



## Original article

Phenology and abundance of date palm mite *Oligonychus afrasiaticus* (McGregor) (Acari: Tetranychidae) in Riyadh, Saudi Arabia

Jawwad Hassan Mirza, Muhammad Kamran, Fahad Jaber Alatawi\*

Acarology Laboratory, Department of Plant Protection, College of Food and Agriculture Sciences, King Saud University, Riyadh 11451, Saudi Arabia

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## ABSTRACT

In the present study, we evaluated the effect of management practices, fruit season, host habitats (young and old fronds, date fruits and grasses), and temperature on the phenology and abundance of the date palm mite (DPM). The study was conducted in two date palm orchards (two plots each): a managed and an unmanaged plot. The phenology of DPM was assessed based on adult cumulative mite days (ACMDs), while mean mite density was used to assess the mite abundance on different host habitats. The ACMDs and mean mite density were significantly different between managed and unmanaged plots on different host habitats in both fruiting and off-seasons. The date fruits had highest ACMDs during fruiting season. While young fronds had significantly higher ACMDs than on old fronds on grasses during both seasons in both plots. The temperature and season type significantly affected the mean density of DPM eggs and adults. There was a significant effect of host habitats mean density of DPM eggs and immatures. Based on the adult phenology and abundance of DPM, the mite overwinters in young fronds and aerial offshoots of infested date palm trees. These overwintering DPM caused the seasonal date fruit infestation, each year. Additionally, different phytophagous and predatory mites, which co-occur with DPM, and were found on different host habitats affected the phenology and abundance of DPM. Moreover, the change in DPM body color was related to the host habitat that they fed in. Exceptionally, the brown color of females collected during the winter season could be due to physiological changes due to low temperature. In DPM males collected from different host habitats throughout the study, some morphological variations in the width of the knob, height of the hook, and the angle between the knob axis and dorsal margin of the shaft were also recorded. The results of this study suggest that young fronds and grasses are the suitable sites for DPM survival and overwintering. Hence, the management practices, early in the fruit season and/or during off fruit winter months, should be directed towards these habitats. These could provide efficient reduction in seasonal infestation of DPM.

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## 1. Introduction

The development of insects and mites depends on and is mainly modified by cues from the prevailing environmental temperature (Belozarov, 2009; Jarošik et al., 2011; Pedigo and Rice, 2014; Hoy, 2011). The changing population levels of insect and mite species in different habitats, when strongly linked with climate or temper-

ature, becomes a measure of its phenology (Nietschke et al., 2007; Pau et al., 2011; Logan et al., 2006; Hodgson et al., 2010; Walton et al., 2010; Vangansbeke et al., 2015). Phenology is defined as “the timing of periodic life history events”, such as diapause, molting, and time of emergence or infestation (Hodgson et al., 2010; Visser, 2008). The factors influencing the phenology of mites include the photoperiod (Visser, 2008), acaricide applications (James, 2000; Kim and Lee, 2003; Woods et al., 2012), the presence of predators (Walton et al., 2010), alternate hosts (James, 2000; Kim and Lee, 2003), and the phenology of the host plant (Herms, 2004; Palevsky et al., 2003, 2004; Samah and Chermiti, 2010; Arnemann et al., 2015; Dar et al., 2015).

The phenology of economically important insect and mite pests is studied to understand the effect of changing climate on their life history traits and to practice integrated management (Nietschke et al., 2007; Richardson et al., 2009). In this regard, numerous

\* Corresponding author.

E-mail addresses: [jmirza@ksu.edu.sa](mailto:jmirza@ksu.edu.sa) (J.H. Mirza), [kamran1513@gmail.com](mailto:kamran1513@gmail.com) (M. Kamran), [falatawi@ksu.edu.sa](mailto:falatawi@ksu.edu.sa) (F.J. Alatawi).

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bio-ecological studies concerning seasonal changes have been conducted in insects (Rock et al., 1993; Menzel et al., 2006; Doi et al., 2008; Doi and Takahashi, 2008; Hodgson et al., 2010) and mites (Kim and Lee, 2003; Walton et al., 2010; Vangansbeke et al., 2015; Palevsky et al., 2010; Patankar et al., 2012; Hardman et al., 2005; James et al., 2001; Woods et al., 2012). As all developmental stages of a species are not vulnerable to control and management practices, phenology data highlights the susceptible pest stages (Ascerno, 1991; Visser, 2008).

The date palm mite (DPM) *Oligonychus afrasiaticus* McGregor (Acari: Tetranychidae) is distributed in the Afrotropical, Nearctic, and Palearctic regions of the world (Migeon and Dorkeld, 2020). It is a severe mite pest of the date palm *Phoenix dactylifera* L. and is also reported to infest other palms such as *Washingtonia* sp. (Palevsky et al., 2003; Alatawi, 2020), and narrow leaf host plants, especially grasses (Alatawi and Kamran, 2018; Migeon and Dorkeld, 2020). The DPM develops exponentially during the unripe, Kimri stage characterized by low sugar, high acidic, and moisture contents (Palevsky et al., 2005). During the entire Kimri fruit stage, the biological (e.g., egg-laying) and behavioral (i.e., web-spinning) activities of DPM are at their peak (Palevsky et al., 2003, 2004, 2005). It results in the whole fruit bunch being covered by highly dense, complicated webs, scarred and damaged fruits. The management practices like release of biocontrol agents (web causes hindrance to predator efficiency) or acaricide applications (dense webs become impermeable to chemicals), become ineffective which causes increased DPM infestation and increased economic loss. During the winter season, DPM individuals have been observed in fronds, crown fibers, grasses, and other alternate host plants (Hussein, 1974; Guessoum, 1986; Ben Chaaban et al., 2011a, b, 2017; Latifian et al., 2014, 2017; Palevsky et al., 2003, 2004; Alatawi, 2020).

