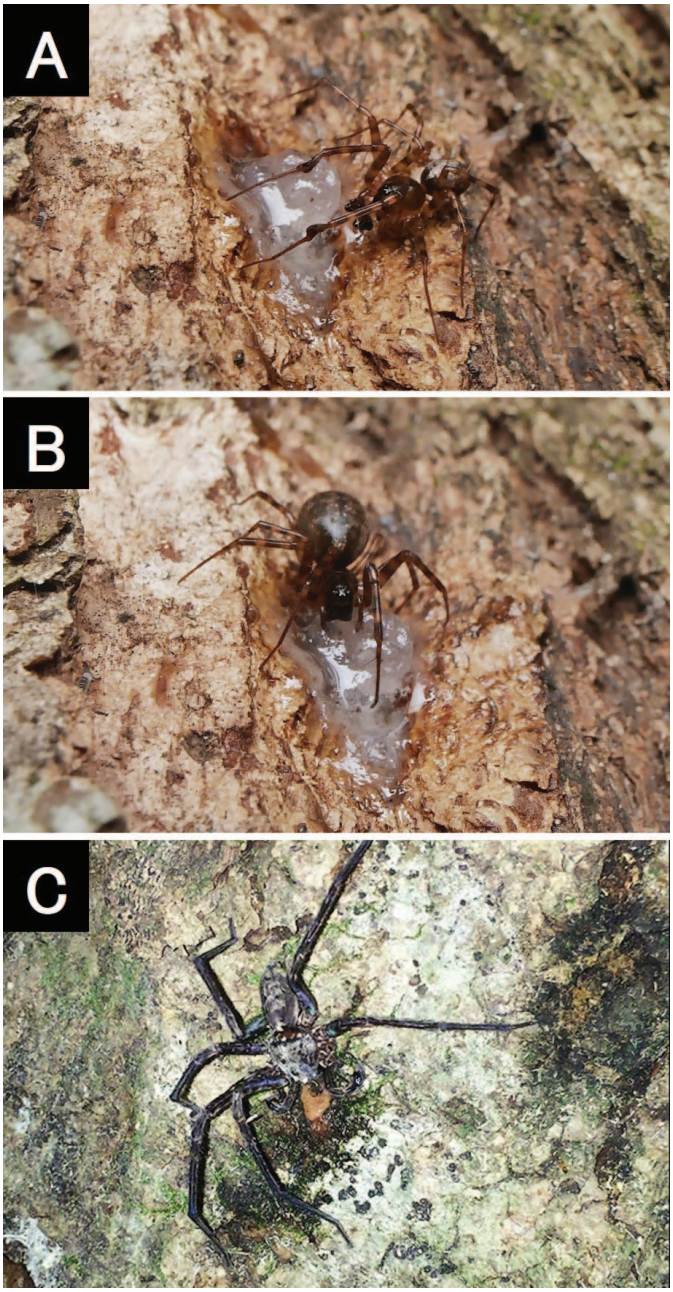

Figure 1.—A–C. Spiders feeding on the fermented sap of *Castanea crenata* (A) and *Quercus serrata* (B–C). A. *Weintrauboa contortipes* adult male. B. *W. contortipes* adult female. C. *Sinopoda forcipata* adult male.

The present study revealed that fermented sap feeding occurs in various spider taxa, namely the web-builders in Araneoidea (i.e., Pimoidae and Linyphiidae) and the cursorial hunters in the RTA clade (i.e., Sparassidae and Phrurolithidae) under natural conditions. This result is consistent with the fact that plant-eating prevails among broad groups of spiders and that a large variety of plant materials are utilized as food by spiders (Nyffeler et al. 2016). The fact that spiders consumed sap during the hours of darkness is parallel to the findings reported in nectarivory by cursorial spiders (Taylor & Foster 1996). Although it is not clear whether spiders feed on fermented sap for water intake purposes or to obtain other kinds of nutrients, the fermented sap of oak trees, which is rich in proteins, amino acids, and sugars (Yajima 2005), could be a beneficial food resource for the survival of spiders. To the best of our knowledge, the present study represents the first report of fermented sap feeding in spiders. Also, this is the first record of plant-eating in the families Sparassidae, Pimoidae, and Phrurolithidae.

Judging from the frequency of sap feeding in the field and natural history of the spiders that were observed, we suppose that the importance of fermented sap as food may vary between the four spider species. *Sinopoda forcipata* is a nocturnal hunter that captures insects such as moths, camel crickets, and cockroaches (Shinkai 2006). The frequency of sap feeding by *S. forcipata* was very low, as it was observed only once during the field survey. Therefore, we suppose that sap feeding might occur only occasionally in *S. forcipata*. As for *Otacilia komurai* and *Doenitzius* cf. *peniculus*, these ground-dwelling species are assumed to feed on small insects (Shinkai 2006) and adults emerge from autumn to spring (Ono & Ogata 2018). Although they were observed feeding on sap only once, it is particularly worth noting these ground-dwelling species climbed from the ground to higher places to forage tree sap. Finally, *Weintrauboa contortipes* is known as a web-building spider inhabiting the trunk of various trees, in which it weaves a horizontal or a diagonal sheet web (Shinkai 2006). Adults emerge from autumn to spring and are even active in winter (Shinkai 2006). However, their feeding habits during winter are poorly known. Notably, a female was observed wandering on a trunk and feeding on a winter moth (Alsophilinae; Ihara, pers. comm.; Fig. 2). Among the four species observed on fermented sap, *W. contortipes* was the most frequent visitor and, hence, might be relatively dependent on fermented sap.

Spiders that actively forage prey or reproduce during cold seasons, also known as winter-active spiders, are recognized in various spider taxa such as Linyphiidae, Lycosidae, Clubionidae, Thomisidae, Anyphaenidae and Philodromidae (Aitchison 1984a, b, 1987; Korenko et al. 2010). *Weintrauboa contortipes* is apparently a member of winter-active species because adults of both sexes are active during the winter (Shinkai 2006; Ono & Ogata 2018). Feeding habits of winter-active spiders have been studied in several species. For instance, the linyphiid *Bolephthyphantes* (=*Bolyphantes*) *index* (Thorell, 1856) forages winter-active collembolans on snow surfaces (Hagvar 1973) and species of *Anyphaena* Sundevall, 1833 (Anyphaenidae) eat various prey such as collembolans, psyllid bugs and spiders of the genus *Philodromus* Walckenaer, 1826 (Philodromidae) on orchard trees (Pekár et al. 2015). Here our studies show that the winter-active web-building spider *W. contortipes* may consume fermented sap as well as foraging on winter moth as alternative tactics to sit-and-wait hunting on a web.

Our field observations from Japan fully confirm the previous reports of plant sap feeding by spiders (Stejskal 1976; Nyffeler 2016; Nyffeler et al. 2016) and by presenting this new evidence, it could be demonstrated that feeding on plant sap is apparently a phenomenon more common than previously thought. In future research, the extent of feeding on tree sap by the spiders in question should be quantified. Furthermore, from a behavioral point of view it would be of interest to find out whether consumption of fermented plant sap containing alcohols is altering the spiders' behavior, as is known in some insects (e.g., ants and wasps) who may lose control of their coordination after getting intoxicated (Stephenson 1981; Adler 2000).

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Figure 2.—*Weintrauboa contortipes* female eating a male winter moth (Alsophilinae) on a tree trunk. The photograph was taken by Y. Ihara at Kamei Park, Otake City, Hiroshima Pref., Japan, on February 5, 2018.

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