



Seasonal population dynamics of *Rhizoglyphus robini* Claparède (Acari: Acaridae) and its predatory mite affected by some environmental factors in the saffron fields of North-Eastern Iran

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ABSTRACT

Saffron, *Crocus sativus* L. (Iridaceae), is known as the most expensive spice in the world and the saffron mite (*R. hizoglyphus robini* Claparède, 1869) causes direct and indirect damage by feeding on healthy or damaged saffron corms and is known as the most important pest of this crop. In this study, the effect of certain environmental factors including temperature, some soil parameters and altitude, on the population of saffron mite (adults and nymphs) and its dominant predatory mite *Gaeolaelaps aculeifer* (Canestrini, 1884) (Acari: Laelapidae) was evaluated in 5-year-old saffron fields in Iran (Mashhad, Gonabad, Torbat Heydariyeh, Dargaz, and Quchan). The relationship between the population growth rate (PGR) of adult and nymphal stages of bulb mite and predatory mite throughout the year was fitted by non-linear regression. Based on this model, the PGR of adult bulb mite was lowest on June 24 and highest on December 3. For the nymphal bulb mite, the PGR was lowest on August 5 and highest on December 12. The PGR of the predator of bulb mite was maximally fitted with the model, with a coefficient of determination (R^2) of 0.612. In this model, the PGR of predatory mite reached its lowest point on August 9 and its highest on January 3. The effect of temperature and soil moisture on the nymphs/adult population ratio (NAPR) of bulb mites was fitted to a multiple linear model, and according to the results, the NAPR increased with increasing temperature and decreasing soil moisture. The results of this study can play an important role in predicting and placing the development of saffron cultivation.

KEYWORDS

Bulb mite, key pest, population fluctuations, Khorasan Razavi, saffron

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INTRODUCTION

The saffron bulb mite, *Rhizoglyphus robini* Claparède (Acari: Acaridae), a key pest of saffron (*Crocus sativus* L., Iridaceae), has infested all saffron-growing cities across Iran to various levels, and its direct and indirect damage to saffron corms leads to reduced saffron yields (Rahimi *et al.* 2018; Koocheki and Khajeh-Hosseini 2019; Rahimi and Nateq Golestan 2020). Saffron is considered a strategic agricultural product in Iran, which accounts for approximately 90% of global saffron production and exports, and its unique characteristics such as low water demand, suitability for cultivation in sandy and clay soils, reliance on family labor, minimal need for machinery, and irrigation requirements outside peak demand periods make it especially attractive (Ghorbani 2006; Karbasi and Zandi Dareh Gharibi 2022). Cultivated



saffron differs from most *Crocus* species in that it is a naturally occurring autotriploid ($3x = 24$), characterized by infertile pollen and stigmas (Nemati *et al.* 2019). This plant blooms in early autumn and has a fleshy, hard and thick underground stem covered with thin, brown, reticulate fibrous skins. As cultivated saffron is a triploid plant that does not produce seeds, it relies entirely on corms for propagation (Fiore *et al.* 2010). Therefore, this pest can be dispersed throughout the infected corms. *Gaeolaelaps aculeifer* (Canestrini) (Acari: Laelapidae) is an edaphic predator of many agricultural pests and one of the most important predators of bulb mites in saffron fields of Iran (Tavakkoli-Korghond and Sahebzadeh 2022).

Investigating the population dynamics of pest insects and mites, along with their natural enemies, is crucial for anticipating pest outbreaks and designing rational and effective control strategies (Rodrigo *et al.* 2012). Soil chemical and physical properties, such as porosity, permeability, soil temperature and moisture, the presence of minerals, organic matter, and pH, are environmental factors that influence the density of soil mite populations (Sharma and Parwez 2017). According to Kamczyc *et al.* (2022), the abundance, species richness, and diversity of mite communities (Acari: Mesostigmata) inhabiting decomposing litter decreased from spring to autumn regardless of litter quality and was related to changes in temperature and precipitation. Similarly, Seniczak *et al.* (2019) investigated seasonal fluctuation in oribatid mite communities in bog ecosystems of Poland and found that mite densities peaked in autumn and declined to their lowest levels during winter. In an agroforestry ecosystem in India, moisture exerts a more pronounced influence than temperature on mite fluctuation, particularly Oribatida and Mesostigmata in the upper soil layers (0–5 cm) (Sharma and Parwez 2017). In Greece, the seasonal dynamics of the dominant mite species, *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) and its predator, *Acaropsis docta* (Berlese) (Acari: Cheyletidae), were evaluated within a wheat storage (Palyvos and Emmanouel 2006). Both species exhibited a preference for microhabitats characterized by elevated relative humidity and temperature. N'Dri and André (2011) in West Africa, demonstrated that population density of Prostigmata, Astigmata, Oribatida, and Mesostigmata mites was higher during the rainy season than in the dry season, highlighting the critical influence of moisture availability on soil. Soil pore volume contributes significantly to the abundance and distribution of soil-dwelling mites in two contrasted habitats in Scotland: heather moorland and birch woodland. The abundance of oribatid mites in both habitats, and mesostigmatid mites in heather moorland, exhibited a strong and positive association with the volume of pores in the 60–300 μm range (Nielsen *et al.* 2008). Elevation plays a critical role in shaping the biological composition and structural organization of soil mite communities, as demonstrated by Liu *et al.* (2023), who showed that oribatid mite community composition is greatly affected by elevation and vegetation type. Manu *et al.* (2016) in Romania, showed that total nitrogen (Nt) and soil moisture (H%) were the strongest predictors for both soil mite abundance and species richness and they confirmed significant correlations between community composition and environmental gradients, including soil pH, Nt, temperature, C, and moisture. Additionally, based on their results, *G. aculeifer* was positively associated with higher soil temperatures. The population density of Astigmata and Mesostigmata exhibited distinct seasonal fluctuations, with the highest abundance recorded during the rainy season (August–September) and the lowest during winter (December) in the semi-arid grasslands of Aligarh, India. Moreover, relative humidity and organic matter showed significant positive correlations with multiple mite groups. In contrast, electrical conductivity (EC) displayed a negative correlation with Mesostigmata and Oribatida (Sharma and Parwez 2017). Notably, in another study, Astigmata (including Acaridae) did not show a strong direct correlation with electrical conductivity (EC) but were positively associated with oribatids in reclaimed soils (Lupardus *et al.* 2021).