Previously, the population dynamics, abundance, and spatio-temporal distribution of the DPM have been studied under the effects of date palm cultivar, physio-chemical properties of fruits, cultural practices, chemical applications, and sand storms (Palevsky et al., 2003, 2005; Ben Chaaban et al., 2011a,b; Latifian et al., 2011, 2014; Guessoum et al., 2016). In the Kingdom of Saudi Arabia, the DPM has been studied for the effect of date palm cultivar on its natural infestation, field sex ratio during the fruiting season and occurrence, alternate host plants, and field mortality factors during the off-season (Aldosari and Ali, 2007; Alatawi et al., 2019; Alatawi, 2020). Also, monitoring and sampling methods, possible causes of its outbreak, and comparison of different management practices have been reviewed (El-Shafie, 2019a,b). Previously, the phenology of the DPM in Saudi Arabia has not been studied. Therefore, the present study aimed to study the effect of temperature, season, different host habitats, and management practices (e.g., acaricide application and clean cultivation) on the phenology and abundance of DPM in Riyadh, Saudi Arabia. The phenotypic variations in DPM adults were also characterized in the present study.

## 2. Material and methods

### 2.1. Study areas

The study was conducted in two date palm orchards (situated in vicinity to each other, about 10 m apart) with the same date palm cultivar in Al-Ammariya (24°48.01 N, 46°26.65E), Riyadh. It was confirmed that the selected orchards were infested with DPM in previous years. Each orchard was divided into two plots: 1) a managed plot at the front of orchard (with different cultural practices, i.e., clean cultivation, pruning of date palm offshoots, and acaricide applications) and 2) an unmanaged plot at the back of orchard

(without any cultural practices or acaricide application). Both the plots were about 5 m apart from each other, within an orchard.

### 2.2. Collection of DPM

DPM sampling began in September 2017 and continued for 16 months until December 2018. Thirty-five visits were made, and the orchards were visited fortnightly during the off-season and at 10-day intervals during the fruiting season. Different DPM developmental stages (eggs, immatures, and adults) were collected throughout the study period from date palm vegetative parts (offshoots or young fronds (YF), old fronds (OF), and crown fibers), ground cover grasses (G), and different date fruit (DF) stages.

During each visit, 16 fronds (eight from each of YF and OF) from four different trees (minimum plant to plant distance = 7 m) were sampled, randomly, from each plot. During the off-season, 90-cm-long frond sections (two each of YF and OF) were taken from each tree. During the fruiting season, nine leaflets from the outer (apical), middle, and inner (basal) sections were cut from each frond. Also, nine fruit strands from three fruit bunches (three fruit strands/bunch) from each tree were sampled. Hence, the sample size for each visit was 32 fronds during the off-season (2 plots × 4 trees × 4 fronds), and 288 leaflets during the fruiting season (2 plots × 4 trees × 4 fronds × 9 leaflets) and 56 fruit strands (2 plots × 4 trees × 9 fruit strands). The offshoots were not found on all sampled trees; thus, they were not considered a separate sampling unit. Instead, DPM stages collected from offshoots were added to the data of young-aged fronds. A handheld aspirator was used to collect mites from tree crown fibers and grasses grown underneath the tree. All the collected samples were placed in labeled disposable bags and brought to the Acarology Research laboratory (King Saud University, Riyadh) for mite extraction and species identification.

The temperature was recorded using a HOBO data logger (Onset) that was placed in each sampled tree during each visit. The daily/monthly temperature and relative humidity data for the entire period of study were taken from the Al-Traif Al-Jadidah Meteorological Station (Al-Diriyah), which was nearest to the study area.

### 2.3. Data collection and identification of DPM

The collected samples and aspirator vials were carefully examined under an Olympus® stereomicroscope (SZX2-FOF) in the laboratory to count the number of DPM. The different DPM stages (eggs, immatures, and adults) were collected using a fine-tipped brush either directly by picking individuals from date palm fronds or by dusting the date fruits (DF) strands and aspirator vials on a petri dish. Some DPM adult specimens (females and males) were mounted on glass slides using Hoyer's medium and were identified under an Olympus® phase-contrast microscope (BX51) using the identification keys in the available literature (Jeppson et al., 1975; Meyer 1987). The body color variations in DPM females were photographed by an Olympus® Microscope Camera (DP72) mounted on a stereomicroscope (M165 C, Leica, Wetzlar, Germany). The male aedeagus shape variations were captured by Auto-Montage Computer Software via a Leica® phase-contrast microscope (DM 2500). The male aedeagus measurements were made following Auger et al. (2013). DPM species identification was further confirmed using the DNA barcoding technique by amplifying the mitochondrial COI gene.

### 2.4. Statistical analysis

The mean mite density of all DPM stages (eggs, immatures, and adults) was used to estimate the effect of different factors on abun-

dance. The data were log-transformed (log(mite + 1)), and the densities of each mite stage were analyzed through multiple regression models ( $P \leq 0.05$  significance). The data of DPM females collected from different host habitats were used to calculate the adult cumulative mite days (ACMDs) to study the DPM phenology. The ACMDs, as defined by Beers and Hull (1990), were calculated as:

$$\sum x_i + x_{i+1}/2 \times \Delta t$$

where  $x_i$  is the total adult number at sampling date ( $i$ ),  $x_{i+1}$  is the total adult number on the next sampling date,  $t$  is days of the sampling interval (10 d and 14 d during fruiting and off-season months, respectively). These were added for each month to calculate the monthly ACMDs separately for each host habitat and subjected to ANOVA to test the significant effect of plots, seasons, and host habitats ( $P \leq 0.05$  significance). The pair wise comparison of means was done by Tukey's HSD test. The data were analyzed using SAS v.9.2 software (SAS Institute, Cary, NC, USA).

### 3. Results

The effects of host habitat, fruit season, environmental temperature, and management practice on phenology and abundance of date palm mite (DPM), *Oligonychus afrasiaticus*, were evaluated by estimating the monthly adult cumulative mite days (ACMDs) and mean mite density (Tables 1 and 2a-b, Fig. 1 and 2a-c). The predatory and phytophagous mite species, other than DPM, were presented in Table 3.

