

SHORT COMMUNICATION

Does minimal pruning and reduced fungicide use impact spiders in the grapevine canopy?

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Abstract. Agricultural management should aim at high densities of beneficial organisms such as spiders. Here, we asked whether spiders in vineyards can be promoted either by using novel disease resistant grape varieties that allow for a reduced number of fungicide applications, or by minimal pruning which enhances the structural complexity of the grapevine canopy. We compared spider communities in vineyards planted with fungus-resistant varieties (PIWIs) to vineyards with traditional grapevine varieties, and minimally pruned vineyards to vertical shoot positioned vineyards. Densities of Theridiidae were more than doubled in fungus-resistant grape varieties, but the remaining families were not significantly affected. Minimal pruning enhanced Philodromidae and Dictynidae but reduced Salticidae. However, neither pruning method, nor the reduced fungicide use in PIWI vineyards, had significant effects on overall spider abundance or species richness. Hence, effects of vineyard management were family-specific and possible consequences for pest regulation will thus depend on the pest control potential of the involved families.

Keywords: Fungus resistant grapevine, natural pest control, predation, viticulture

Spiders play an important role in the control of arthropod pests in many crops including grapevines (Young & Edwards 1990; Sunderland & Samu 2000; Pfannenstiel 2008; Pennington et al. 2018), and are often the most abundant group of predatory arthropods in vineyards (Costello & Daane 1999). As generalist predators, they can act against a broad spectrum of potential vineyard pests, such as leafhoppers (Hogg & Daane 2011) or the tortricid grape berry moth *Lobesia botrana* (Denis & Schiffermüller, 1775) and *Eupoecilia ambiguella* (Hubner, 1796) (Pennington et al. 2018; Thiéry et al. 2018). Despite the important role of spiders as biocontrol agents, there are few studies focusing on the effects of different viticultural practices on spider abundance and diversity in the grapevine canopy. Here, we investigate the spider community in the canopy, where the presence of spiders is most relevant for natural pest control in grapevines. We compare spider communities between vineyards managed with: 1) different pruning methods and 2) traditional, fungus-susceptible versus fungus-resistant grapevine varieties, receiving different levels of plant protection. The canopy in minimally pruned vineyards (SMPH) is more voluminous and contains more old, woody branches than in vertical shoot positioning (VSP), where old wood is removed annually except for one or two short branches from the previous growing season (Intrieri et al. 2011). Therefore SMPH vineyards offer a structurally different habitat with more space and potentially more resources such as prey and shelter (Langellotto & Denno 2004; Kraus et al. 2018), which is why we expected a higher spider abundance than in VSP vineyards. The different microclimate induced by the denser canopy in SMPH than in VSP was expected to affect spider species differently according to their shading and moisture preferences (Entling et al. 2007). Our second comparison was between vineyards planted with traditional grapevine varieties and vineyards planted with fungus resistant cultivars (PIWIs). Traditional varieties need to be sprayed over ten times per season to prevent fungal disease, whereas sprayings can be reduced by 50–90% in vineyards planted with fungus resistant cultivars (Töpfer et al. 2011). In the organic vineyards studied here, fungal diseases were controlled with combined sprayings of copper- and sulphur-containing products. Both direct and indirect (via prey organisms) effects of these substances on spiders are likely, but poorly

known (Bruggisser et al. 2010; Pekár 2012, 2013). For example, sulphur and copper are toxic to other arachnids such as mites (Hanna et al. 1997; Duso et al. 2012; Pennington et al. 2017), they can affect insects that are important spider prey (Thomson et al. 2000; Pennington et al. 2018; Vogelweith & Thiéry 2018), and spraying might physically destroy spider webs. We expected that: (i) minimal pruning leads to different, more diverse and abundant spider communities than VSP; and (ii) that vineyards planted with PIWI varieties have different, more diverse and abundant spider communities than vineyards with traditional varieties.