The population development and life history traits of *R. robini* are highly dependent on three key factors: temperature, relative humidity, and food quality/quantity (Diaz *et al.* 2000). In winter-grown garlic, in Egypt, the population of *R. robini* peak in the mid-winter months during cooler, moist conditions. In this study, temperature appeared to be a key driver, and higher temperatures had a significant negative correlation with *R. robini* abundance; as temperatures rose, mite numbers declined (El-Khalik *et al.* 2024). Seasonal monitoring in two separate garlic and onion growing areas in Kastamonu Province, Turkey during the years 2018–2019 suggests that *R. robini* populations can increase as the growing season progresses (Cilbircioğlu 2025). Based on their results, *R. robini* densities in onions were

relatively low in April in both years. Additionally, a gradual increase was observed from mid-May, reaching peak density by the end of June. The fluctuations of the predatory mite, *G. aculeifer*, on *R. robini* in lily crops (both field and experimental) are influenced by temperature, humidity, soil type, and spatial complexity factors that can either enhance or hinder the predator's effectiveness (Lesna *et al.* 2000). In India (Kashmir), this pest has been reported in major saffron cultivation areas and remains active throughout the year. However, its highest abundance in Kashmir, is observed in spring and autumn, when optimal conditions for growth and reproduction exist (Sherwani *et al.* 2023).

The seasonal population dynamics of *R. robini* and their correlations with environmental factors in saffron fields, particularly in Iran, the world's main saffron producer, have been poorly studied. As outlined in the preceding sections, the fluctuation of *R. robini* was analyzed on other crops in different regions. Rahimi (2018a) briefly mentions that the population of *R. robini* mites in saffron fields (Khorasan Razavi, Iran) increased significantly in spring and autumn due to favorable humidity and temperature conditions, while it decreased considerably in summer due to hot weather and dry soil, and in winter due to cold temperatures. The main objective of this study was to estimate the seasonal population dynamics of *R. robini* mites in Khorasan Razavi Province, Iran and to analyze the effects of temperatures, moisture, electrical conductivity (EC), phosphorus levels of soil, soil texture, corms weight and field elevation, on changes in the mite population across five distinct saffron fields.

MATERIAL AND METHODS

Experimental locations

The experiment took place in five-year-old saffron fields in Quchan (37° 04' 40.7" N, 58° 29' 39.4" E, 1342 m a.s.l.), Mashhad (36° 28' 53.4" N, 59° 37' 33.5" E, 1059 m a.s.l.), Torbat Heydariyeh (35° 35' 57.8" N, 59° 27' 45.5" E, 1744 m a.s.l.), Dargaz (37° 32' 43.8" N, 58° 55' 46.8" E, 681 m a.s.l.), and Gonabad (34° 22' 45.5" N, 58° 45' 34.5" E, 1047 m a.s.l.) cities possessing different climates in Khorasan Razavi Province, Iran, from May 5, 2022 to May 5, 2023. Based on the perspective of Jones *et al.* (2025), this study is considered valid due to its implementation across multiple different sites and the high time-sensitivity of bulb mite population dynamics within a single year.

Sampling, extraction, and identification

Samplings were carried out periodically every two months on the 5th of May, July, September, November, January, March. Five sampling locations were selected in a cross-shaped pattern within the saffron field and clearly marked. At each location, between 200 and 300 grams of saffron corms were excavated using a shovel. Five samples were taken from each location in each sampling round according to an X-pattern. Because we were evaluating population fluctuations, resampling was performed from the exact points as previous sampling rounds. Each sample consisted of 200 g of saffron corms and 200 g of soil surrounding the saffron corms. To obtain the density of the sample, mite specimens were extracted using a modified washing method (2% soap and 1% bleach), following the protocol described by Fathi *et al.* (2024). The mite specimens were mounted on microscope slides using Heinze PVA (polyvinyl alcohol) medium and incubated in an oven at 50 °C for two weeks to be cleared, following a modified method based on Evans (1992). Identification of the specimens was carried out using the keys provided by Fan and Zhang (2004).

Soil parameters

The soil parameters including acidity, electrical conductivity (EC), organic matter content, and mineral levels (N, P, and K) were measured and recorded for soil samples from each region at the Soil Science Laboratory of the Agricultural and Natural Resources Research and Education Center of Khorasan Razavi Province, Mashhad. The air temperature information was obtained from the Iran Meteorological Organization (<https://nivar.irimo.ir>) and the percentages of soil moisture content were determined using the oven dry technique based on Okoh *et al.* (1999).

Data analysis

Population data were standardized using ecological indices based on methodologies from Vargas-

Madriz *et al.* (2025) and Block (1966) into three indices: PGR (Population Growth Rate), NAPR (Nymph-to-Adult Population Ratio), and PF (Population Fluctuation), to analyze the effects of environmental factors on population fluctuation of the saffron bulb mite throughout the year across five experimental regions. The relationship between the population growth rate (PGR) of adult and nymph bulb mite and its predatory mite and the nymph/adult population ratio (NAPR) of the saffron bulb mite and population fluctuation (PF) of bulb mite with some environmental factors including temperature and soil parameters; corm weight was analyzed using regression models.

$$\text{Population growth rate (PGR)} = \frac{\text{sample population density}}{\text{Maximum samples population density (in year)}}$$

$$\text{Nymph/adult population ratio (NAPR)} = \frac{\text{Nymph population density}}{\text{Adult population density}}$$

The effect of temperature and soil moisture on the NAPR of saffron bulb mites in the corm and the surrounding soil separately, and the effect of soil parameters as well as saffron corm weight on the PGR of bulb mites in November and May was analyzed using a regression model. The simultaneous effect of soil moisture and saffron corm weight on the PGR of adult bulb mite, as well as the simultaneous effect of the PGR of nymph and adult saffron bulb mite on the PGR of predatory mite in the saffron corm and surrounding soil, was analyzed separately using a regression model. The relationship between population fluctuation (PF) of adult, nymph, and total bulb mites during the year with the altitude of the sampling areas was fitted to a regression model ($P\text{-value} < 0.05$). All data were analyzed using SPSS version 16 software (SPSS 2007).