Among the vegetative host habitats, the monthly ACMDs and mean mite density of all development stages of DPM were higher on young fronds and aerial offshoots (YF) than on ground cover grasses (G), while very low on old fronds (OF). It was consistent in both plots (managed and unmanaged) during both, off-fruit and fruiting seasons (Table 1, Fig. 1 and 2a-c).

In both plots, a gradual increase in the ACMDs (Fig. 1) and mean mite density of all DPM stages (Fig. 2a-c) on YF was recorded during April and May 2018, just before the onset of fruiting season. It decreased on all vegetative habitats, in contrast to sudden increases

**Table 1**

Mean ( $\pm$ SE) adult cumulative mite days (ACMDs) of date palm mite (DPM), *Oligonychus afrasiaticus*, on date palm fruits, fronds and grasses during different fruit and off fruit seasons in managed and unmanaged plots.

	Fruit Season				$F_{7,112} = 13.91$ $P < 0.0001$	Off-Fruit Season			$F_{5,120} = 9.47$ $P < 0.0001$
	YF	OF	G	DF		YF	OF	G	
Managed Plots	13.12 $\pm$ 3.64aA	4.87 $\pm$ 1.55aA	11.33 $\pm$ 3.54aA	48 $\pm$ 13.07bA		23.61 $\pm$ 7.52aA	4.94 $\pm$ 1.63bA	8.42 $\pm$ 3.04bA	
Unmanaged Plots	39.27 $\pm$ 8.41aB	19.97 $\pm$ 5.87aB	22.67 $\pm$ 5.71aA	133.16 $\pm$ 25.67bB		48.69 $\pm$ 6.83aB	15.61 $\pm$ 3.23bB	25.19 $\pm$ 5.55bB	

YF = young fronds, OF = old fronds, G = ground cover grasses, DF = date fruit

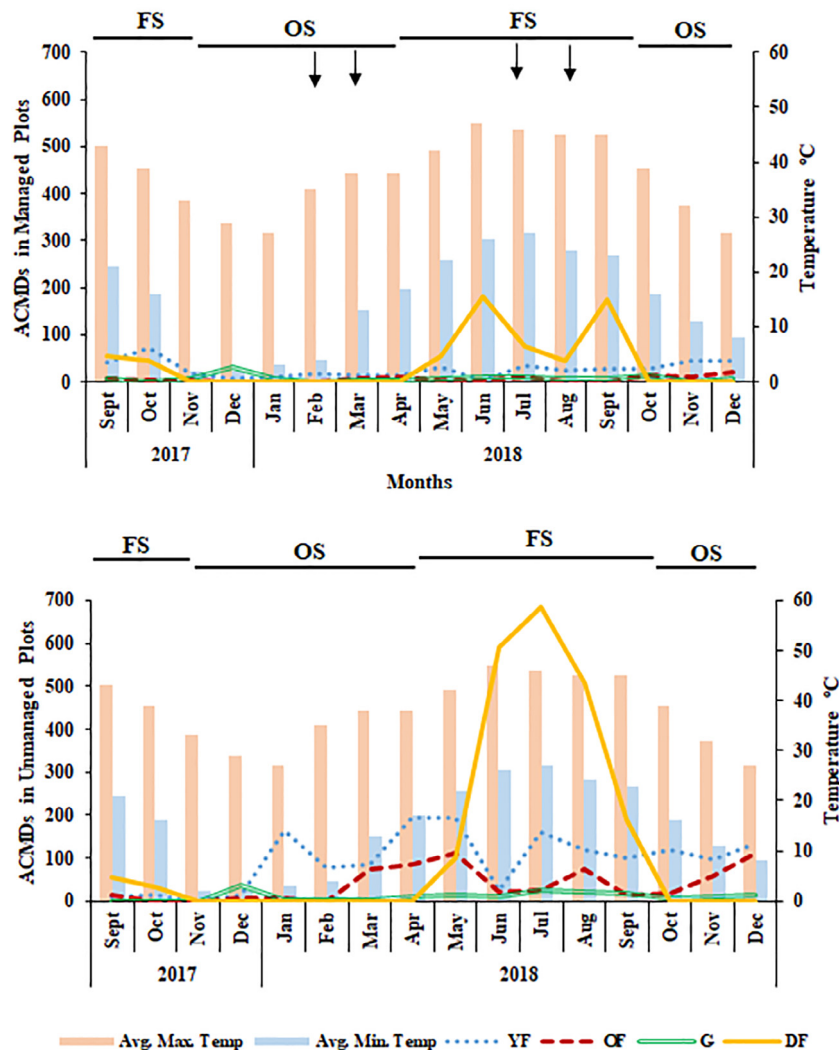
Means within a column in a season followed by different capital letters are significantly different ( $P < 0.05$ ) followed by Tukey's HSD test (significant at  $P \leq 0.05$ )

Means within a row in a season followed by different small letters are significantly different ( $P < 0.05$ ) followed by Tukey's HSD test (significant at  $P \leq 0.05$ )

**Table 2**

Regression model (significant at  $P \leq 0.05$ ) for the effect of different factors on abundance of eggs, immatures and adult stages of DPM on a) date fruits during fruiting season and b) date palm fronds and grasses during fruit and off-fruit seasons.

