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Original article (Orijinal araştırma)

Coexistence of four orb-web spiders in an oil palm plantation in Peninsular Malaysia

Batı Malezya'da yağlık palmiye plantasyonunda küresel ağlı dört örümcek türünün bir arada bulunması

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Abstract

Thirty adult female individuals of each of the four orb-web spider species namely *Araneus* sp. (Araneidae), *Gasteracantha kuhli* Koch, 1837 (Araneidae), *Gasteracantha hasselti* Koch, 1837 (Araneidae) and *Opadometa grata* (Simon, 1877) (Tetragnathidae) were randomly sampled between 1000 and 1400 h from May to July 2017 in an oil palm plantation in Perak, Malaysia. Morphological and web characters of these orb-web spiders were obtained and analyzed using principal component analysis (PCA) and bootstrapping methods. For the morphological characters, the PCA results captured a total of 99% of the variance and indicate that the Araneid species have distinct clustering. For the web characters, the PCA captured 76% of the total variance and did not show any distinct clustering with significant overlapping between them. Moreover, the mean and 95% confidence intervals using bootstrapping identified significant differences in the morphological and web characters for most spider species with little overlap. This study indicates that the four orb-web spider species could coexist in terms of their spatial territory and food resources in the oil palm plantation, suggesting that these resources were not a limiting factor.

Keywords: Agriculture, co-occurrence, homogeneous habitat, niche overlap

Öz

Araneus sp. (Araneidae), *Gasteracantha kuhli* Koch, 1837 (Araneidae), *Gasteracantha hasselti* Koch, 1837 (Araneidae) ve *Opadometa grata* (Simon, 1877) (Tetragnathidae), isimli küresel ağlı dört örümcek türünden her birinden otuz yetişkin dişi birey, Perak, Malezya'daki bir yağlık palmiye plantasyonunda Mayıs-Temmuz 2017 tarihleri arasında 1000 ila 1400 saat arasında gündüz rastgele olarak örneklenmiştir. Bu küresel ağlı örümcek türlerinin, morfolojik ve ağ karakterleri, temel bileşen analizi ve önyükleme yöntemleri kullanılarak elde edilmiş ve analiz edilmiştir. Morfolojik karakterler için, temel bileşen analiz sonuçları, varyansın toplam %99'unu yakalamış ve Araneid türlerinin ayrı bir grup oluşturduğunu göstermiştir. Ağ karakterleri için, temel bileşen analizi toplam varyansın %76'sını yakalamış ve aralarında belirgin bir örtüşmeyle ayrı bir grup özelliği göstermemiştir. Öte yandan, önyüklemeyi kullanan ve ortalama %95 güven aralığında, örümcek türlerinin çoğunda küçük çakışmalar için morfolojik ve ağ karakterlerinde önemli farklılıklar tespit etmiştir. Bu çalışma, küresel ağlı dört örümcek türünün, yağlık palmiye plantasyonundaki alansal topraklar ve besin kaynakları açısından bir arada bulunabileceğini ve bu kaynakların sınırlayıcı bir faktör olmadığını göstermektedir.

Anahtar sözcükler: Tarım, birlikte bulunma, homojen habitat, niş örtüşmesi

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Introduction

In agricultural pest management, beneficial organisms were used for biological control of insect pest populations (Norma-Rashid et al., 2014). Spiders, a highly successful group of natural predators have been identified as efficient natural predators in agriculture ecosystems (Maloney et al., 2003). Their polyphagous diet (Marc & Canard, 1997), high resistance to insecticides (Hoque et al., 2002) and coexistence capability in different niches (Norma-Rashid et al., 2014) make them potential agents for effective biological control in agriculture ecosystems. Previous studies have demonstrated the importance and benefits of different spider species in pest control (Riechert & Lawrence, 1997; Motobayashi et al., 2007; Tahir et al., 2009). These studies revealed that different spider species have specific roles and thus, higher spider species diversity can provide more effective control of pest populations (Marc et al., 1999).