$$\text{Population fluctuation (PF)} = \frac{\text{Maximum population density (in year)}}{\text{Minimum population density (in year)}}$$

RESULTS

Seasonal population dynamics of the saffron bulb (adult and nymph) mites and their predatory mite (adult)

The population growth rate (PGR) of adult mites in all cities was relatively low (0.2–0.4) in March and May (except Gonabad), and the maximum PGR of adult was observed in November and January. This rate was lowest (0.0–0.1) in July and September (Fig. 1A). The PGR of nymph reached its maximum value of one in all five cities in May, then gradually decreased until September, reaching its minimum (0.1–0.2), except in Dargaz (Fig. 1B). However, the population peak of adults was higher in November and January than in May (except in Gonabad), demonstrating a different population behavior compared to nymphs (Fig. 1A). Overall, the PGR of adult and nymphal mites showed an increasing trend from early autumn, continuing until early winter. A decline was observed during winter, followed by a re-increase in early spring. The decreasing trend then began in mid-spring and persisted until late summer.

Soil moisture reached its lowest levels (below 5%) in July and September, while the highest levels (10–17%) were recorded in November and January (Fig. 2A). Also, the maximum air temperature (25–35 °C) was observed in July and September. The decreasing temperature trend continued from September to January, and in January, the lowest temperature (around 0 °C) was recorded across in all cities (Fig. 2B).

The relationship between the PGRs of adult and nymphal stage of bulb mite and predatory mites throughout the year was modeled using a cubic non-linear regression. The coefficient of determination (R^2) for the PGR of adult bulb mite model was calculated to be 0.527. Based on this model, the PGR was lowest on June 30 with vertex point (V.P.) = 103 day and highest on December 3 (V.P. = 258.9) (Fig. 3). The coefficient of determination for the PGR of nymphal bulb mite model was 0.293. The PGR was lowest on August 7 (V.P. = 141.04) and highest on December 12 (V.P. = 267.8). The PGR of predatory adult mite showed the highest fit with the model, with a coefficient of determination of 0.612. In this

model, the PGR reached its lowest point on August 11 (V.P. = 145.07) and its highest on January 3 (V.P. = 289.7) (Table 1 and Fig. 3).

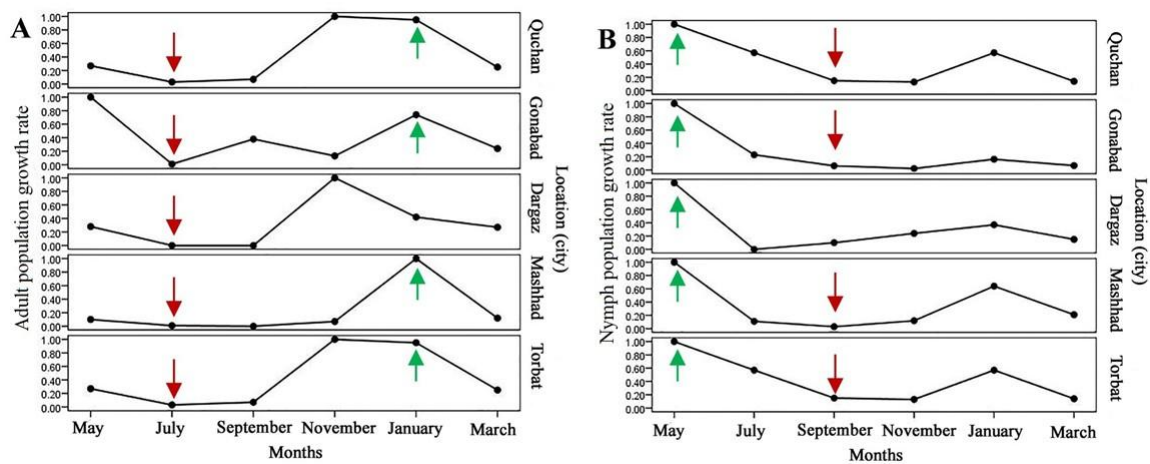


Figure 1. Adult (A) and nymphal (B) saffron bulb mite population growth rate throughout the year in different cities.

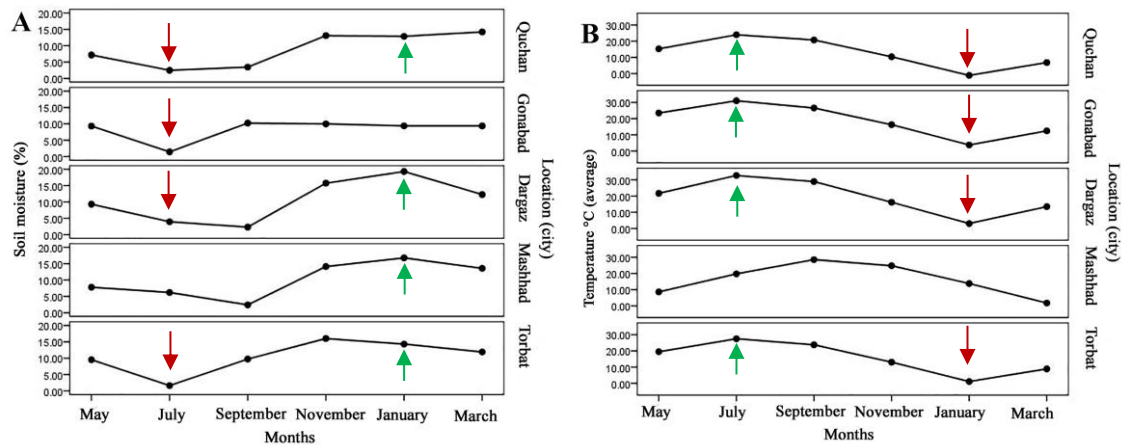


Figure 2. Trends in soil moisture (A) and temperature (B) changes throughout the year in different cities.