a) Date fruits							
Stages		Intercept	Temperature	Plots			
Eggs	Parameter Estimate	-2.43	0.02	1.01			$F_{4,271} = 42.87$
	Standard Error	1.02	0.02	0.07			$P < 0.0001$
	t-value	-2.37	1.12	12.9			
	P	0.01	0.26	<0.0001			
Immatures	Parameter Estimate	-1.71	-0.004	1.71			$F_{4,271} = 31.65$
	Standard Error	1.98	0.04	0.15			$P < 0.0001$
	t-value	-0.86	-0.09	11.16			
	P	0.39	0.92	<0.0001			
Adults	Parameter Estimate	-1.31	-0.0005	1.29			$F_{4,271} = 31.21$
	Standard Error	1.51	0.03	0.11			$P < 0.0001$
	t-value	-0.87	-0.02	11.14			
	P	0.38	0.98	<0.0001			
b) Date palm fronds and grasses							
Stages		Intercept	Temperature	Plots	Season	Host habitat	
Eggs	Parameter Estimate	-0.23	0.007	0.28	-0.12	-0.23	$F_{6,1220} = 53.27$
	Standard Error	0.13	0.003	0.02	0.03	0.01	$P < 0.0001$
	t-value	-1.79	2.29	10.7	-3.25	-13.27	
	P	0.07	0.02	<0.0001	0.001	<0.0001	
Immatures	Parameter Estimate	-0.62	0.003	0.41	-0.11	-0.14	$F_{6,1220} = 24.21$
	Standard Error	0.22	0.005	0.04	0.06	0.03	$P < 0.0001$
	t-value	-2.82	0.71	9.3	-1.82	-4.86	
	P	0.005	0.47	<0.0001	0.06	<0.0001	
Adults	Parameter Estimate	-0.87	0.009	0.43	-0.22	-0.0001	$F_{6,1220} = 26.47$
	Standard Error	0.2	0.005	0.04	0.05	0.02	$P < 0.0001$
	t-value	-4.29	1.91	10.82	-3.77	-0.01	
	P	<0.0001	0.05	<0.0001	0.0002	0.99	



**Fig. 1.** Adult cumulative mite days (ACMDs) of date palm mite (DPM), *Oligonychus afrasiaticus* in managed and unmanaged plots alongwith average monthly maximum and minimum temperature. FS: fruit season, OS: off-fruit season, YF: young fronds, OF: old fronds, G: ground cover grasses, DF: date fruit strands. Arrows indicate the time of acaricide applications in managed plots.

ing DPM population on date fruits (DF), at “Kimri” stage, in June 2018 during fruiting season (Fig. 1 and 2a-c). A significantly high ACMDs and mean mite density were recorded in DF during July 2018 ( $P < 0.0001$ ) (Table 1, Fig. 1 and 2a-c). The DPM population started to decline from August 2018 onward, as the DF developed to the “Khalal” stage (Fig. 1 and 2a-c).

A regression model was used to test the effect of environmental temperature, season (fruit and off-fruit) and plot (managed and unmanaged) on abundance of DPM on DF (only during fruiting season) and among vegetative habitats (during whole study period) (Tables 2a-b). It was found that the temperature did not affect, significantly, the abundance of DPM on DF during the fruiting season (Table 2a). The plots had significant effect on abundance of DPM eggs, immatures and adults ( $P < 0.0001$ ) (Table 2a).

The regression model for abundance of DPM among vegetative host habitats showed positive effect of temperature on DPM eggs (parameter estimate = 0.007,  $t = 2.29$ ,  $P = 0.02$ ) and adults (parameter estimate = 0.009,  $t = 1.91$ ,  $P = 0.05$ ). The DPM abundance of eggs (parameter estimate = - 0.12,  $t = - 3.25$ ,  $P = 0.001$ ) and adults (parameter estimate = - 0.22,  $t = - 3.77$ ,  $P = 0.0002$ ) were 0.12 and 0.22 units lower in off-fruit season as compared to fruiting season, respectively. It was also found that as compared to young fronds (YF), the abundance of DPM immatures and eggs

were lower on old fronds (OF) and grasses (G) (for eggs; parameter estimate = - 0.23,  $t = - 13.7$ ,  $P < 0.0001$ ) (for immatures; parameter estimate = - 0.14,  $t = - 4.86$ ,  $P < 0.0001$ ) was also found.

The managed plots always had low DPM abundance compared to unmanaged plots, on different habitats (Table 1, Fig. 2a-c). In managed plots during the fruiting season, the ACMDs and mean density peaked on DF during mid-June 2018 (Fig. 1 and 2a-c). The acaricide applications reduced DPM numbers from July to August 2018. At the same time, increased ACMDs and mean density values were recorded on YF (Fig. 1 and 2a-c). However, the DPM population reached a peak again, on DF, in mid-September 2018.

The differential abundance and diversity of different predatory and phytophagous mites (other than DPM) were recorded between both plots (Table 3). Overall, the grasses had a high diversity of predatory and phytophagous mites followed by OF and often from off shoots and deformed leaves. The crown fiber (CF), DF and YF often had predatory mites. No phytophagous mite species other than DPM were found in DF, YF and CF in either managed or unmanaged plots. In the managed plots no predatory mite species could be recovered from YF and DF (Table 3).

Some variations in color of DPM females and shape of male adeagi were mentioned (Fig. 3a-d and 4a-h). In the present study,