Sampling took place in 16 pairs of adjacent vineyards around Nußdorf, Germany (49°13'26"N, 08°06'34"E), which were all managed organically and thus received neither insecticides nor herbicides. We used a spatially paired design with eight pairs consisting of one SMPH and one VSP pruned vineyard to investigate the effects of pruning system, and eight pairs consisting of one vineyard planted with a fungus resistant grapevine variety, paired with a vineyard planted with a traditional, fungus-susceptible variety to investigate the effects of fungicide application frequency. All SMPH vs. VSP vineyards were planted with traditional grapevine varieties and most of them received the same plant protection treatments, consisting of 10 sulphur and 13 copper sprayings. One of the plots received eight sulphur and 10 copper sprayings. PIWI vineyards were all VSP trained and received three sulphur and either no or four copper sprayings. The adjacent vineyards with traditional grapevine varieties received on average nine sulphur and 11 copper sprayings and were also VSP trained. Vineyards were between two and 52 years old and at least two rows wide. Minimally pruned and vertical shoot positioned vineyards were on average 26.7 ± 8.5 and 20.6 ± 8.5 years old, respectively. Due to the novelty of fungus resistant cultivars, PIWI vineyards were on average 12.5 ± 6 years old, whereas the vineyards planted with traditional varieties were on average 27 ± 11.7 years old. Where possible, the outer rows were excluded from sampling to prevent edge effects. There were no known arthropod pest outbreaks during the sample period. Spiders were collected using a drop cloth method. They were dislodged from the plants by shaking them onto a beat sheet with a 72 cm diameter, where they were collected and later conserved in 70% EtOH. Fifteen

Table 1.—Adult spiders caught in minimally pruned (SMPH) and vertical shoot positioned (VSP) grapevines, as well as in vineyards planted with PIWI (fungus resistant) and traditional varieties.

Family	Species	Pruning		Grapevine type	
		SMPH	VSP	PIWI	Traditional
Araneidae	<i>Araneus diadematus</i> Clerck, 1757	2			
	<i>Araniella cucurbitina</i> (Clerck, 1757)		1		
	<i>Araniella opisthographa</i> (Kulczyński, 1905)	3		1	
	<i>Mangora acalypha</i> (Walckenaer, 1802)	1		4	1
	<i>Zygiella x-notata</i> (Clerck, 1757)			1	
Dictynidae	<i>Dictyna uncinata</i> Thorell, 1856	4	1	5	2
Linyphiidae	<i>Agyreta rurestris</i> (C.L. Koch, 1836)		1	1	
	<i>Araeoncus humilis</i> (Blackwall, 1841)	1	1		
	<i>Erigone dentipalpis</i> (Wider, 1834)			1	
	<i>Tenuiphantes tenuis</i> (Blackwall, 1852)	5	3	2	3
Philodromidae	<i>Philodromus cespitum</i> (Walckenaer, 1802)	6	3	11	12
Salticidae	<i>Ballus chalybeius</i> (Walckenaer, 1802)			1	
	<i>Heliophanus auratus</i> C.L. Koch, 1835	2	6	5	5
	<i>Marpissa muscosa</i> (Clerck, 1757)	3	2	6	8
	<i>Pseudicius encarpatus</i> (Walckenaer, 1802)				1
	<i>Salticus scenicus</i> (Clerck, 1757)	4	8	3	2
	<i>Salticus zebraneus</i> (C.L. Koch, 1837)				4
	<i>Synageles venator</i> (Lucas, 1836)	3	2	1	1
Theridiidae	<i>Dipoena melanogaster</i> (C.L. Koch, 1837)	2	1		
	<i>Enoplognatha latimana</i> Hippa & Oksala, 1982			2	2
	<i>Neottiura bimaculata</i> (Linnaeus, 1767)	1			1
	<i>Phylloneta impressa</i> (L. Koch, 1881)	2	6	4	1
	<i>Theridion asopi</i> Vanuytven, 2014		1	3	
Thomisidae	<i>Synema globosum</i> (Fabricius, 1775)			2	
Uloboridae	<i>Hyptiotes paradoxus</i> (C.L. Koch, 1834)	1	1		