Table 1. Non-linear regression model of the effect of time on the population growth rate of nymphal and adult bulb mites and adult predatory mite.

Model regression			Constant		Time ^{^1}		Time ^{^2}		Time ^{^3}	
Parameter	R ²	F	B	S.E.	B	S.E.	Beta	B	S.E.	Beta
Bulb mite (adults)	0.527	11.514*	1.146	0.232	-0.028	0.006	-8.395	1.9E-4	3.6E-5	21.483
Bulb mite (nymphs)	0.293	4.281*	1.155	0.264	-0.017	0.007	-5.659	9.2E-5	4.1E-5	11.139
Predatory mite (adults)	0.612	16.327*	1.66	0.220	-0.029	0.006	-8.276	1.5E-4	3.5E-5	16.001

* = significant at 0.01.

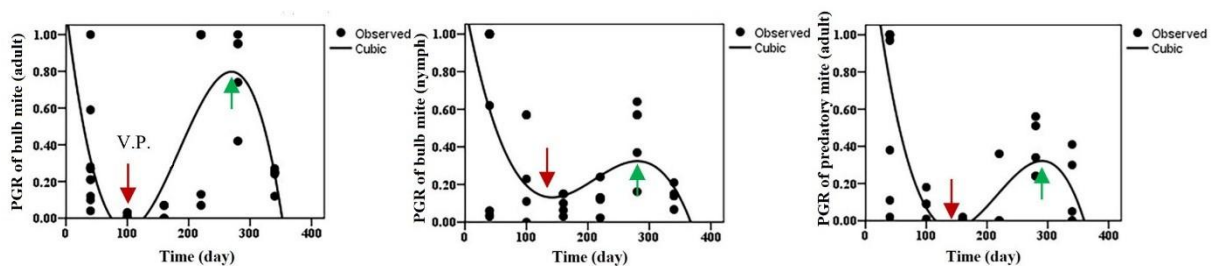


Figure 3. Non-linear regression model of the effect of time on the population growth rate of mites on saffron corms in the nymphal and adult stages and their predatory adult mites (starting from March 20, 2022).

The relationship between the PGRs of nymphal to adult stage of bulb mites and time fitted to a cubic non-linear regression (Table 2). Based on this model, the highest NAPR of bulb mites in saffron corm was obtained on July 4 (V.P. = 107.17) with a value of 3.68 and the lowest was obtained on January 4 (V.P. = 290.65) with a value of -0.087 (Fig. 4A). Also, the NAPR in the soil around the saffron corm was calculated to be the highest on July 9 (V.P. = 115.3) with a value of 2.42, and the lowest on January 6 (V.P. = 293.49) with a value of -0.36 (Fig. 4B).

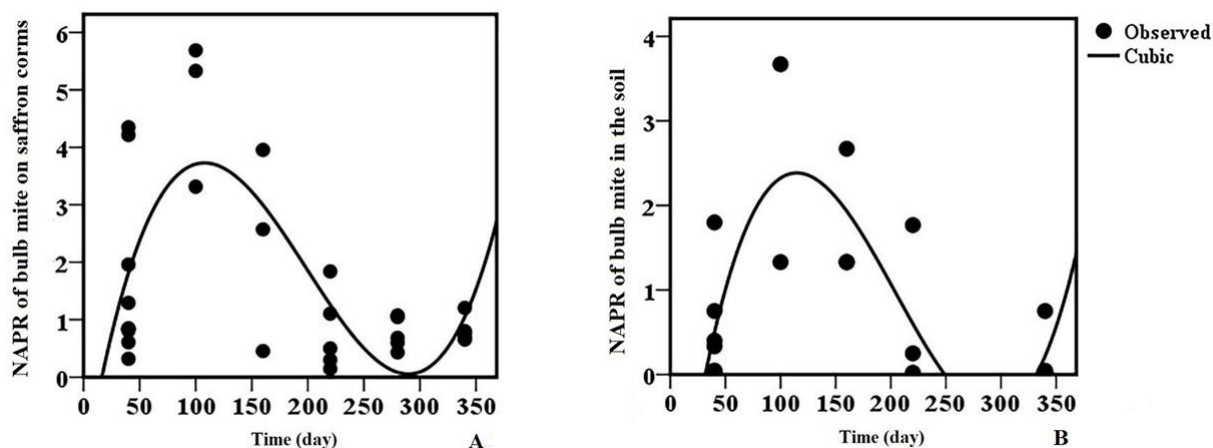


Figure 4. Non-linear regression model for the effect of time on NAPR of the saffron bulb mite – **A.** On saffron corms; **B.** In the soil around the corms.

Table 2. Non-linear regression model for the effect of time on the ratio of nymph/adult population of the saffron bulb mite population.

Model regression			Constant		Time ¹			Time ²			Time ³		
Parameter	R ²	F	B	S.E.	B	S.E.	Beta	B	S.E.	Beta	B	S.E.	Beta
Nymph/Adult ratio (Corm)	0.456	7.266*	-1.677	1.224	0.114	0.032	8.305	-7.28E-4	1.98E-4	-19.535	1.22E-6	3.43E-7	11.15
Nymph/Adult ratio (Soil)	0.546	6.025*	-2.585	1.023	0.1	0.029	11.31	-6.04E-4	1.91E-4	-26.00	9.85E-7	3.39E-7	14.86

* = significant at 0.01.

The effect of soil temperature and moisture on the NAPR of the saffron bulb mite throughout the year

The effect of temperature and soil moisture on the NAPR of the saffron bulb mite on the corm and the surrounding soil was fitted separately to a simple linear regression model (Fig. 5). Based on this model, the relationship between temperature and NAPR of bulb mites became direct and 20.4% ($R^2 = 0.204$) and 41.6% ($R^2 = 0.416$) of the variations in the NAPR in corm and surrounding soil were determined by temperature changes respectively. Additionally, the relationship between soil moisture and NAPR of saffron bulb mites became indirect, with 20.4% ($R^2 = 0.204$) and 41.6% ($R^2 = 0.416$) of the variations in NAPR in corm and surrounding soil being determined by temperature changes, respectively. In other words, as the temperature rises in the climatic conditions of Khorasan Razavi (semi-arid), the NAPR increases. Additionally, variations in soil moisture could inversely account for 27.8% ($R^2 = 0.278$) and 37.5% ($R^2 = 0.375$) of the changes in the NAPR of bulb mite in saffron corm and the surrounding soil, respectively. In other words, as soil moisture increases, this ratio decreases (Table 3).