**Table 3**  
Mite species, other than DPM, found from different host habitats in the present study.

Sr#	Host Habitat	Technical Name (Family)	Importance	MP	UP
1	Young fronds	<i>Tydeus</i> sp. (Tydeidae)	–	✓*	✓*
		<i>Cydnoseius negevi</i> (Phytoseiidae)	Predator	✗	✓*
		<i>Spinibdella</i> sp. (Bdellidae)	Predator	✗	✓*
2	Offshoots and deformed leaves	<i>Tydeus</i> sp. (Tydeidae)	–	✓*	✓*
		<i>Spinibdella</i> sp. (Bdellidae)	Predator	✓*	✓*
		<i>Raoeilla indica</i> (Tenuipalpidae)	Phytophagous	✓*	✓***
3	Old fronds	<i>Raoeilla indica</i> (Tenuipalpidae)	Phytophagous	✓***	✓***
		<i>Phyllotetranychus aegyptiacus</i> (Tenuipalpidae)	Phytophagous	✗	✓*
		<i>Tenuipalpus eriophyoides</i> (Tenuipalpidae)	Phytophagous	✗	✓*
4	Crown fiber <sup>†</sup>	<i>Tydeus</i> sp. (Tydeidae)	Predator	✗	✓*
		<i>Anystis baccharum</i> (Anystidae)	Predator	✓*	✓*
		<i>Decaphyllobius gersoni</i> (Camerobiidae)	Predator	✓*	✓*
5	Grasses	<i>Saniosulus nudus</i> (Eupalopselidae)	Predator	✗	✓*
		<i>Raphignathus zhaoui</i> (Raphignathidae)	Predator	✗	✓*
		<i>Bryobia praetiosa</i> (Tetranychidae)	Phytophagous	✓***	✓***
		<i>Petrobia latens</i> (Tetranychidae)	Phytophagous	✓***	✓***
		<i>Tetranychus urticae</i> (Tetranychidae)	Phytophagous	✗	✓*
		<i>Oligonychus orthius</i> (Tetranychidae)	Phytophagous	✓**	✓**
		<i>Euseius scutalis</i> (Phytoseiidae)	Predator	✓*	✓***
		<i>Neoseiulus</i> sp. (Phytoseiidae)	Predator	✓*	✓***
		<i>Cydnoseius negevi</i> (Phytoseiidae)	Predator	✓**	✓***
		<i>Mexeches</i> sp. (Cheyletidae)	Predator	✗	✓*
		<i>Tydeus</i> sp. (Tydeidae)	–	✗	✓**
		<i>Raphignathus zhaoui</i> (Raphignathidae)	Predator	✓*	✓*
		<i>Spinibdella</i> sp. (Bdellidae)	Predator	✗	✓*
		<i>Anystis baccharum</i> (Anystidae)	Predator	✗	✓*
		<i>Agistemus vulgaris</i> (Stigmaeidae)	Predator	✗	✓***
<i>Decaphyllobius gersoni</i> (Camerobiidae)	Predator	✓*	✓*		
6	Date fruits	<i>Tydeus</i> sp. (Tydeidae)	–	✓*	✓*
		<i>Cydnoseius negevi</i> (Phytoseiidae)	Predator	✗	✓*
		<i>Saniosulus nudus</i> (Eupalopselidae)	Predator	✗	✓*
		<i>Spinibdella</i> sp. (Bdellidae)	Predator	✗	✓*

MP = managed plots, UP = unmanaged plots, ✓ = found, ✗ = not found, \* = average ≤ 5 individuals, \*\* = average 10-15 individuals, \*\*\* = average more than 15 individuals  
† no DPM individuals were found

DPM female color morphs were observed (Fig. 3a-d). The adult females, which were collected from date palm fronds, fruits, and grasses throughout the study period, appeared light green, pale yellow, and dark green, respectively (Fig. 3a-c). In December 2018 (two visits, fortnightly), brownish-orange females (n = 50) were collected from YF (Fig. 3d).

Furthermore, the variations in DPM male aedeagi were also observed in; the length of the knob, the height of the hook, and the angle between the knob axes to the dorsal margin of the shaft (Fig. 4a-h). Prominent variations were found in the angle between the knob axis and the dorsal margin of the shaft. Males collected from fronds, fruits, and grasses had angles ranging from 0°–18° (Fig. 4a-c), 16°–20° (Fig. 4d-e), and 0°–23° (Fig. 4f-h), respectively. The aedeagi in few males (n = 10) collected from grasses in December 2018 had a bulbous knob with an anterior projection more extended anteriorly, posterior knob extended downward, and the width of the neck was comparatively thinner, the knob axis at an angle with the dorsal margin axis (Fig. 4f). Variations in male aedeagi morphology were found throughout the study period in all sampling units (Fig. 4k).

#### 4. Discussion

The increased ACMDs and mean mite density of DPM on YF, throughout the study period, in both plots showed the habitat preference of DPM individuals over G and OF. It was found that the YF played an important role in DPM population development and survival during harsh winters and the fruiting off-season. The YF have been previously reported to be DPM overwintering sites (Guessoum, 1986; Ben Chaaban et al., 2011a,b, 2017; Latifian

et al., 2014, 2017; Palevsky et al., 2003, 2004; Alatawi, 2020; El-Shafie, 2019). Like many other pest mites, DPM individuals approach their overwintering sites before the onset of the winter season, as shown by increased ACMDs and mean density values on YF in September and October 2018. The YF were comprised of partially closed leaflets which served as suitable and protected overwintering sites for DPM. The mites, such as false spider mites, are known to overwinter, hidden in protected places found on abaxial leaf surfaces (Zhang, 2003). The clover mite, *Bryobia praetiosa*, is reported to active move toward protected places for overwintering (Jeppson et al., 1975). Other than spider mites, the behavior of hiding within the leaves of the host plant has also been reported in the gall mite, *Aceria carvi* (Zemek et al., 2005).

Other than YF, significant monthly ACMDs and mean density of DPM on ground cover grasses, usually belonging to the family Poaceae, were also recorded in the present study. It indicates that YF and G are potential overwintering sites of DPM, as mentioned in the previous studies from Saudi Arabia and different countries (Hussain, 1974; Guessoum, 1986, 2016; Ben Chaaban et al., 2011a,b, 2017; Latifian et al., 2017; Palevsky et al., 2003, 2004; Alatawi, 2020; El-Shafie, 2019).

As found in the present study and consistent with a previous off season study in Riyadh (Alatawi, 2020), the increased DPM population on YF early in the fruiting season was in preparation for the DF infestation and that the seasonal infestation occurs primarily from the date palm tree itself. The overwintering population of DPM occupy the YF and aerial offshoots as these habitats are much closer to fruit bunches and are protected places for survival during off-fruit season. It is easy for them to crawl up to fruit bunches to cause seasonal fruit infestation. Field population studies conducted by Ben Chaaban et al. (2011a,b, 2017) and Palevsky et al.

(2004) have also confirmed similar DPM behavior. Chaaban et al. (2017) found that mobile forms of DPM actively moved from fronds to DF just after the fruit setting and they later moved from fruits to fronds to overwinter at the end of the fruiting season.

The highest population of DPM was reported on DF during June–July 2018 in the fruiting season. The DF at the “Kimri” fruit stage is most suitable for the DPM as it has multiple nutritional and structural features, allowing the DPM to reproduce and develop exponentially, and to create dense, complicated webbing structures (Aldosari and Ali, 2007; Barreveld, 1993; Samah and Chermiti, 2010; Palevsky et al., 2003, 2004, 2005; Ben Chaaban et al., 2011a, b, 2017). This was the reason that the abundance of DPM declined on all vegetative feeding habitats and increased on DF, early in the fruiting season.