randomly selected vines in each vineyard were shaken for five seconds and the collected spiders were combined into one sample. This process was repeated four times between June and September 2017. Adult spiders were identified to species and immatures to the family level using the identification keys of Roberts (1987, 1995) and Nentwig et al. (2018). Nomenclature follows the World Spider Catalog Version 20.5 (World Spider Catalog 2019). Since the majority of individuals were immature, our analysis used pooled family data from all four sampling dates. We used paired t-tests in Sigma Plot (Systat Software, San Jose, CA) to detect effects of pruning and fungicide application frequency on total spider abundance and family richness, as well as the abundance of single spider families. To compare spider communities between treatments we used a permutational MANOVA in R (version 3.0.2) (function 'adonis' in the vegan package (version 2.2-1), 999 permutations) using the number of individuals per family, with vineyard pairs as "strata" to account for the paired design (R Development Core Team 2010; Oksanen et al. 2015). Since PIWI vineyards were on average 14.5 years younger than traditional vineyards, we also tested for a possible confounding influence of vineyard age on the spider community, using the same procedure as described above.

Overall, we collected 1,481 spider individuals, 175 of which were adults. They belonged to at least 25 species in 16 families (Table 1). Most spiders belonged to Salticidae (22.2 % of individuals) closely followed by Theridiidae (20.2 %), Araneidae (19.9 %) and Philodromidae (17.4 %). *Philodromus cespitum* (Walckenaer, 1802) (Philodromidae) (19.4 % of adult spiders), *Marpissa muscosa* (Clerck, 1757) (10.9 %) and *Heliophanus auratus* C. L. Koch, 1835 (10.3%) (both Salticidae) were the most common species.

While neither the overall abundance nor the species richness of spiders was significantly affected by the applied pruning method, spider communities differed significantly between minimally pruned vineyards and VSP vineyards ($R^2 = 0.21$, $P = 0.002$, Fig. 1A).

Dictynidae and Philodromidae were significantly more abundant in SMPH than in VSP vineyards (Dictynidae: $t_7 = 2.56$, $P = 0.04$, Philodromidae: $t_7 = 3.17$, $P = 0.02$). Salticidae, on the other hand, were more abundant in VSP than in minimally pruned vineyards ($t_7 = -4.47$, $P = 0.003$) (Fig. 1A).

Overall spider abundance and species richness were not significantly higher in PIWI grapevines compared to traditional varieties, which received about three times as many plant protection treatments. More intense plant protection measures in traditional grapevines also didn't cause a significant change in the spider community ($R^2 = 0.09$, $P = 0.11$, Fig. 1B). We found no significant effects of vineyard age on spider communities ($R^2 = 0.22$, $P = 0.82$). Theridiidae were the only family in which abundance was significantly affected by plant protection intensity. Their abundance was more than two times higher in PIWI vineyards than in vineyards with traditional grapevine varieties ($t_7 = -2.715$, $P = 0.03$, Fig. 1B).

The significantly different spider communities between SMPH and VSP vineyards can probably be explained by the drastic differences in the structure of the canopy, which also affects the microclimate, making the SMPH canopy slightly cooler and more humid than in VSP (Kraus et al. 2018). There are examples in the literature describing a positive relation between the structural diversity of vegetation and spider diversity (Greenstone 1984; Scheidler 1990; Whitmore et al. 2002). We can confirm this positive relation for Dictynidae and Philodromidae, which benefitted from SMPH versus VSP grapevine. The one member of the Dictynidae we could identify to the species level is *Dictyna uncinata* Thorell, 1856. We assume that most immature Dictynidae can be grouped in the same genus or even the same species. *Dictyna uncinata* is often found high in vegetation, especially in brush and hedges, where it builds webs on tips of branches and on the underside of leaves (Harvey et al. 2002). There were significantly more branches and leaves per plant in SMPH than in VSP vineyards, which provides more habitat for these small spiders