Orb-web spiders of similar guild living in the same habitat often compete for the same resources so may differentiate their niches (Richardson & Hanks, 2009; Dzulhelmi, 2016). They can be distinguished morphologically, and portray distinctive web characteristics and/or web placement within a particular vegetation type, which results in a confined spatial use and non-interfering target and amount of prey (Richardson & Hanks, 2009; Tahir et al., 2009, 2012; Dzulhelmi et al., 2017). Spiders divide their habitat niches at fine scales, facilitating different hunting strategies, attuned naturally to capture specific types of prey (Wise, 1993; Schmitz & Suttle, 2001; Malumbres-Olarte et al., 2013). As sit-and-wait type of predators, orb-web spiders opt to regularly alter their web characteristics and/or relocating the placement of the web to a more profitable locations to increase prey-capture efficiency (Scharf et al., 2011). Factors that influence the process include the maturity, competition, predation risks and prey types of spiders within a particular habitat (Dzulhelmi, 2016). However, there is no defined optimum capture efficiency in the mechanism for changing the placement of the web, except through lifelong trial and error (Scharf et al., 2011). This strategy will create niche partitioning that reduces the amount of niche overlaps between the competitor species and allows the spiders to coexist within the same area (Tahir et al., 2012). Moreover, when the habitat is less complex, there is likely to be fewer niches available (Jimenez-Valverde & Lobo, 2007). In this study we focus on four common diurnal open-hub orb-web spider species, *Araneus* sp. (Araneidae), *Gasteracantha kuhli* Koch, 1837 (Araneidae), *Gasteracantha hasselti* Koch, 1837 (Araneidae) and *Opadometa grata* (Simon, 1877) (Tetragnathidae). Our objective was to determine if there are any niche overlaps between these species in an oil palm plantation using morphology and web characteristics differences as proxy measures of the species niche spaces.

Material and Methods

Study area

The fieldwork was conducted at an oil palm plantation (4°02’51” N, 101°01’08” E) in Perak State, Peninsular Malaysia. The sampled plot of 10 ha consists of palms aged 10-years old with tree height of about 10 m growing in peat soil.

Data collection

Thirty adult female individuals for each of the four orb-web spider species were randomly sampled between 1000 and 1400 h from May to July 2017. The vertical distance of the orb-web from the ground (height) was measured from the soil surface to the center of the orb-web *in-situ*. The webs were then dusted with white powder to increase visibility and to enhance photography resolution. Then, a measuring tape was held next to the webs to ensure proper scaling of the web during photography (Dzulhelmi et al., 2017). Other web characteristics, i.e., web-area, free-zone area, hub-area, mesh-size, number of spirals and number of radii, were measured directly from the photographs with the scale calibrated using KLONK Image measurement software. The occupant of the individual on each web were collected, stored in vials containing 75% ethanol and brought to the laboratory. The individuals collected were photographed, and body length and carapace width measured using a Portable Capture Pro v2.1 Dinolite (China). Wet weights of each individual were measured with weighing scale. Species determinations were made according to Koh & Ming (2013) and Dzulhelmi & Suriyanti (2015).

Statistical analysis

The mean and standard deviation of each morphological and web characteristic variable of each spider species were plotted to examine the spread of the data. Principal component analysis (PCA) was used on the multivariate data sets to be easily visualize by reducing the number of dimensions within the dataset (PCA has been widely used to describe the niche space of spider species). In this study, the morphological and web characteristics were analyzed separately. PCA analysis was used to determine if there was distinct clustering in terms of morphological and web characteristics. The variables were standardized by taking the log and default settings were used for the PCA. Also, the bootstrap is a statistical tool to quantify uncertainty associated with a given estimator. From relatively small datasets, it can produce accurate estimates and standard errors of the parameters in the original distribution by resampling the dataset. Unlike null hypothesis statistical tests such as ANOVA, bootstraps can be applied to data in which there are violations of parametric assumptions and yield standard error estimates which do not depend on the parametric assumptions of traditional tests. The 95% confidence intervals (CI) derived from each parameter can be used as a hypothesis test, in which significant differences between estimates can be detected when there is no overlap between 95% CI. The bootstrap estimates of the mean and 95% CI were plotted on a radar chart to visualize the fundamental niche space of each of these spider species. The vegan package was used for PCA (Oksanen et al., 2017), boot package for bootstrapping (Canty & Ripley, 2017) and FMSB was used to plot the radar graphs (Nakazawa, 2017). All the analysis was performed using R 3.2.2 (R Core Team, 2015).