The regression model showed a non-significant effect of temperature on abundance of DPM on DF, during fruiting season. The

effect of temperature on DPM abundance was masked due to the availability of most favored “Kimri” DF. These findings are in consistent with previous studies (Guessoum, 2016; Ben Chaaban et al., 2017; Alatawi et al., 2019) and showed the impact of DF stages on DPM dynamics compared to temperature during the fruiting season. As mentioned earlier, the “Kimri” DF stage is nutritionally superior to DPM for development and reproduction. The DPM individuals migrated towards YF and G during August 2018 when the DF entered “Khalal” stage while the temperature was still suitable for DPM development. Hence, it shows that the fruit stage is important regulating factor of DPM phenology and abundance during fruiting season.

The DPM abundance was found higher on YF as compared to OF and G, through regression model. It could be due to nutritional differences among these habitats and increased competition due to presence of various phytophagous and predatory mites (Table 3).

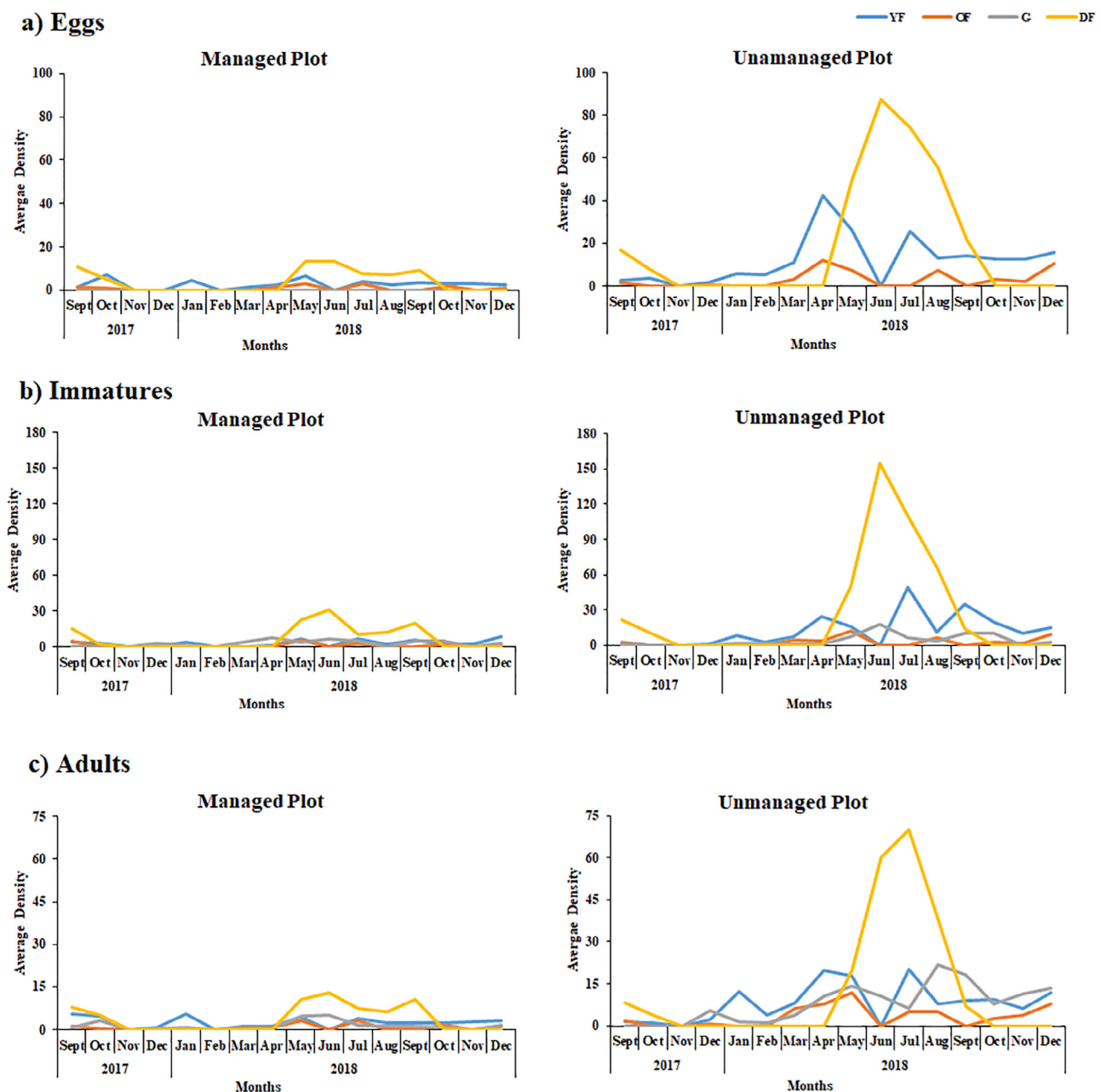
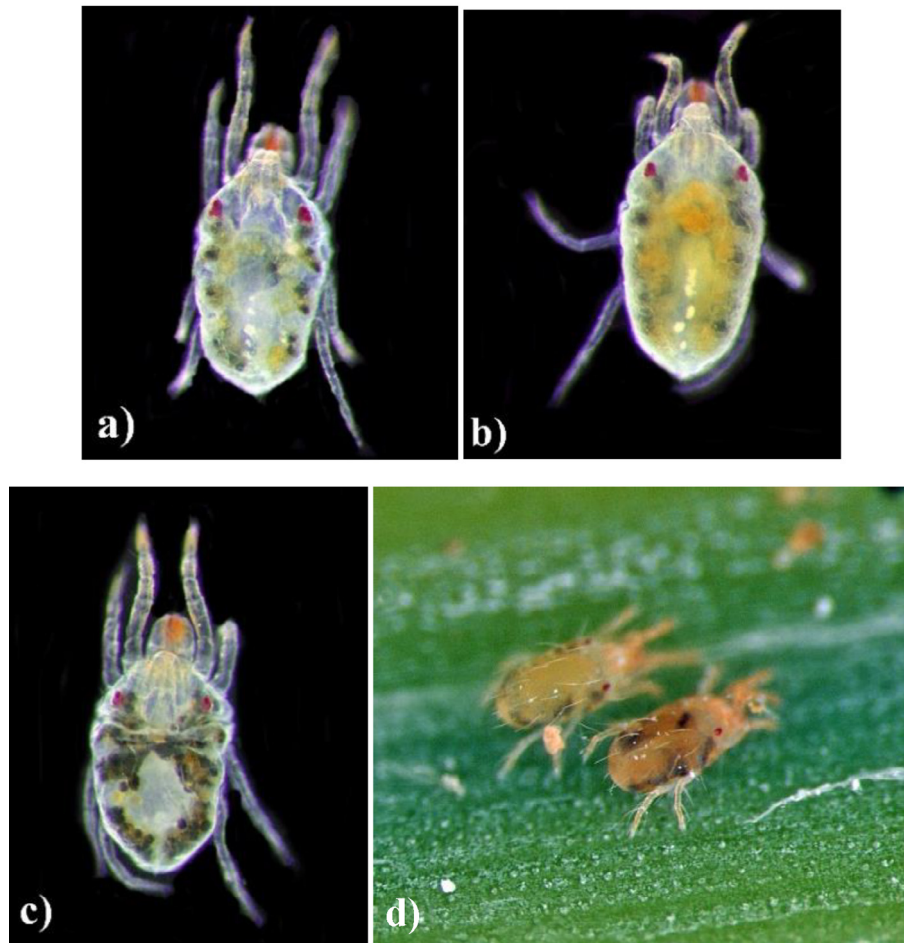


