Article

A field study on the biology of the purple scale, *Lepidosaphes beckii* (Newman) (Hemiptera: Diaspididae) on citrus trees in Mazandaran, Iran

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Abstract
The purple scale, *Lepidosaphes beckii* (Newman) (Hemiptera: Diaspididae), is one of the important citrus pests in Mazandaran Province, north ofIran. The bioecology of this pest was studied on citrus trees (*Citrus aurantium*) in citrus orchards of Mazandaran during 2018 and 2019. The results showed that this scale insect produces three generations per year and overwinters in the form of the second nymphal instars and adult females. A study on population flactuations revealed that the first generation of this pest, depending on the weather conditions, has been active since late May and its growth stages were completed in the first decade of August. Afterwards, the activity of the second generation begins and the first instar nymphs related to the second generation appear in the second decade of August. The activity of the third generation begins in the first decade of October. The crawlers disperse at the same time and the armored scale overwinters in the form of second nymph instars and adult females after establishing and completing growth. The trend of population fluctuations on the upper and lower of the leaves was similar. The activity of parasitoids was observed mainly on adult females in April to May and July to October, but the peak of their activity was in April to May.

Keywords population fluctuations; purple scale; *Citrus aurantium*; overwintering; parasitism.

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1 Introduction

Mazandaran Province, having more than 100,000 citrus orchards and an average annual production of 1,800,000 tons of fruit, has the first rank among citrus-producing provinces in Iran (MafiPashakolaei, 2012; Anonymous, 2019). The diversity and abundance of pests in citrus-growing areas in the north of the country are extremely higher than those inthe southern areas, which is due to high rainfall and relative humidity in this region (Ismaili, 2007). Scale insects, such as citrus cottony cushion scale, wax scales, soft scales, and other scales are the most common insects in citrus orchards, especially in the hot and humid months of the year (early June to late October) (Gulan, 2004).

Lepidsaphes beckii (Newman) is one of the most important and serious species of scale insectsglobally (tropical and subtropical regions) (Danzig and Pellizari, 1998; Claps et al., 2001; Foldi, 2001; Aly, 2011). It is a polyphagous pest and has been reported almost on 176 genera, belonging to 83 families of plants (Davidson and Miller, 1990; Aly, 2011; Garcia et al., 2016), which most important hosts include mango (*Mangifera indica* Linnaeus) belonging to the family Anacardiaceae, cypress species (*Cupressus* spp.) belonging to the family Cupressaceae, fire croton (*Codiaeum variegatum* (Linnaeus)) belonging to the family Euphorbiaceae, olive (*Olea europaea* (Linnaeus)) belonging to the family Oleaceae, apple (*Malus domestica* (Borkhausen)) and pear (*Pyrus communis* (Linnaeus)) both belonging to the family Rosaceae, and *Citrus* sp. belonging to the family Rutaceae (Watson, 2002; Miller and Davidson, 2005). This pest was first observed on citrus trees in Ramsar area (north Iran) and probably entered from Palestine to Iran in 1937 with citrus seedlings (Davatchii and Taghizadeh, 1954). At the moment, in addition to citrus, *L. beckii* has also been observed on *Camellia sinensis* (L.) Kuntze and *Buxus hyrcana* Pojark (Moghaddam, 2013). The main hosts of this pest in Iran are different species of citrus (Moghaddam, 2013). This pest is distributed from Rudsar city (Gilan Province) to Behshahr city (Mazandaran Province) and rarely Gorgan (Golestan Province), north of Iran.The highest density of this insect is between Tonekabon and Nowshahr cities in Mazandaran Province. Due to its need for subtropical and humid climate, it has not reached other parts of Iran, including the citrus-rich areas of the south (Azmayeshfard, 2014). The purple scale attacks leaves, young shoots, old branches and fruits of citrus trees, causing severe drying of the young leaves and twigs, and the affected area looks like a fire burn, and the severity of its attack is more in the inner and shady parts of the trees, and often a sheet of purple scales is covered on the fruits (Moghaddam, 2013; Damavandian, 2020). The purple scales reproduce as bisexual or parthenogenesis. It usually has up to four generations per year, depending on environmental conditions (Zuniga, 1971; Bénassy et al., 1975; Davidson and Miller, 1990; Gill, 1997). In california, this pest often overwinters in the form of eggs or adult females and in colder regions, overwintering may occur in the egg stage (Watson, 2002).

Number of the purple scale's generations per year varies around the world. For examples, it has four generations in South Africa (Bedford et al., 1998), one to four (mostly three) generations in Egypt (Aly, 2011; El-Amir et al., 2012), 3–4 overlapping generations in California (USA) (Gill, 1997), one generation in Chile (Zuniga, 1971), and two generations in France (Bénassy et al., 1975). The life cycle of this scale lasts about 6–8 weeks in Australia (Smith et al., 1997). Fadamiro et al. (2008) stated that all stages of *L. beckii* are present throughout the year in citrus orchards of south Alabama, Alabama, USA, indicating overlapping generations, with the highest densities recorded in the early season. Ebeling (1959) stated that *L. beckii* prefers moist areas and is found in shady areas of the tree and on leaves and fruits. Avidov and Harpaz (1969) reported that the developmental period of females and males of the pest in summer is 50 and 44 days, respectively, while it takes about 115 days in winter.

According to the studies and researches carried outon *L. beckii* in Iran, no accurate report has been made on the biology of this scale in Iranso far, and the presented cases are based on conjectures or observations. According to the high population of this pest and its considerable damage, and since farmers and pest control workers should be familiar with its biology and the most sensitive pest stagesto achieve sufficient success (Azmayeshfard, 2014), the present study was conducted to investigate the biology of this pest, its overwintering pattern and its parasitism rate based on the climatic conditions in north of Iran.