Results

A total of 120 adult females representing four orb-web spider species with 30 individuals for each species were collected in the study area. The morphological characteristics of these four-spider species were distinctive especially in terms of total length and carapace width, when these two characters are examined together the spider species can be quite easily differentiated (Figure 1). The four-spider species differed significantly in wet weight (df = 3, F = 169, $P < 0.0001$), total length (df = 3, F = 152, $P < 0.0001$) and carapace width (df = 3, F = 427, $P < 0.0001$).

For PCA on morphological characteristics, the PC1 captured 97% of the variance while the PC2 captured 2% of the remaining variance, resulting in a cumulative total of 99% of the variance explained (Figure 2, Table 1). The PCA biplot of morphological characteristics indicates that the Araneid spider species form distinct clustering. The *G. kuhli* is smaller than *G. hasselti* while *Araneus* sp. is distinctly larger than the two former spider species. However, *O. grata* did not form a distinctive cluster, overlapping with *G. kuhli* in terms of body size. There was no significant difference between *G. hasselti* and *O. grata* in body length. *Gasteracantha hasselti* has longer body protruding from the side equipped with long spines while *O. grata* has a pyriform abdomen and strongly overhang the carapace. Absence of significant differences in wet weight and carapace width between *G. kuhli* and *O. grata* may have contributed to obvious overlap between the two spider species in the PCA biplot.

Whereas, most web characteristics of these four-spider species had overlaps in standard deviation (Figure 1). For PCA on web characteristics, the percentage of variance captured in PC1 was 56% while PC2 captured 20% of the remaining variance for a cumulative total of 76% of the variance (Figure 3, Table 2). The PCA biplot of web characteristics show that the four orb-web spider species did not show any distinct clustering in their web characteristics, with large amount of overlap between them.

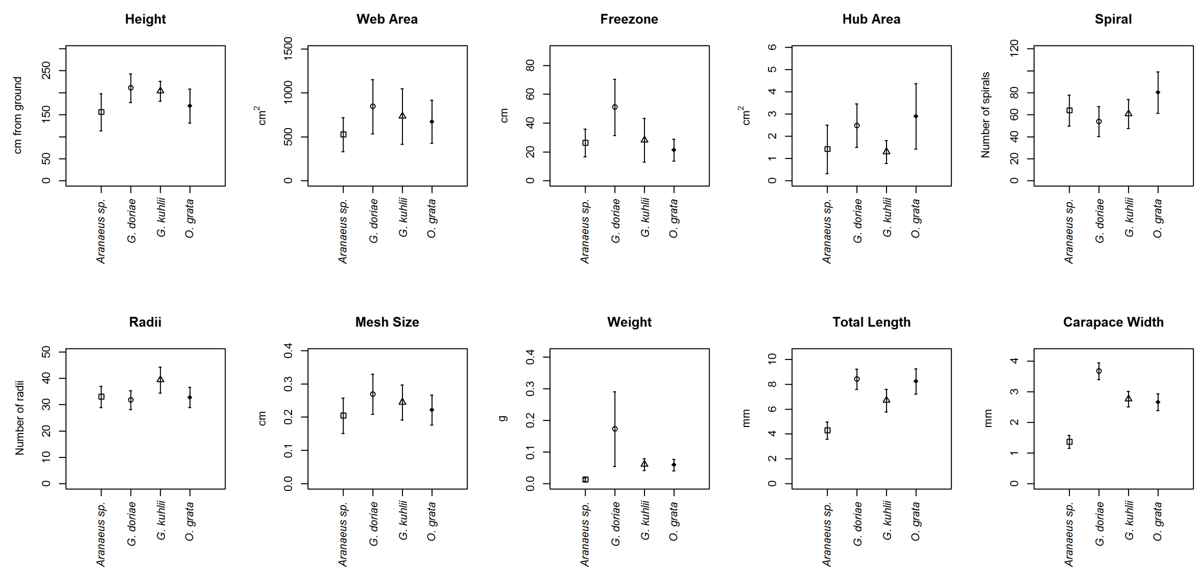

Figure 1. The means and the standard deviations of each species.