Fig. 2. Relative abundance (average density) of DPM a) eggs, b) immatures and c) adults on different host habitats during the off fruit and fruit seasons (2017–2018). YF: per a young frond, OF: per an old frond, G: ground cover grasses per tree, DF: per three date fruit strands.

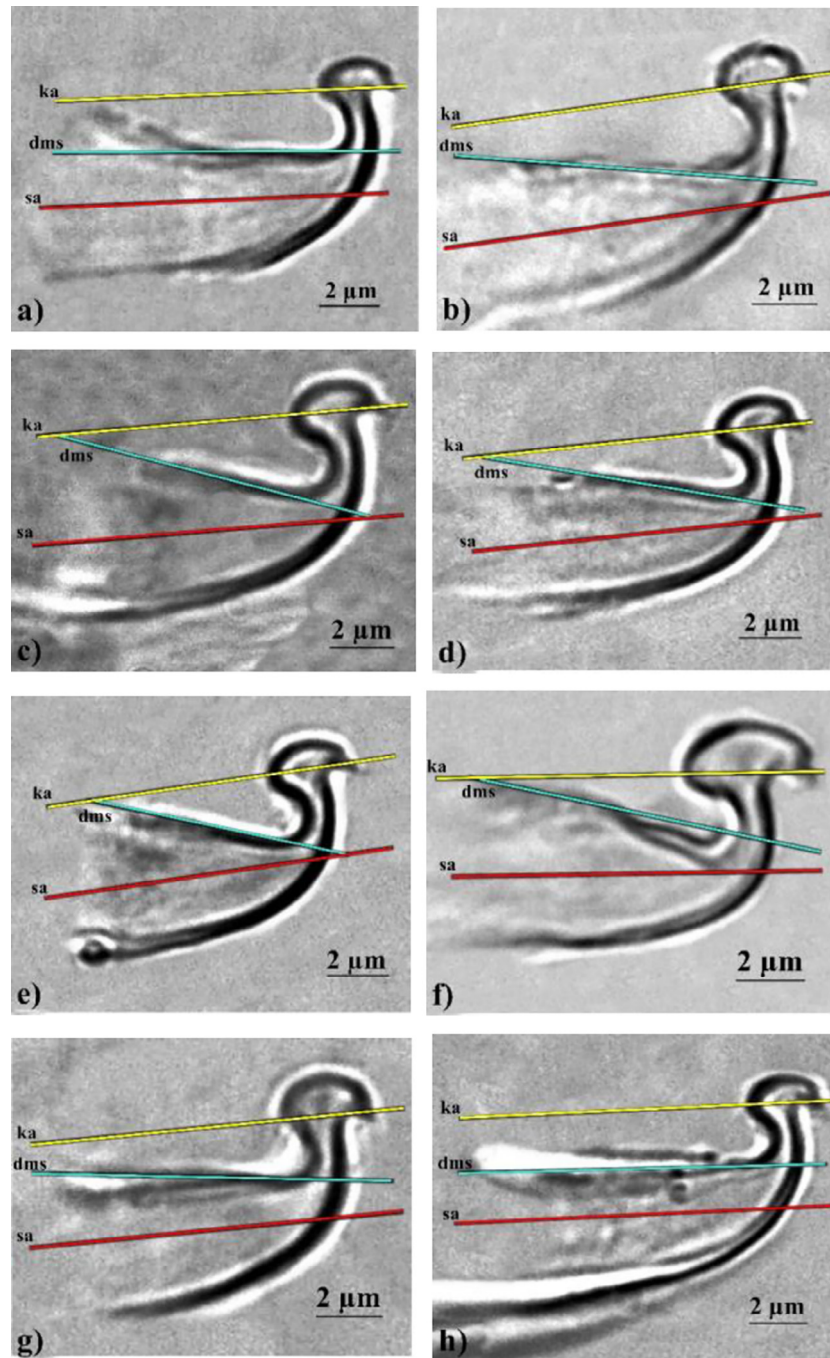


**Fig. 3.** Body colors in DPM, adult females; a) light green from fronds, b) pale to yellow from date fruits, c) dark green from grasses, and d) brownish on young aged fronds only during winter season.