2 Materials and Methods

2.1 Location and time of study

This research was conducted in an area of one hectare located in Amolvicinity in Mazandaran Province (northern Iran) from May 2018 to July 2019.The experiments were performed on 10-year-old *Citrus aurantium* Linnaeus orange trees. The distance between the trees on the rows was 5 m and the distance between the rows was 8m. No insecticides were used in the orchard during the sampling.The geographical characteristics of the studied area included 36° 28' N and 52° 21' E with an altitude of 76 m above Caspian sea level

2.2 Sampling and laboratory experiments

To study of the population and determine the overwintering pattern, samplings were performed for 13 months from 29.05.2018 to 15.07.2019 with a time interval of 10 days during the growing seasons. A total of 39 samples were taken. The sampling method was to select 10 infected citrustrees. Thereafter, 12 leaves from each tree were randomly separated from four geographical directions (each side 3 leaves) once every 10 days. To retain moisture, the samples were packed in polyethylene bags and transferred to the laboratory of Sari University, and stored in a refrigerator at 3 to 4°C until considering. This scale was identified using valid identification keys (Evans et al., 2009; Henderson, 2011; Hang et al., 2018). In the laboratory, the leaf specimens were examined by stereomicroscope and number of the purple scale by age stages (first and second instar nymphs, and adult females) on the upper and lower surfaces of the leaves were counted and recorded. It should be noted that in first instar namphs, males and females are indistinguishable, but in second instar namphs, by removing the insect shield, there were pupae in males, while there wereno pupae in females. Determination of sexes in adulthood was easy, because of free winged males and motionless females under the shields. Moreover, the number of parasitized scales was counted to determine months in which the highest percentage of parasitization occured. The number of parasitized individuals were determined by counting the number of scales that had perforated shields and existed any of the growth stages of the parasitoid lower their shields. In the cases, where the number of scale insects were plenty, a 2 × 2 cm (4 cm^2) box made of cardboard was used to count the scales (Damavandian, 1994). Also, according to the sampling of leaves in different geographical directions on the tree to estimate the density and population flactuation, the effect of geographical directions on the density of the scale population was evaluated which is necessary for pest management forecasting.

2.3 Statistical analysis

The obtained data were statistically analyzed using SAS statistical software (version 9.4) and the comparison of the mean data was performed using Duncan's Multiple Range Test at a 5% probability level. Relevant charts were drawn using Excel software (version 2013).

3 Results

3.1 Population flactuationsof different developmental stages of the purple scale on the upper and lower surfaces of the leaves

3.1.1 First instar nymph

Population fluctuations of the first instar nymph during sampling are shown in Fig. 1. As it is clear, the first instar nymph had the highest populationsin four dates. These dates included mid June 2018, mid August 2018, mid October 2018, and late May 2019 with the averages of 1793.5, 919.2, 1451.6, and 1839.7 nymphs per 12 leaves per tree, respectively. According to the flactuations, the population of first instar nymphs had an increasing trend on May 22nd to June 21st and had the most activity in the same time, but except in July 23rd to August 23rd, its population was lower thanthat occurred in June 22nd to July 22nd and August 23rd to September 22nd. From September 23rd to October 22nd, its population increased again and its population gradually decreased from October 23rd to November 22nd, so that the population of the first instar nymph was zero from early January 2019 to late April 2019. The population increased from early May 2019 and reached its highest range on late May 2019 (26.05.2019) and then began to decrease, so that its population reached zero again on 25.06.2019 and 05.07.2019, but began to increase on 15.07.2019. As can be seen in Fig. 1, a comparison of population fluctuations in relation to the temperature changes shows that with a gradual increase in temperature from late April 2018 to early May 2018, the average population of first instar nymph also reached its peak from early June 2018 to mid June 2018 with an increase in temperature from 25 to 26.3°C. An increase in the population of first instar nymphs was observed again from mid July 2018 to early August 2018 with an increase of approximately four degrees in temperature. The population of first instar nymphs reached almost zero with a sharp decrease in temperature from late December 2018 and this trend has continued until late April 2019. Increasing the temperature from late April 2019 to late May 2019 by 11°C caused an increase in population and the average population reached from zero to 983.6 nymphs.