Table 1. The loadings for the principle component analysis for morphological characteristics

Morphological characteristics		
Variables	PC1	PC2
Weight	3.0666	0.1670
Total length	0.8729	-0.3438
Carapace width	1.1494	-0.1845

Table 2. The loadings for the principle component analysis for web characteristics

Web characteristics		
Variables	PC1	PC2
Height	0.1902	0.1550
Web-area	1.0375	0.0857
Freezone-area	1.5520	0.8676
Hub-area	1.6011	-0.9806
Number of spirals	-0.0364	-0.6061
Number of radii	-0.0160	0.0000
Mesh-size	0.3180	0.2612

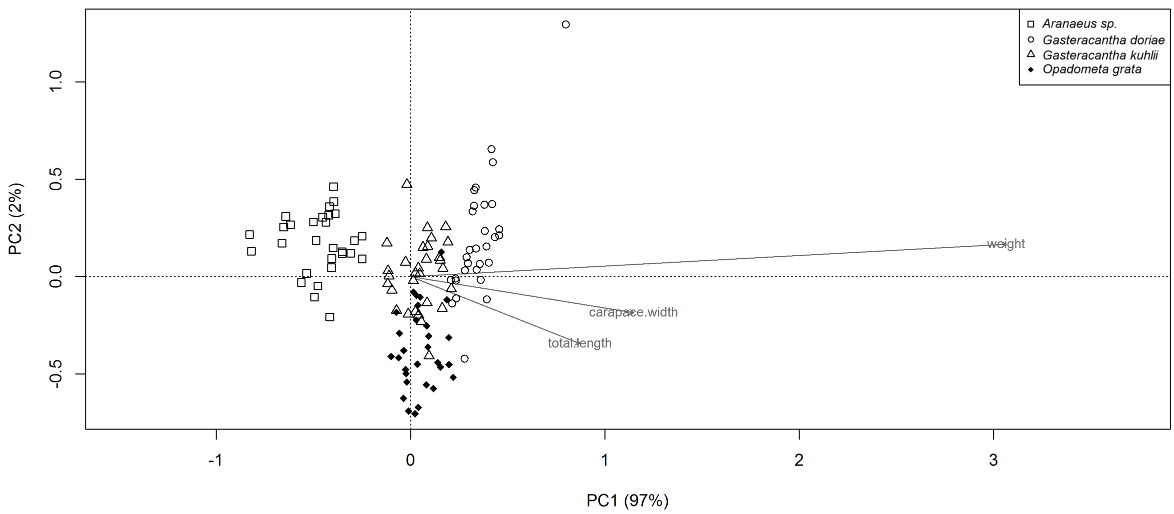

Figure 2. The principle component analysis biplot of morphological characters.

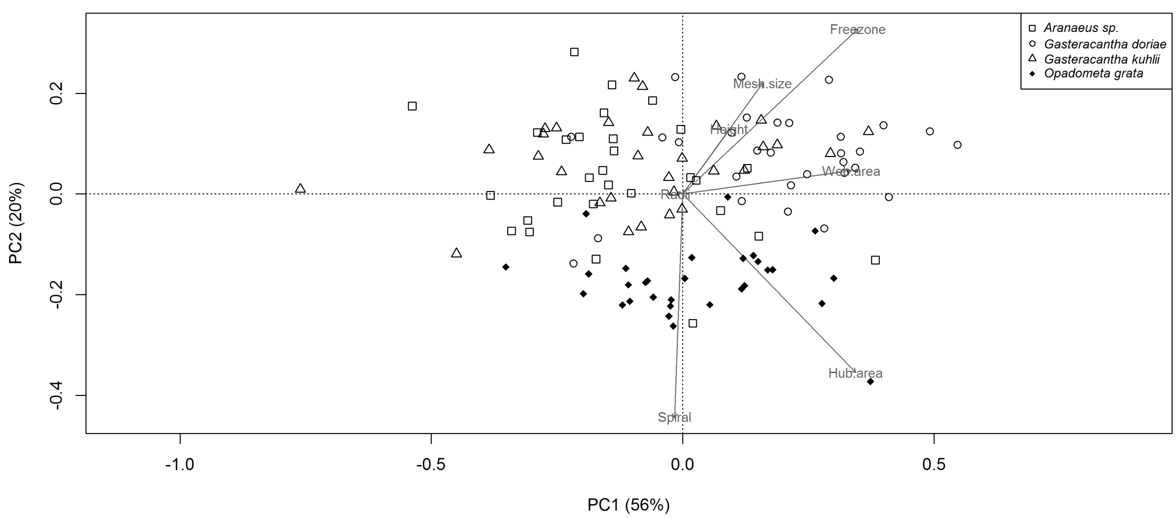

Figure 3. The principle component analysis biplot of web characters.