The data on temperature and soil moisture were separately fitted with the NAPR of bulb mites across the five cities using simple linear regression (P-value < 0.05). The effect of temperature on the NAPR of the adult mite was determined to be inverse, while the effect of soil moisture was direct. Under the semi-arid climatic conditions of Khorasan Razavi Province and considering the phenology of the saffron plant (growth occurs in autumn and winter) a simple linear regression model effectively determined 21.3% ($R^2=0.213$) of the variations in the NAPR as inversely related to environmental

temperature changes, while this value for NAPR and soil moisture was 42% ($R^2=0.420$) directly (Table 4).

Table 3. Simple linear regression model of the effect of temperature ($^{\circ}\text{C}$) and soil moisture (%) on the NAPR of bulb mite separately.

	Model summary			Coefficients			
	Parameter	R^2	F	Constant	B	S.E.	Beta
Saffron corms	Temperature	0.204	7.18 *	0.311	0.084	0.031	0.452
	Soil moisture	0.278	10.78 *	3.63	-0.191	0.058	-0.527
Surrounding soil	Temperature	0.416	12.12 *	-0.719	0.085	0.024	0.645
	Soil moisture	0.375	10.21 *	2.303	-0.148	0.046	-0.613

* = significant at 0.01.

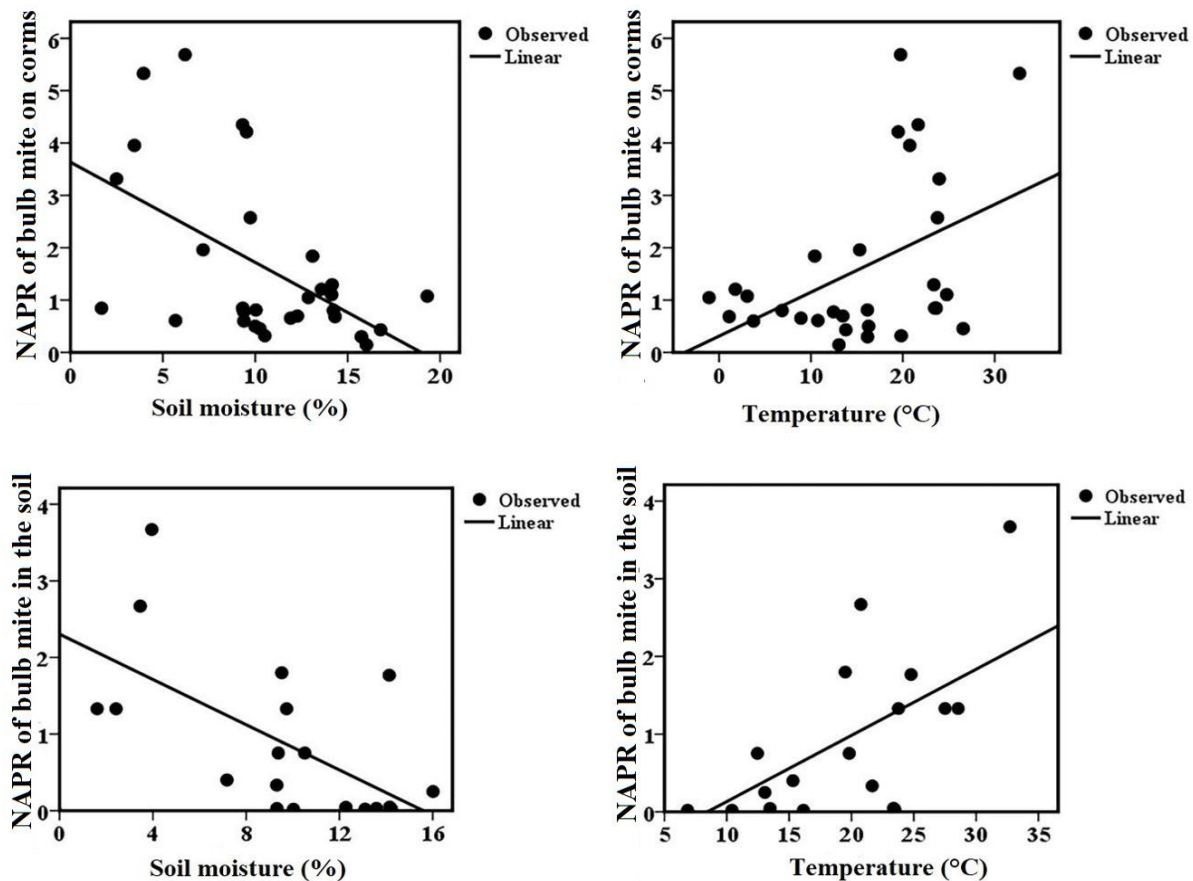


Figure 5. Simple linear regression model of the effect of temperature ($^{\circ}\text{C}$) and soil moisture (%) on the NAPR of bulb mite separately.

Table 4. Simple linear regression model of the effect of temperature ($^{\circ}\text{C}$) and soil moisture (%) on the NAPR of bulb mite separately.

Parameter	Model regression		Coefficients			
	R^2	F	Constant	B	S.E.	Beta
Temperature ($^{\circ}\text{C}$)	0.213	8.95*	0.656	-0.018	0.006	-0.462
Soil moisture (%)	0.420	23.89*	-0.111	0.048	0.01	0.648

* = significant at 0.01.

The effect of saffron corm weight changes during the year on the PGR of saffron corm mite

The effect of soil relative humidity and saffron corm weight factors on PGR of adult bulb mite was analyzed and fitted to a multiple linear regression model. Based on this model, the effect of soil

moisture was found to be direct, while the influence of saffron corm weight was assessed as inverse (Table 5). In other words, these two independent factors determined 30.2% of the variations in the PGR. According to the results, as saffron corm weight increased, the PGR exhibited a declining trend. However, the influence of soil moisture (Beta = 0.573) was found to be more significant than that of saffron corm weight (Beta = -0.314).