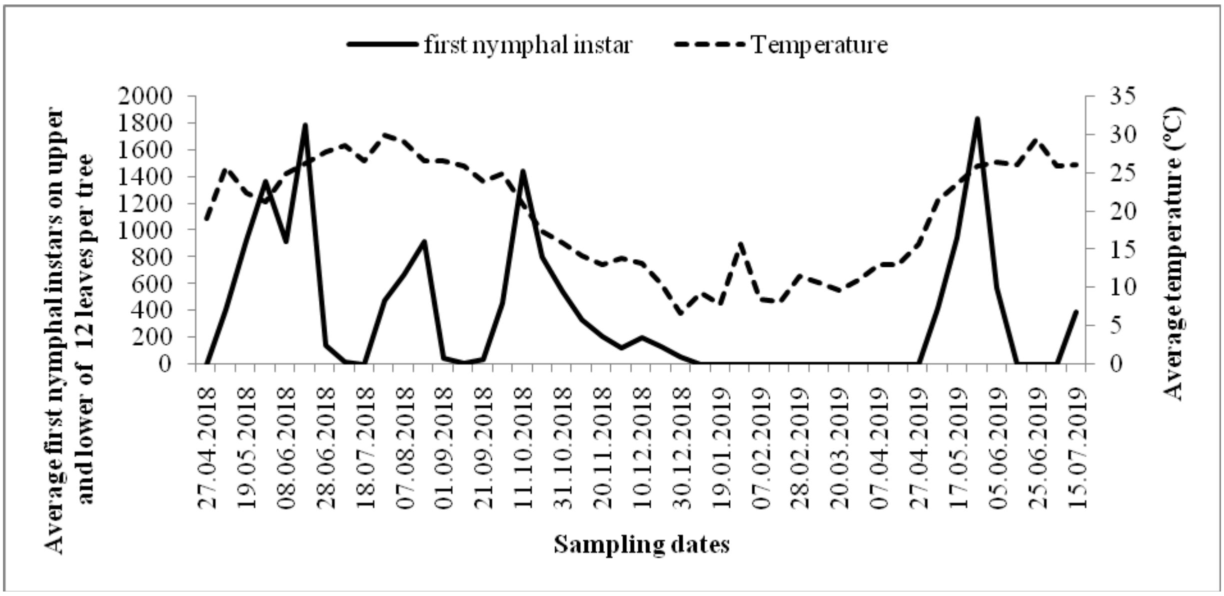

Fig. 1 Population fluctuations of the first instar nymph of *Lepidosaphesbeckii* on the upper and lower surfaces of citrus leaves at sampling dates.

3.1.2 Second instar nymph

According to the population fluctuations of the second instar nymphs of the purple scale (Fig. 2), this nymphal stage was similar to the first instar nymph and had four population peaks in four dates. These dates included late June 2018, early September 2018, late October 2018, and early June 2019 with averages of 332.4, 263.9, 319.5, and 348.3 nymphs per tree, respectively. It is important to note that the population of second instar nymphs was lower than that of first instar nymphs.In this nymphal stage, similar to the previous stage, the trend of fluctuations in the population of nymphs was increasing from April 21st to May 21st, 2018. With the increase of temperature in May 21st–June 22nd, the population started to increase, so that it reached its highest level in the last June (28.06.2018). From early July 2018 to late July 2018, the population decreased, but reached its peak again on early September 2018 (01.09.2018). The population of the second instar nymphs has decreased until September 22nd, but it has started to increase again on early October 2018 (01.10.2018), so that it reached its peak on late October 2018 (31.10.2018). The trend of decreasing and increasing the population with low rates continued on 10.11.2018 and 20.11.2018 and from late November 2018 (22.11.2018) to late January 2019 (22.01.2019). Its decreasing trend started from late January 2019 and reached zero on late March 2019 (20.03.2019) and this trend continued until 27.04.2019. The population of nymphs has started to increase from early May 2019 and reached its peak on early June 2019. The population had a decreasing trend from this time to mid July 2019. According to the diagram presented in Fig. 2, the increase in temperature from 21.2°C on late May 2018 to 27.8°C on late June 2018 caused an increase in the average population from 90.4 to 175.5 nymphs. From late July 2018 to early September 2018, although we saw a decrease of almost three Celsius degrees in temperature, the average population was increasing. With the gradual decrease of temperature from early October 2018 to late March 2019, the general trend of population fluctuations has been decreasing. With increasing temperature from 23.6 to 26.4°C from mid May 2019 to early June 2019, the average population of second instar nymphs also increased.

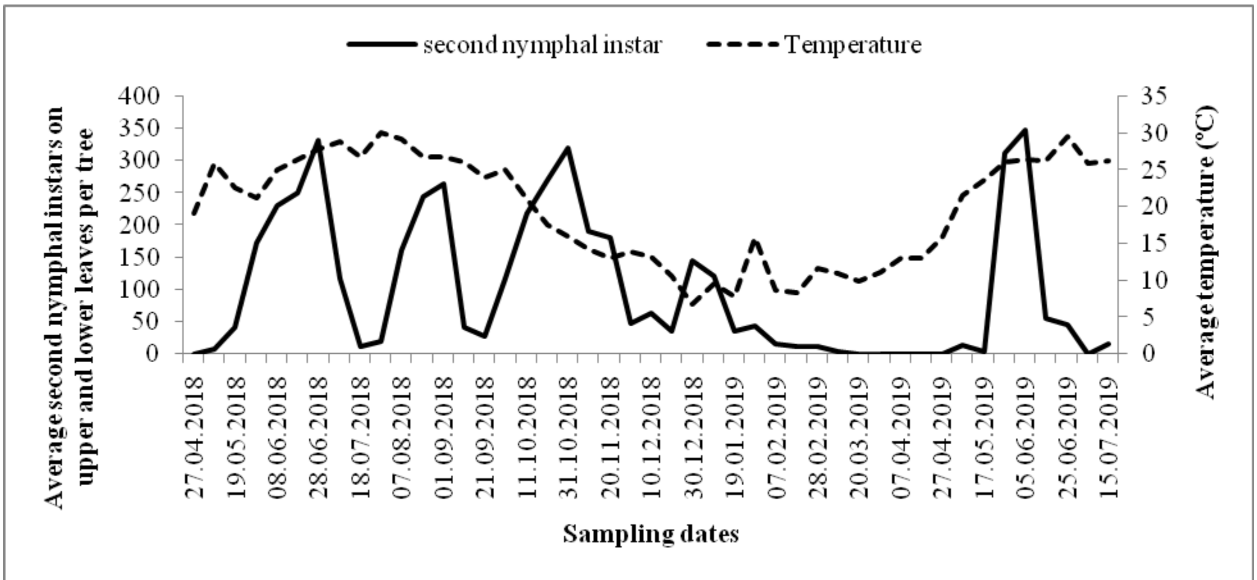

Fig. 2 Population flactuationsof the second instar nymph of *Lepidosaphesbeckii* on the upper and lower surfaces of citrus leaves at sampling dates