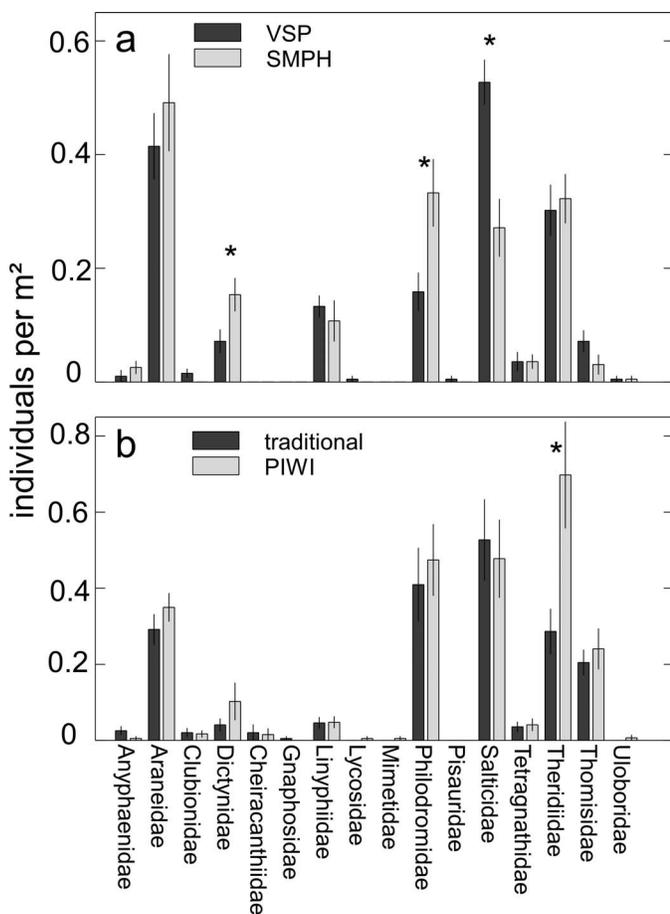


Figure 1.—Number (\pm SE) of spider individuals per m²: (A) in vertical shoot positioned (VSP) or in minimally pruned (SMPH) vineyards ($n = 32$); (B) in vineyards planted with traditional grapevine versus fungus resistant (PIWI) grapevine varieties ($n = 32$). * $P < 0.05$.

(Kraus et al. 2018). Philodromidae are cursorial spiders, which likely benefit from better and more abundant overwintering opportunities provided by old wood in SMPH vineyards (Pékar 1999a). In VSP vineyards, all old wood other than the stem is removed, severely limiting shelter during winter. *Philodromus cespitum* is abundant in orchards across Europe (Bogya et al. 1999; Pekár 1999a,b) and is useful for biocontrol of a wide range of pest insects, but also preys on other spiders (Michalko & Pekár 2015). In contrast to the aforementioned spider families, Salticidae were significantly less abundant in SMPH than in VSP pruned vineyards. They are visually oriented hunters (Harland et al. 2012) and may benefit from more light and higher temperatures in VSP pruned grapevines.

The only family that was significantly affected by PIWI vs. traditional varieties were Theridiidae. This pattern might be explained by their web-building lifestyle and the higher frequency of disturbances in traditional varieties, which needed three times as many plant protection treatments during the growing season in our study. Usually, Theridiidae build webs that stay in place for an extended period of time (Benjamin & Zschokke 2003). Frequent disturbances by fungicide treatments might destroy those webs and thereby be a fitness disadvantage. Spider webs have also been shown to be efficient at collecting agricultural spray (Samu et al. 1992), hence web-building spiders might be even more exposed to the fungicides than cursorial spiders. Such negative effects of fungicides on non-target arthropods can reduce natural biological control of grapevine pests (Pennington et al. 2018), even if reduced activity of ants rather than spiders

appeared responsible for the reduced predation of grape berry moth (*L. botrana*) eggs under intensive fungicide regimes in that study.

As the effects of fungicide application frequency and minimal pruning on spiders were family-specific, possible consequences for natural pest control by spiders requires specific knowledge about the roles of the affected spider families in the vineyard canopy. Conclusions from our study are limited by the moderate number of sampled spiders. However, we demonstrate that spiders in grapevine canopies are sensitive to management, and should be more widely considered in ecological studies of vineyards, especially given the known sensitivity of ground-dwelling spiders to different management practices in vineyards and other agricultural systems (Schmidt et al. 2005; Bruggisser et al. 2010).

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