Table 5. Multiple linear regression model for the effect of soil moisture and corm weight on the adult bulb mite population growth rate.

dependent variable	Model summary		Constant		Independent factors					
					Soil moisture			Corm weight		
	R ²	F	B	t	B	S.E.	Beta	B	S.E.	Beta
PGR of adult bulb mite	0.302	6.916*	184.32	0.99 n.s.	46.58	12.81	0.573	-41.11	20.63	-0.314

* = significant at 0.01; n.s. = non-significant.

The effect of the population density of the bulb mite on the population density of predatory mites

The effect of total population of nymphal and adult bulb mite on the population density of predatory mite *Gaeolaelaps aculeifer* in both the saffron corms and surrounding soil was separately fitted using a multiple linear regression model. The effect of both life stages of the bulb mite on the predator population was obtained directly, but the effect of the nymphal stage of bulb mite population on the population of predator in corm (Beta = 0.444) and the surrounding soil (Beta = 0.782) was greater than that of the adult stage of bulb mite (Table 6). Additionally, the relationship between the adult population of predatory mite and the nymphal stage of bulb mite was modeled using a logistic model (Table 7, Fig. 6).

Table 6. Multiple linear regression model for the effect of population of bulb mite on predatory mite in surrounding soil and on the corms separately.

Dependent variable	Model summary		Constant		Independent factors					
					Adult			Nymph		
	R ²	F	B	t	B	S.E.	Beta	B	S.E.	Beta
Predatory mite in soil	0.449	13.05*	4.480	0.59 n.s.	0.032	0.019	0.289	0.051	0.020	0.444
Predatory mite on	0.886	124.9*	0.463	0.98 n.s.	0.054	0.013	0.281	0.164	0.014	0.782

* = significant at 0.01; n.s. = non-significant.

Table 7. Logistic model between the population of nymphal bulb mite and the population of adult predatory mite.

Parameter	R ²	F	Constant	B	S. E.	Beta
Nymphal bulb mite population	0.842	15.97**	0.171	0.995	0.001	0.4

** = significant at 0.05.

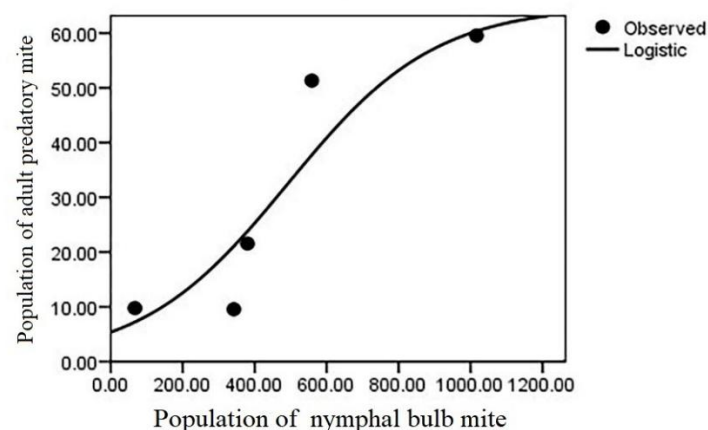


Figure 6. Logistic model between the population of nymphal bulb mite and the population of adult predatory mite.

The effect of some soil and corm parameters on bulb mite population density

According to the obtained data on the high PGR of saffron bulb mite in two-time intervals from October to December and from March to May in a total of five cities (Fig. 1), the effect of soil minerals (N, P and K), EC, sand and saffron corm weight on the population density of the mite in November (adult) and May (nymphs) was fitted with a simple linear regression model (Table 8). In November (saffron flowering time), among the factors examined, the relationship between sand content percentage, EC and soil phosphorus was inversely with the population density of adult mites, while the weight of the saffron corm showed a direct effect. In other words, in soils with high percentage of sand, EC and soil phosphorus and also low weight of the saffron corm, the population of adult mites shows a decreasing trend in November. The analyzed data from May indicate a direct effect of sand content percentage, EC and soil phosphorus, as well as an inverse effect of saffron corm weight on the nymph mite population (Table 8). Based on the obtained data, higher soil sand content, salinity, and phosphorus levels, along with a decrease in saffron corm size, create favorable conditions for increased reproduction and a higher population density of saffron corm nymphs.

Table 8. The effect of soil and corm factors on the PGR of bulb mite population at two peak times.

Parameter	Adult stage of bulb mite (November)						Nymphal stage of bulb mite (May)					
	R ²	F	Constant	B	S.E.	Beta	R ²	F	constant	B	S.E.	Beta
Sand	0.505	23.44*	2832.49	-51.920	10.723	-0.710	0.445	18.44**	-7617.15	332.22	77.356	0.667
EC	0.390	14.71*	778.063	-203.05	52.943	-0.625	0.614	36.512**	-5227.08	4978.63	823.932	0.783
Phosphorus	0.454	19.11*	779.992	-24.603	5.628	-0.674	0.559	29.21**	-1128.1	241.33	44.655	0.748
Weight corm	0.53	25.97*	-564.78	113.125	22.197	0.728	0.550	28.1**	18492.47	-1851.6	349.28	-0.742

* = significant at 0.01.

The effect of altitude on bulb mite population fluctuation of during the year

The population fluctuation (PF) of the bulb mite was calculated throughout the year as the difference between the maximum and minimum populations in different cities. The resulting data on the PF of adult, nymph, and total mite were fitted to the altitude of the sampled areas and showed a non-linear power relationship between these variables (Table 9). According to this relationship, as altitude increases, PF in the bulb mite decreases (Fig. 7). According to this model, population fluctuation reaches its minimum at approximately 1750 meters and its maximum at around 500 meters.