3.1.3 Adult female

The trend of population fluctuations of adult females of *L. beckii* was different from those occurred in nymphs (Fig. 3), because it had less intense population fluctuations and has been present in nature almost all year round. At this growth stage, three population peaks were observed on late November 2018, early March 2019, and early June 2019 with averages of 981.8, 569.8, and 423.0 females per tree, respectively. From April 21st to May 21st, the trend of adult female population fluctuations on trees was decreasing. On late May 2018 (29.05.2018), its population began to increase with the warming of the weather until late June 2018. Population fluctuations continued with a relatively decreasing trend until early August 2018. On mid August 2018 (17.08.2018) and early September 2018 (01.09.2018), an increase in population was observed. The decreasing trend of the population was followed from mid September 2018 to mid October 2018, but from mid October 2018, the population started to increase, so that reached its peak on early November 2018 (30.11.2018). Since then, the population has fluctuated and decreased, so that again peaked on early March 2019 (10.03.2019). From late February 2019 to mid May 2019, the trend of population fluctuations was decreasing. On late May 2019 (26.05.2019), the population started to increase again and reached its peak on

05.06.2019 but from then the trend was declining until mid July 2019. The graph of adult female population fluctuations in Fig. 3 shows that with increasing temperature from 21.2°C on late May 2018 to 27.8°C on late June 2018, the average adult female population has increased from 14 to 122.9 females. Also, with the gradual decrease of temperature on early October 2018 to late March 2019, we observed that the peak of the population on late November 2018 (30.11.2018) and the high average population until late December 2018 (30.12.2018), despite its relative decrease, which indicates thatthe overwintering of this pest wasin the form of adult females and some extent a second instar nymphs.The increase in temperature from March 21st to April 20th and May 22nd to June 21st caused an increase in the average population of adult females in these times.

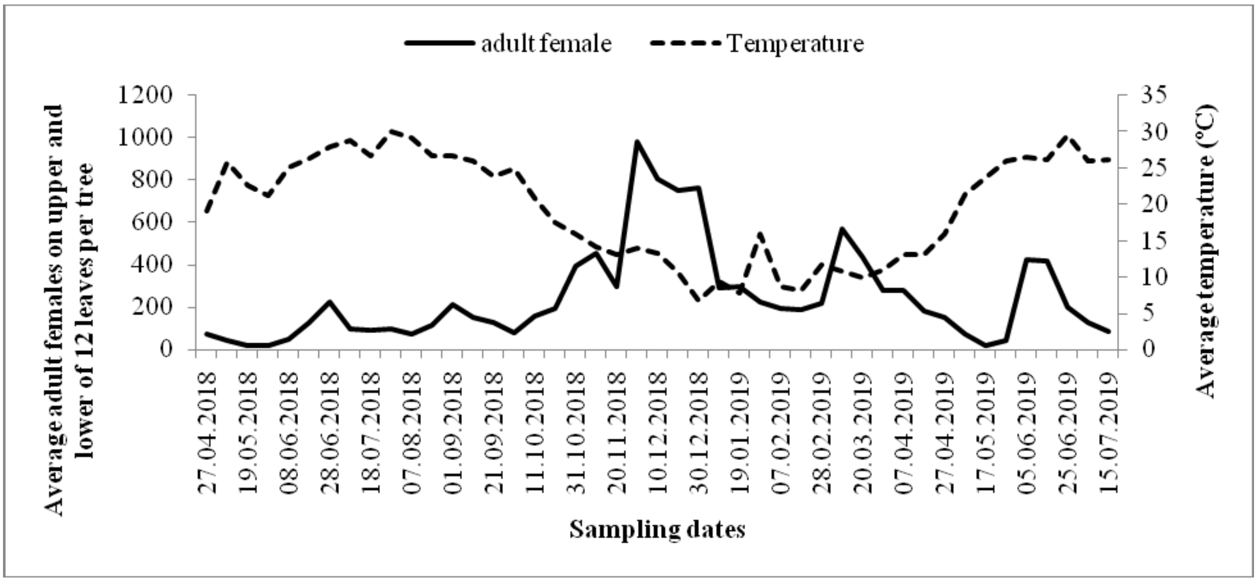

Fig. 3 Population flactuationsof the adult female of *Lepidosaphesbeckii* on the upper and lower surfaces of citrus leaves at sampling dates

3.1.4 Parasitized scales

The trend of fluctuations in the population of parasitized scales, in other words, the activity of parasitoids of *L. beckii* is shown in Fig. 4. As can be seen, the trend of parasitic insect population fluctuations was increasing from late April 2018 to early May 2018, but was decreasing onmid May 2018 (19.05.2018). The trend of parasitized scale population fluctuations was increasing from late May 2018 to late September 2018. This indicates that the activity of parasitoids increased during this period. The population of parasitized insects has started to decrease from early October 2018, so that it reached the lowest value on late January 2019 (28.01.2019), and parasitoids had little activity with decreasing temperature and their activity reached its lowest point with the peak of cold. The activity of parasitoids has started again from17.02.2019, and their activity has increased until early March 2019, and the increasing and decreasing fluctuations with low range continued until late April 2019. On early May 2019 (07.05.2019), the population of parasitized scales increased, but the activity of parasitoids gradually decreased from mid May 2019, so that the population of parasitized insects was greatly reduced on mid June 2019 (15.06.2019). There was an increasing trend from late June 2019 to mid July 2019. Population and temperature fluctuations in Figure 5 show that the increase in temperature from late April 2018 to early May 2018 caused an increase in the average number of parasitized scales, although, despite the increase in temperature to late June 2018, the trend of parasitized scales population fluctuations was decreasing. With the increase of temperature on the mentioned date until late July 2018, the number of parasitized scales increased, despite the relative decrease of temperature from late July