The crown fibers always contain predatory mite species in very low number (average  $\leq 5$  individuals), which may explain why the present study did not report a single DPM individual from that habitat. In addition, the crown fibers are non-palatable plant parts for DPM. The predator species were also collected from the YF, but they were only collected occasionally, with very low abundance. The G and OF contained phytophagous and potential predatory species (Table 3). It was also previously reported that predatory mites, especially phytoseiids, were less abundant on YF and DF (Ben Chaaban et al., 2011a,b). The scarcity of these predators on DPM rich habitats (YF and DF) was due to low humidity (Helle and Sabelis, 1985) and the complicated, dense webbing of DPM. It has been reported that the webs of spider mites reduce predation risk (Gerson, 1985; Roda et al., 2000; Lemos et al., 2010; Yano, 2012). It could be related to acaricides having non-target effects (James et al., 2002; Costello, 2007). Additionally, this result could be due to the availability of abundant and diverse food sources, e.g., phytophagous mites in places other than YF and DF, such as grasses. The intra- and interspecific competition and predator-prey relationships could also have led to the observed negative effect of vegetative host habitats on DPM abundance. Intraspecific competition is a density-dependent factor, resulting in dispersal to low-density breeding sites (Bowler and Benton, 2005). It has been reported that the individuals of *T. urticae* dispersed toward low-density feeding sites due to intraspecific competition (Bonte et al., 2014). Additionally, the old and young date fronds in management plots were chemically treated during the fruiting and

off-season, while the grasses were only eradicated, which could have caused the negative effect.

The managed plots, where date palm trees were treated with acaricides and clean cultivation was practiced, the DPM population was constantly low as compared to unmanaged plots. The suppression of the spider mite population through chemical control dates back over 50 years (Lindgren and Vincent, 1949). The date palm growers have been using synthetic acaricides for the purpose (Palevsky et al., 2004; Aldosari, 2009; Latifian, 2017). For several years, the banks grass mite *O. pratensis* has been managed through acaricides on date palms in California (Carpenter and Elmer, 1978; Latifian, 2014). In our study, the significant suppression of the DPM population in managed plots was achieved through four chemical applications on date palms, two of which were on fronds during the off-season. However, previous findings encouraged a single seasonal chemical application at the first appearance of DPM (Palevsky et al., 2004; Al Doghairi, 2004; Latifian, 2014), but this recommendation was considered problematic as DPM monitoring was labor-intensive for growers (Palevsky et al., 2004). The DPM population peaked again after acaricide application on DF during fruiting season. The resurgence phenomenon is well documented in spider mites. Sub-lethal doses of non-selective acaricides cause hormesis, which results in increased fecundity and oviposition (Dutcher, 2007). It was reported that *T. urticae* populations show varying degrees of resurgence against different groups of synthetic chemicals (Gerson and Cohen, 1989; James et al., 2001; Abrol and Singh, 2003; Woods et al., 2012; Patil et al., 2018).



**Fig. 4.** Variations in aedeagus morphology of DPM males; collected from YF (a: parallel, b-c: at angle), DF (d-e: at angle) and grasses (f-g: at angle, h: parallel); n = 5 each. ka = knob axis, dms = dorsal margin of shaft, as = shaft axis.

The light green (on date palm fronds) to dark green (on grasses) body colors in DPM females were the result of the type of host they fed on. Similarly, the pale yellow body color was related to its feeding on date fruits. The cuticle of mites is colorless (Veerman, 1974; van der Geest, 1985); hence, mite coloration is caused by pigments present in the diet (Auger et al., 2013). It has been reported in different studies that color may vary according to the host plant (Pritchard and Baker, 1952; Van de Bund and Helle, 1960; Auger et al., 2013). In the two-spotted spider mite, *Tetranychus urticae* (Koch), the two color morphs (green and red) were due to the differential quantities and biosynthesis of keto-carotenoids present in the host plant they fed on (Altincicek et al., 2012). During the win-

ter months, the brown-coloring of adult DPM females that were only collected from date palm YFs (Fig. 3d) could be related to the accumulation of certain metabolic compounds. The color change in *T. urticae* diapausing females from green to orange-red in the winter season has been reported to be due to the differential expression of keto-carotenoid metabolic proteins (Bryon et al., 2013). These compounds enhance the mite's ability to tolerate environmental stressors. The overwintering strategies of DPM (i.e., diapausing or non-diapausing) and its physiological adaptations are yet to be investigated.

In the present study, we also found some variations in the shape of DPM male aedeagi. However, these variations may not cause spe-



cies misidentification. The identity of these *O. afrasiaticus* populations was confirmed using DNA barcoding techniques using the COI gene. The *O. afrasiaticus* males have been described and illustrated by many authors (Meyer, 1974, 1987; Jeppson et al., 1975; Pritchard and Baker, 1955; Baker and Pritchard, 1960), but the variations, if any, were not discussed. To know whether the variations in DPM male aedeagi were due to host plants, winter/ summer seasons, or other factors requires further research.

## 5. Conclusions

The phenology and abundance of DPM were significantly influenced by the season type, host habitat (DF, YF, OF, and G), temperature, and management practices (cultural control and acaricide application). The present study provided important information for managing DPM infestation on date palms in Riyadh. It is concluded that host habitat is the primarily factor regulating the DPM phenology and abundance. During the fruiting off-season, the YFs and offshoots were the primary overwintering sites of DPM and responsible for seasonal fruit infestation. These must be observed for DPM presence and treated properly either by pruning or by target-oriented acaricide spraying practices. Additionally, the ground cover grasses should also be removed periodically because they also serve as an alternate host for DPM. These grasses can also be used as trap crops if they were allowed to grow in a certain area of the orchard. Predators would develop there as well, which could be helpful in the biological control of DPM. It is recommended that predators are released on the YF and offshoots as the DPM overwinters there. Predators can either be collected from the same orchard or reared in control conditions. These predators should be released just before the fruiting season (early March to April) so that the predators can effectively suppress the DPM population in their overwintering sites and thus reduce pest infestation on DF. The overwintering adaptations of DPM should be investigated to understand the biological activities of this pest further. The aerial dispersal of DPM should be investigated in the future to prevent large scale infestations in date palm orchards.

## Declaration of Competing Interest

The authors have declared that no conflict of interests exist.

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