Table 9. Regression of power model between adult, nymph and total population fluctuation with altitude

Parameter	R ²	F	B	S. E
Adult	0.872	20.523 **	-3.430	0.757
Nymph	0.885	23.029 **	-4.092	0.853
Total	0.916	32.769 **	-4.432	0.774

** = significant at 0.05.

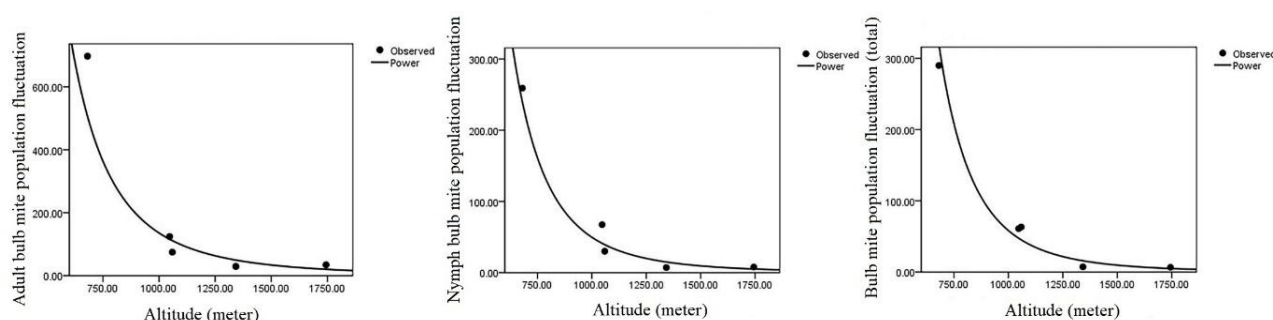


Figure 7. Regression power model between adults, nymphs, and total population fluctuation with altitude.

DISCUSSION

The population growth rate (PGR) of bulb mite (adult + nymph) in saffron fields of five cities (Mashhad, Dargaz, Torbat Heydariyeh, Gonabad and Quchan in Khorasan Razavi Province, Iran) increased from early autumn and decreased during winter, then increased in early spring and decreased from mid-spring to late summer. According to the results obtained, the peak of PGR occurred at two different times, so that the second peak of the PGR of nymphs in May was maximum and higher than the first peak in January, regarding PGR of adult bulb mite, the main peak of population was showed in November to January (Fig. 1). Accordingly, it seems that changes in environmental conditions, especially temperature and humidity (Fig. 2), have different effects on adult and nymphal populations of the bulb mite. It seems that after September, with the first irrigation and increased humidity and appropriate temperature, conditions are provided for the growth of the adult population, and these conditions contribute to the maximum adult population growth (November to January) after saffron flowering and the beginning of the saffron vegetative stage that mother corms begin to decompose and provide soft, nutritious tissue that facilitates feeding and further oviposition (egg-laying) by the adult mites. Consequently, in January, the maximum population growth of nymphs appears with a delayed phase, which is an introduction to the creation of resistant forms in summer (July).

The results obtained regarding the low bulb mite population in summer in this study (lowest adult bulb mite growth rate on June 24; V. P. = 103) are consistent with the findings of Rahimi *et al.* (2008); however, they do not align with the reported low population in winter (Fig. 3). This discrepancy could be due to the relative increase in winter temperatures in the last two decades. Also, the highest PGR occurs in late autumn (December 3; V.P. = 258.9). This pattern of population growth aligns with the study of Sherwani *et al.* (2023). As noted by Rahimi (2018a), in recent years, the absence of cold winters has allowed the mite to remain active during winter, often with high population densities. The elevated winter population observed in the present study, likely driven by climate change, is consistent with the findings reported by Rahimi (2018a). The absence of winter cold was also found in the data of this study. According to meteorological data from the five cities of Khorasan Razavi, the maximum air temperature (25–35 °C) was observed in July and September. The temperature decrease trend continued from September to January, and the lowest temperature (around 0 °C) was observed in January, in all cities (Fig. 2B). The difference in the time of population peaks first in adults of the saffron mite, its nymphs and finally in the predatory mites indicates that a lag phase of about one month (258.9–289.7) has been created from the time of the population peak of adults of the saffron mite to the population peak of the predatory mites (in December). This lag phase indicates the complete dependence of the predatory mite population on the populations of adults and nymphs of the saffron mite (Fig. 3).

The effect of temperature and humidity on the nymph/adult population ratio (NAPR) of the saffron mite fluctuated throughout the year. The highest NAPR was observed in summer (107.17 days), which indicates that the presence of resistant nymphs of hypopus is required to survive the harsh summer conditions, and it seems that the increase in the nymph population is due to the development of this resistant form of nymphs. While the lowest NAPR, which means an increase in the population of adults relative to nymphs, occurred in winter (290.65 days), which seems to be the best nutritional and temperature conditions (due to the lack of cold winters) for adults (Fig. 3).

The direct relationship of temperature and inverse soil moisture with NAPR can be a function of the environmental conditions of this region (semi-arid). Because in this region, higher temperatures (> 27 °C) in summer are accompanied by reduced rainfall and reduced soil moisture. These conditions tend to reduce the population of saffron mite and create a resistant form (hypopus), and for this reason, the NAPR increases (Fig. 5, Table 3).

According to the results in Table 5, saffron corm weight has an inverse effect on population growth rate (PGR). It seems that saffron corms with greater weight gain are more resistant to mite activity and reproduction, and it can be recommended that proper nutrition of saffron fields can help manage this pest. Also, the effect of soil moisture on mite PGR was direct, and its high effect (57.3%) on population changes indicates a warning in conditions of lack of stable cold in winter and early start of irrigation in summer (so-called double irrigation of saffron before flowering).

The higher direct effect of the nymph population compared to the adult population of saffron mite on the predator mite population in the multiple linear regression model indicates the food preference of this predator mite to be the nymphal stage of saffron mite. The 78.2% effect of changes in the nymph population of saffron bulb mite on changes in the predator mite population within the corm indicates the highest dependence of the predator mite on the nymphs of the pest mite (Table 6). Fitting the relationship between the nymph population of saffron mite and the predator mite with a nonlinear logistic model indicates a three-stage growth of the predator mite population, with the first and last stages of the growth response being slow. Therefore, according to Figure 6 and Table 7, the population ratio of predator mite to saffron bulb mite is about 20:1, which in explosive populations of saffron mite, the predator mite cannot practically maintain this population ratio and synchronize its population with the pest mite population.