2018 to late September 2018, the number of parasitized scales was increased.The decrease in temperature from early October 2018 caused a decrease in the number of parasitized scales, and this decreasing trend continued with the decrease in temperature until mid February 2019. The increase in temperature on early May 2019 (07.05.2019) caused an increase in the number of parasitized scales (the average of 29 parasitized females), although the number of parasitized scales decreased with increasing temperature, although on mid July 2019 (15.07.2019), with a relative increase in temperature, the numberofparasitized scales have increased.

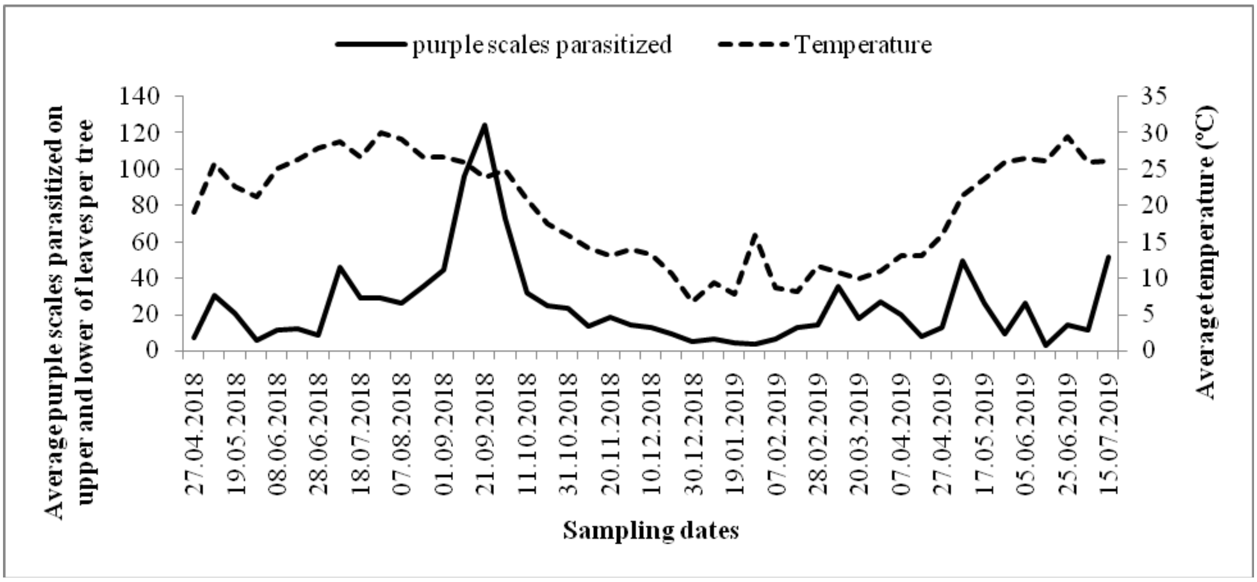

Fig. 4 Population fluctuations of the parasitized scales of *Lepidosaphesbeckii* on the upper and lower surfaces of citrus leaves at sampling dates.

3.2 Evaluation of parasitism of *L. beckii* on the upper and lower surfaces of citrus leaves

The percentage of parasitism of *L. beckii* on the upper and lower of citrus leaves is presented in Table 1. It should be noted that most of the parasitized scales were adult females. According to the obtained results, the highest percentage of parasitism on the upper of leaves was obtained on mid May 2019 (17.5.2019) at the rate of 63.20%, followed by late September 2018 (21.09.2018), mid May 2018 (19.05.2018), and early October 2018 (01.10.2018) with 51.05, 50.88, and 49.86% parasitism, respectively. On the other hand, the lowest rate of parasitism occurred on 30.12.2018 and 15.06.2019 with 0.54 and 0.80%, respectively.

Regarding the rate of parasitism on the lower of the leaves, the highest rate was obtained on mid May 2018 (19.5.2018) with 55.00%, followed bythe dates of 21.09.2018, 01.10.2018, and 17.05.2019 with 47.03, 46.26, and 46.12% of parasitism, respectively. Also, the lowest rate of parasitism on the lower of the leaves was obtained on mid June 2019 (15.06.2019) with 0.41%, followed by late December 2018 (30.12.2018) with 0.75%. Comparison of the total mean between the percentage of parasitism on the upper and lower of the leaves showed that the mean percentage of parasitism between the upper and the lower of the leaves did not differ significantly (t = 1.57, df = 44, sig = 0.123).

Table 1 The rate of parasitism (%) of *Lepidosaphes beckii* on the upper and lower surfaces of the leaves on sampling dates.