The means and 95% CI using bootstrapping for the morphological and web characteristics were estimated (Figure 4). Unlike the means and standard deviations, the nonparametric 95% CI were significantly different for most species with little overlap. This indicates that the means that generate the distribution of web characteristics are distinctly different between these orb-web spider species.

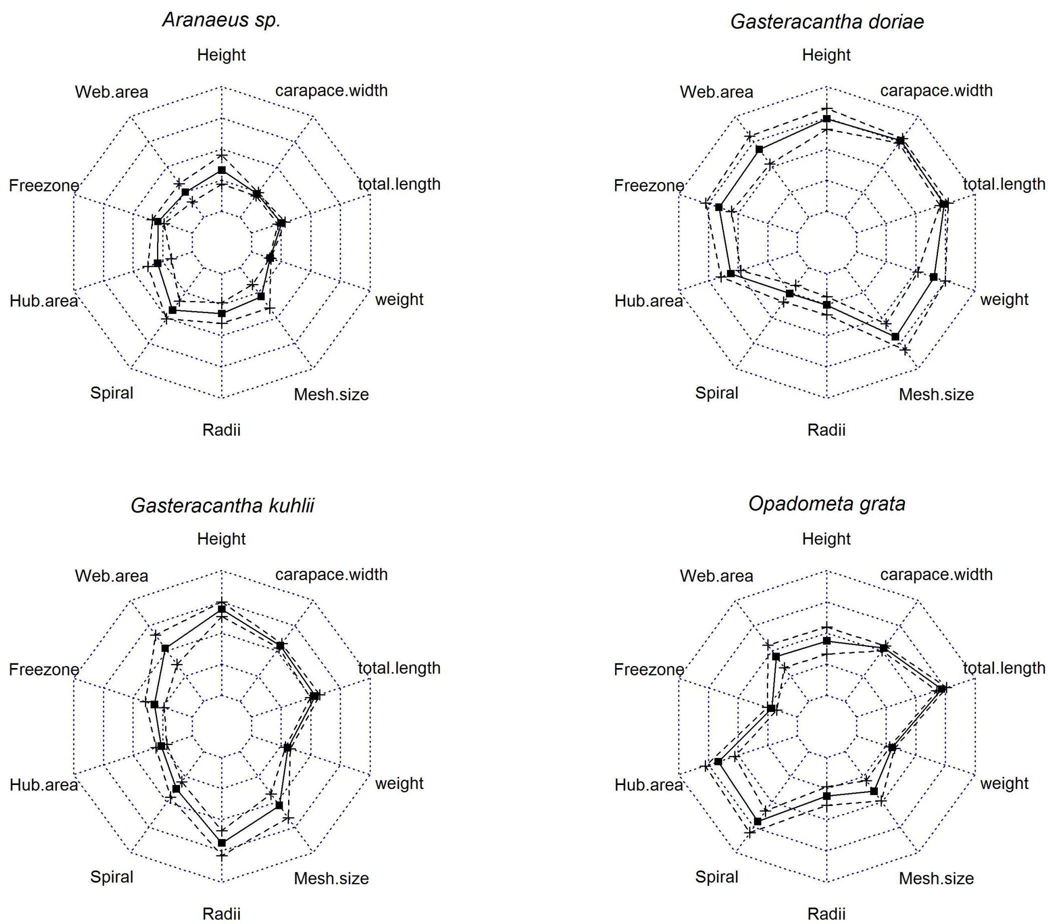

Figure 4. Radar plots of the means and 95% confidence intervals for the web and morphological characters of each species. The square represents the mean while the dotted lines are the 95% confidence intervals for each estimate.

Discussion

Web-building spider species differ in where webs are positioned within the vegetation, which is driven by differences in web type and web structure (e.g., spacing of mesh, web size, height of web placement, and the sizes of prey captured) (Gómez et al., 2016). Orb-web spider species found at higher distance from the ground are normally larger and heavier than the lower ones (Henaut et al., 2006; Tahir et al., 2010). They may target larger prey types that can be captured at higher sites. The prey types captured were associated with the body size of the orb-web spiders, where larger spider tends to capture larger prey types (Richardson & Hanks, 2009). In this study, the PCA biplot on morphological characteristics indicate that the three Araneid spider species had distinct clustering, while *O. grata* overlaps with *G. kuhli* in their body sizes. There was no significant difference between *G. hasselti* and *O. grata* in body length. *G. hasselti* has longer body protruding from the side equipped with long spines while *O. grata* has a pyriform abdomen and strongly overhang the carapace. Absence of significant differences in wet weight and carapace width between *G. kuhli* and *O. grata* may have contributed to obvious overlap between the two spider species in the PCA biplot.