Considering the peak population of adult saffron mite in November and the peak population of nymphs in May (Fig. 3), the relationship between the PGR of these life stages during their peak population was investigated with some factors (EC, phosphorus, soil texture, corm weight). Interestingly, the opposite effect of these factors on adults and nymphs during their peak population period is noteworthy. As an explanation, increasing corm weight in November increases the population of adult saffron mite because the mother corms begin to decay in November and the high biomass of food under these conditions increases the population of adult saffron mite. On the other hand, decreasing corm weight in May increases the population of nymphs because the smaller daughter corms are weaker and have a more fragile texture for nymphs to penetrate. The decrease in the percentage of sand in the soil and the consequent heavier soil texture in November are generally beneficial to adult saffron bulb mite and increase their population because they retain more moisture and because of the greater strength and mobility of adults, this heavy soil does not interfere with their activity. Conversely, increasing the percentage of sand in the soil and making the soil texture lighter in May is suitable for nymphs and increases their population because nymphs have low mobility and are better able to spread in light soils (Table 8).

Population fluctuation (PF) of saffron corm mite showed a nonlinear power relationship with altitude of the cultivation area. The decrease in mite population fluctuations with increasing altitude can indicate a relative increase in the mite population in summer or a relative decrease in the mite population in winter, or a combination of both. In justification of this relationship, it can be said that increasing altitude reduces temperature fluctuations and, in most cases, increasing altitude will also increase rainfall. Accordingly, it can be said that at higher altitudes there are more moderate summers in terms of temperature and humidity, which are not beneficial for dormant saffron corms in terms of increasing saffron corm mite activity. On the contrary, higher altitudes, due to harsher winters and more frost, limit the growth conditions of saffron corm mite, and this can be a positive point (Table 9).

CONCLUSION

The population dynamics of the saffron bulb mite (*Rhizoglyphus robini*) in Khorasan Razavi saffron fields exhibit a clear seasonal pattern influenced by environmental conditions, host plant phenology, and agronomic practices. Two major peaks were observed: the first in adults during late autumn to mid-winter (November–January) and the second in nymphs during mid spring (May), with the latter exceeding the former in magnitude. These fluctuations are strongly associated with the temperature and soil moisture, where mild winters and early irrigation create favorable conditions for mite activity. The presence of resistant hypopus stages during summer highlights an adaptive survival strategy under harsh conditions. The differential response of life stages to ecological and soil factors, such as corm weight, soil texture, and irrigation, underscores the complexity of population regulation. Moreover, predator mites exhibited a delayed numerical response, indicating limited potential for natural control under high pest densities. Climatic variability, particularly warmer winters, appears to enhance overwintering survival and population build-up, potentially linked to climate change. In general, it can be said that areas with mild winters that do not often experience temperatures close to or below zero degrees, and summers with

rainfall, although low and scattered, increase the population of this pest and are therefore not suitable for saffron cultivation. Based on the altitude data of the cultivation areas, it seems that the sharp difference in temperature and humidity in winter (cold and humid) and summer (hot and dry) are the limiting and controlling conditions for the pest population and are therefore suitable for saffron cultivation.

From a management perspective, strategies such as maintaining optimal corm weight through proper nutrition, regulating irrigation schedules, and improving soil structure can play a significant role in suppressing mite populations in saffron fields. Long-term monitoring and predictive modeling that integrate climatic trends and ecological interactions are essential for sustainable management of saffron bulb mite specially under changing environmental conditions.

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پویایی فصلی جمعیت هرناهی *Rhizoglyphus robini* Claparède (Acari: Acaridae) و هرناهی شکارگر آن و تأثیر برخی عوامل محیطی در مزارع زعفران شمال شرقی ایران

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چکیده

زعفران، *Crocus sativus* L. (Iridaceae)، به عنوان گران‌ترین ادویه جهان شناخته می‌شود و هرناهی زعفران (*Rhizoglyphus robini* Claparède, 1869) با تغذیه از بنه‌های سالم یا آسیب‌دیده زعفران، خسارت مستقیم و غیرمستقیم ایجاد می‌کند و به عنوان مهم‌ترین آفت کلیدی این محصول شناخته می‌شود. در این مطالعه، تأثیر عوامل محیطی شامل دما، برخی پراسنجه‌های خاک و ارتفاع از سطح دریا، بر جمعیت کنه زعفران (بالغ و پوره) و هرناهی شکارگر غالب آن (مشهد، گناباد، تربت حیدریه، درگز و قوچان) ارزیابی شد. رابطه بین میزان رشد جمعیت (PGR) مراحل بالغ و پوره هرناهی زعفران و هرناهای شکارگر در طول سال با استفاده از رگرسیون غیرخطی برازش داده شد. بر اساس این مدل، PGR هرناهی بالغ زعفران در ۲۴ ژوئن کمترین و در ۳ دسامبر بیشترین مقدار را داشت. برای پوره هرناهی زعفران، PGR در ۵ آگوست کمترین و در ۱۲ دسامبر بیشترین مقدار را داشت. PGR هرناهی شکارگر با ضریب تعیین $R^2 = 0.612$ حداکثر برازش را با مدل داشت. در این مدل، PGR کنه شکارگر در ۹ آگوست به کمترین مقدار و در ۳ ژانویه به بیشترین مقدار خود رسید. اثر دما و رطوبت خاک بر نسبت جمعیت پوره/بالغ (NAPR) هرناهای زعفران با یک مدل خطی چندگانه برازش داده شد و بنابر نتایج، NAPR با افزایش دما و کاهش رطوبت خاک افزایش یافت. نتایج این مطالعه می‌تواند نقش مهمی در پیش‌بینی و تعیین توسعه کشت زعفران داشته باشد.

واژگان کلیدی: هرناهی زعفران، آفت کلیدی، نوسانات جمعیت، خراسان رضوی، زعفران.

دریافت

۲۲ مهر ۱۴۰۴

پذیرش

۲۳ آذر ۱۴۰۴

انتشار

۲۵ دی ۱۴۰۴

دبیر تخصصی

م. سیدی

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