Sampling date	Parasitism (%)		Sampling date	Parasitism (%)	
	Upper	Lower		Upper	Lower
27.04.2018	6.35	12.45	30.12.2018	0.54	0.75
09.05.2018	43.93	34.31	09.01.2019	1.81	2.04
19.05.2018	50.88	55.00	19.01.2019	1.00	2.29
29.05.2018	17.16	24.47	28.01.2019	1.05	1.94
08.06.2018	18.46	18.15	07.02.2019	2.63	3.69
18.06.2018	8.09	9.23	17.02.2019	5.63	7.37
28.06.2018	3.15	3.94	28.02.2019	4.77	8.02
08.07.2018	33.16	30.28	10.03.2019	5.90	5.68
18.07.2018	24.59	23.96	20.03.2019	4.04	3.78
28.07.2018	33.89	15.64	28.03.2019	8.82	8.54
07.08.2018	30.08	22.92	07.04.2019	7.40	5.80
17.08.2018	23.20	23.74	17.04.2019	3.60	4.58
01.09.2018	16.96	17.56	27.04.2019	7.91	6.78
11.09.2018	37.94	39.78	07.05.2019	47.70	31.75
21.09.2018	51.05	47.03	17.05.2019	63.20	46.12
01.10.2018	49.86	46.26	26.05.2019	15.76	17.86
11.10.2018	17.26	16.23	05.06.2019	5.80	5.65
21.10.2018	9.64	13.70	15.06.2019	0.80	0.41
31.10.2018	5.54	5.48	25.06.2019	6.92	5.90
10.11.2018	2.39	3.49	05.07.2019	7.71	7.60
20.11.2018	4.72	7.25	15.07.2019	45.09	31.63
30.11.2018	1.49	1.19	**Total mean***	**16.46a**	**15.17a**
10.12.2018	1.84	1.17			
20.12.2018	1.08	1.25			

*Same letters in a total mean row do not indicate a significant difference.

3.3 The effect of cardinal directions on the number of different developmental stages of *L. beckii* on the upper and lower surfaces of the leaves

Based on the results obtained from the analysis of variance, cardinal directions had a statistically significant effect on the number of different developmental stages of *L. beckii* settled on the upper and lower surfaces of the leaves in seven of 10 studied trees (Table 2). The results of the mean comparison showed that in five of 10 trees (numbers: 4, 5, 6, 7, and 8), the highest number of scales was settled in the north direction, while in trees 2 and 10, the highest number of scales were settled in the south direction and in trees 3 and 9, the highest number of scales were counted in the east direction. According to the results, only in one tree (No. 1), the highest number of scales was observed in the west direction. Also, the results of the mean comparison showed that the lowest number of scales settled on the upper and lower of the leaves were counted in the west (5 trees) and south (4 trees) directions. As can be seen from the results, the highest number of *L. beckii* were settled in the north direction of the trees, which was not significantly different from that in the east direction, while the lowest number was observed in the west and south directions, which were in a statistical group and had significant differences with two other directions.

Table 2 Mean comparison of the number of different developmental stages of *Lepidosaphes beckii* (first, second instar nymphs and adult female) settled on the upper and lower surfaces of the leaves in different cardinal directions in the studied trees.

Number of trees	Cardinal direction ǂ				F value
	North	South	East	West	
1	94.89c	86.50c	121.17b	169.17a	3.63^{*}
2	84.28a	87.17a	65.39b	38.17c	5.82^{**}
3	84.50c	90.89c	154.28a	129.56b	3.61^{*}
4	152.11a	74.17c	98.72b	36.28d	7.20^{**}
5	135.94a	57.11c	95.89b	65.61c	8.64^{**}
6	133.17a	93.17bc	110.50ab	64.61c	0.77^{ns}
7	145.17a	89.94b	130.50a	95.22b	2.11^{*}
8	134.06a	63.44c	96.83b	61.83c	7.70^{**}
9	98.44ab	66.11c	116.39a	86.83bc	1.23^{ns}
10	66.94abc	81.89a	75.50ab	41.44c	2.58^{ns}
mean	**112.95ab**	**79.04c**	**106.25b**	**78.87c**	**3.58^{*}**

ns shows no statistically significant difference between cardinal directions (p>0.05); * and **show statistically significant differences between cardinal directions at the 5% and 1% probability level, respectively.
ǂ Different letters in each row indicate a significant difference between cardinal directions.

3.4 The effect of cardinal directions on the parasitism of *L. beckii*

Because the rate of parasitism of *L. beckii* in July-August, August-September, and September-October 2018 and April-May 2019 was higher than other dates, so the effect of cardinal directions on the rate of parasitism was evaluated in those period of times. As the results in Table 3 show, the effect of cardinal directions in the two sampling dates (21.09.2018 and 01.10.2018) on the number of parasitized scales was statistically significant. In the 12 sampling dates studied, the highest number of parasitized scales in the seven dates was related to the east direction, while in the five dates, the highest number of parasitized scales was observed in the north direction of the trees. On the other hand, the lowest number of parasitized scales counted in the six sampling dates was related to the west direction and in the other four dates, the lowest number of parasitized scales was counted in the south direction. According to the results, the highest number of parasitized scales was counted on 21.09.2018 in the east direction with an average of 19.20 per tree and the lowest number was observed on 27.04.2019 in the south direction with an average of 0.50 per tree.

Table 3 Mean comparison of the number of parasitized scales of *Lepidosaphes beckii* in different cardinal directions of 10 trees in the studied sampling dates.