In order to coexist, orb-web spider species need to segregate in other niche dimensions such as food, time and microhabitat resources in a shared environment (Butt & Tahir, 2010). They need to avoid competition by specializing in specific niche spaces that do not overlap with those of other orb-web spider species (Richardson & Hanks, 2009; Dzulhelmi et al., 2017). However, in this study, this does not appear to have been the case as indicated by both the PCA biplots, and the mean and standard deviations. In some of the web characteristics, there were many overlaps between the four orb-web spider species. For instance, *G. hasselti* with *G. kuhli* and *Araneus* sp. with *O. grata* constructed their webs at similar locations. *Araneus* sp., *G. hasselti* and *O. grata* were close in number of radii, while *Araneus* sp. and *G. kuhli* had about the same freezone-area and hub-area. The extent of the overlap in web characteristics among these orb-web spider species implies that prey availability is not a limiting factor in this particular habitat. Hence, two communities can share the same resource without competing with one another, and niche overlap may be higher (Uetz et al., 1978; Butt & Tahir, 2010). They would maintain their webs at that particular locations especially when there is enough available space to construct their webs with excessive food resources within reach and less competition (Dzulhelmi et al., 2018). However, when prey availability becomes a limiting factor, some orb-web spider species might exploit different food and occupy different space resources to reduce competition (Enders, 1974; Uetz et al., 1978; Butt & Tahir, 2010).

In contrast, the nonparametric 95% confidence intervals for web characteristics showed that there was a significant difference in the means for most orb-web spider species with little overlap. This indicates that while the spiders were building webs that overlapped in terms of size, shape and placement, many of the parameters that were generating the variation of web design in each species were significantly different from one another. It could be that those mean values represent an optimum web design for the natural habitat of the spiders, while the observed webs in the PCA were webs that were free of the resource constraints of the original habitat. These mean values suggest that webs of each species were designed for their natural niche constraints. The *Araneus* sp. constructed small webs at lower height, while *O. grata* constructed larger web but at almost similar height to *Araneus* sp. Lower height provided vegetation with suitable attachment points for smaller webs (McCravy & Hessler, 2012). Larger orb-web spider species tend to construct larger web-area, but do not necessarily construct webs at greater height (Tahir et al., 2012). Then again, *G. hasselti* and *G. kuhli* constructed their webs with comparable web-area and at greater height. This little overlap in either web-area or distance from the ground has been identified as contributor to resource partitioning and may reflect difference in use of space resources for *Micrathena gracilis* and *M. mitrata* (McCravy & Hessler, 2012). This demonstrates that the spiders may have evolved to avoid niche overlap in certain types of habitat. Anthropogenic disturbance caused by oil palm plantation may have caused the spiders to refine their web structures to suit the new environment, though a stable equilibrium point has yet been reached.

The shape, structure and sites in which webs are placed are in response to prey availability (Moore, 1977; Blackleadge et al., 2003), where orb-web spiders may relocate their webs in response to these prey types (Moore, 1977; McReynolds, 2000; Henaut et al., 2006). It is possible in an oil palm plantation there is an altered availability of prey compared to the spiders natural habitats, and deviation from evolutionarily optimized web designs are necessary to take advantage of these new conditions. However, web design may still be influenced by evolutionary trends. This study was not able to quantify the prey captured by these orb-web spider species, but understanding what prey the spiders consume in oil palm plantations may give better insights into the niche plasticity of these species as well as possible commercial benefits of using spiders for integrated pest management.

Conclusion

The results of this study showed obvious overlap of web characteristics despite the morphological differences in the four orb-web spider species. This study indicates that the four orb-web spider species were tolerant of their spatial territory and food resources in the oil palm plantation, suggesting that these were not a limiting factor. The naturally occurring spider in the oil palm plantation should also be further investigated and manipulated for insect pest management.

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