Sampling date	Cardinal direction**				F value
	North	South	East	West	
28.07.2018	2.50a	1.60a	3.30a	5.10a	0.70^{ns}
07.08.2018	2.70a	2.50a	2.50a	2.40a	0.54^{ns}
17.08.2018	3.80a	6.30a	6.30a	2.90a	0.77^{ns}
01.09.2018	5.50a	5.50a	5.50a	4.10a	0.27^{ns}
11.09.2018	11.70a	10.30a	12.30a	15.30a	0.68^{ns}
21.09.2018	11.90c	15.80b	19.20a	16.50b	2.53*
01.10.2018	11.30a	7.30b	11.30a	7.20b	1.94*
11.10.2018	4.40a	3.60a	4.50a	2.20a	1.21^{ns}
21.10.2018	3.40a	2.80a	4.00a	2.90a	0.51^{ns}
27.04.2019	1.60a	0.50a	0.60a	16.0a	3.94^{ns}
07.05.2019	4.40a	4.60a	6.30a	4.70a	0.93^{ns}
17.05.2019	2.70a	2.50a	2.50a	2.40a	0.03^{ns}

ns shows no statistically significant difference between cardinal directions ($p>0.05$); * shows a statistically significant difference between cardinal directions ($p<0.05$).
** Different letters in each row indicate a significant difference between directions at the 5% probability level.

4 Discussion

The results of the population fluctuations of nymphs and adult scales of *L. beckii* showed that this pest has three complete generations in the climate of Mazandaran province. While the results of Watson (2002) showed that *L. beckii* has up to 4 generations per year depending on environmental conditions. Numerous studies have shown that this pest has 1 to 4 generations depending on climatic conditions (Zuniga, 1971; Bénassy et al., 1975; Davidson and Miller, 1990; Gill, 1997). Debach and Landi (1961) mentioned that it takes about two months to complete one generation of this insect on lemon and it had about 6 generations per year. They also stated that this pest produces approximately 2 and a half to 4 generations per year, depending on the annual climate fluctuations in the coastal areas of Southern California. Bedford et al. (1998) reported that the pest has four generations per year in South Africa. Habib et al. (2009) noted that *L. beckii* has four generations per year and tends to accumulate in shady areas of citrus trees. Ebeling (1959) stated that the purple scale prefers moist areas and is found in shady areas of the tree and on leaves and fruits. In the present study, the highest number of *L. beckii* settled on the upper of the leaves and in shady areas of tree in the north and east directions of the trees, which is in the agreement with the above research findings. Avidov and Harpaz (1969) reported that the developmental periods of the pest in females and males in summer are 50 and 44 days, respectively, while in winter it takes about 115 days. They mentioned that the temperature threshold for the development of this scale is 8ºC, and 1104 degree days is needed to produce a generation. They also stated that the pest prefers trees with thick leaves and settles more on the upper of leaves and fruits than young branches. We also observed high density of *L. beckii* population on the leaves than the branches and more on the young branches than old branches (Authors' observations). Avidov and Harpaz (1969) also found that the females settled on the fruit produced more nymphs than the females settled on the leaves. El-Amir et al. (2012) reported that the upper leaf surface harbored heavier infestation of *L. beckii* compared with the lower one in both years (April, 2004 to March, 2006). In the present study, the population density of different developmental stages of *L. beckii* on the upper of the leaves was higher compared to density on the lower of the leaves, which is in agreement with the findings of the above study. The results of El-Sayed Darwish (2020) on the population density of *L. beckii* on Valencia orange trees in two consecutive seasons showed that the average number of different developmental stages of male and female on the upper of the leaves is higher than that on the lower of the leaves, which is consistent with the results of the present study. Smith et al. (1997) reported that the life cycle of this scale in Australia lasts about 6–8 weeks. Moghadam (2017) and Damavandian (2020) reported that *L. beckii* has 2 to 3 generations per year in northern Iran, based on their observations. As mentioned, the present study found that this pest has four generations per year, Since Aly (2011) reported that *L. beckii* has three generations per year on mango in Egypt, our results is consistent with that study. This researcher also stated that the maximum and minimum temperatures had a significant effect on the population of *L. beckii* and its parasitoid, *Aphytis lepidosaphes* Compere, while relative humidity had no significant effect. In present stusy, population flactuations revealed that the first generation of this pest, depending on the weather conditions, has been active since late May and its growth stages were completed in the first decade of August. Afterwards, the activity of the second generation begins and the first instar nymphs related to the second generation appear in the second decade of August. The activity of the third generation begins in the first decade of October. The first instar nymph had the highest populations in four dates included mid June 2018 (1793.5 nymphs), mid August 2018 (919.2 nymphs), mid October 2018 (1451.6 nymphs), and late May 2019 (1839.7 nymphs). The second instar nymphs of the purple scale had four population peaks in four dates included late June 2018 (332.4 nymphs), early September 2018 (263.9 nymphs), late October 2018 (319.5 nymphs), and early June 2019 (348.3 nymphs). Adult females of *L. beckii* was different from those occurred in nymphs, because it had less intense population fluctuations and has been present in nature almost all year round. Adult females had three population peaks on late November 2018 (981.8 females), early March 2019 (569.8 females), and early June 2019 (423.0 females). Moustafa (2012) showed that this pesthad two population peaks on citrus trees in Egypt and the maximum population of this scale was during July. Stathas et al. (2015) reported three population peaks of *L. beckii* in June, August and October. Drazet al.(2011) recorded three peaks of overlapping generations per year. They reported that in the first year, the infestation peaks were on early May, early September, and mid November, and in the second year on late April, midOctober, and late November, respectively. In their study, the highest population densities were recorded in March and April, which then declined to August, then increased again in September, October and November. The researchers also noted that there was a positive correlation between mean temperature and population density of *L. beckii*. In the present study, the infestation peak was on late May, mid June, mid August, and mid October. Aly (2011) stated that the population density of *L. beckii* nymphs and adults peaked on mid September, 2009, and mid October, 2010.Damavandian (2020) stated that the nymphs of the first generation emerge in the middle June, the nymphs of the second generation emerge in the late August, and in some years the nymphs of the third generation emerge in the middle November. The nymphs are very small and yellow, and as soon as they find a suitable place to feed, they feed on the sap with a snout, and their legs decay. Draz et al. (2011) indicated Positive strong correlations between daily minimum and daily mean of temperature and total counts of *L. beckii* population. Therefore, considering the different climatic conditions of countries and studies on different plant hosts, the observed difference between the present study and the above studies can be justified. We also observed that the population of second instar nymphs was lower than that of first instar nymphs. It can be due to climate conditions at initiation time of the generation (personal notes).

The study of fluctuations in the population of *L. beckii* in 2018 and 2019 showed that the overwintering of this insect was in the form of second instar nymphs and an adult female. Of course, it should be noted that in some cases, samples of nymphs of younger ages were observed that for some reason could not reach older ages, most likely these nymphs were created during the last reproductive period of female insects or the place of stabilization has not been suitable for them, but what was certain is that decreasing the ambient temperature and cold had a greater lethal effect on younger nymphs, although *L. beckii* showed great resistance to adverse environmental conditions and suffered many losses while continuing and surviving its generation. A large number of adult females and a lesser number of second instar nymphs have passed winters and have grown very slowly for seven months, from late October to mid May, and when the weather was favorable, they became adult insects and started reproducing (first generation) in the next year. Watson (2005) reported that this pest often overwinters in the form of eggs or adult females in UK. She showed that it overwinters in colder regions in the form of eggs. Moghadam (2017) and Damavandian (2020) stated that this pest usually overwinters in the form of second instar nymphs and adult females in Iran. The results of present study agree partially with the results of above researches.

Damavandian (2020) reported active parasitoids on *L. beckii* in citrus orchards of northern Iran, which include *Aphytis lepidosaphes* (Compere), *A. chrysomphali* (Mercet), *A. proclia* (Walker), *Encarsia citrinus* (Craw), *E. aurantii* (Howard), *E. fasciata* (Malenotti), *E. berlesei* (Howard), *Ablerus atomon* (Walker) (Hymenoptera: Aphelinidae) and *Comperiella bifasciata* (Howard) (Hymenoptera: Encyrtidae). It should be noted that by sampling the parasitoids observed in the study area, *Aphytis* spp. was identified as an active parasitoid, which previously reported as the parasitoids of this pest in the citrus orchards by damavandian (2020). Also, Feli Kohikheili et al. (2013) reported *Aphytis* spp. as common parasitoids of *L. beckii* in citrus orchards of northern Iran on August and September. Acorrding to above findings and Aly (2011), Moustafa (2012) and El-Sayed Darwish (2020) that reported *A. lepidosahpes* and *A. chrysomphali* as two dominant parasitoids of *L. beckii*, therefore, these two species can be the dominant and identified parasitoids in the present study. The results of the present study showed that the maximum number of parasitized scales by the parasitoid wasp (124.2 per 10 leaves) was observed in the late September 2018.Moustafa (2012) reported that the number of parasitized scales by *Aphytis lepidosaphes* reached a maximum (25 per 30 leaves and 15 branches) during July and December of the first year, while in the second year it reached a maximum (28 per 30 leaves and 15 branches) during July. The results of the present study also showed that parasitism by *A. chrysomphali* reached a maximum during May 17^{th}, 2019 (63.2% on the upper of the leaves and 46.12% on the lower of the leaves). Also in the late September 2018, the rate of parasitism was high (51.05% on the upper of the leaves and 47.03% on the lower of the leaves). Minimum parasitism was observed in the late December 2018 (0.54% on the upper of the leaves and 0.75% on the lower of the leaves). Abd-Rabou (1997) stated that the total parasitism of *L. beckii* was maximized by aphelinid species (*Encarsia* sp.) during August in Behira and Giza in Egypt. The results of the present study showed that the highest parasitism rate occurred in spring followed by summer and the lowest rate was recorded in winter. Moustafa (2012) showed that the simple correlation between the population of *A. lepidosaphes*, maximum, minimum temperatures, % of relative humidity and the mean number of *L. beckii* were significant or highly significant. El-Sayed Darwish (2020) reorted that the rate of parasitism by *A. lepidosaphes* reach maximum in summer, because environmental conditions prevailing throughout summer are the most favorable for the development of parasites and its population increase. As it mentioned, in the present study, the effect of parasitism was high in late summer, early autumn, and mid-spring, while minimal parasitism was observed in winter. Moustafa (2012) stated that the effect of parasitism was low during summer and winter, while it was high during autumn.This reached a peak in October and minimum parasitism occurred in February. Aly (2011) stated that during 2009 and 2010 no parasitism on *L. beckii* occurred during January and February, but it persisted in small numbers until late summer and peaked in early autumn, 25 and 31 per 60 leaves in 2009 and 2010, respectively.It seems that in the present study, spring and summer were the most favorable seasons for the development and activity of the parasitoid.

In the present study, most of the parasitized specimens were adult females and the parasitism percentage on the upper surface was higher than that on the lower surface. El-Sayed Darwish (2020) stated that the parasitoid, *A. lepidosaphes* had a significant preference for the older host stages of *L. beckii*. This researcher reported that the highest parasitism percentage were observed on the gravid females of *L. beckii* in both upper and lower surfaces, While the lowest rates of parasitism were recorded on the 2nd male and female instars. El-Sayed Darwish (2020) reported that parasitism percentages in upper surface of the Valencia orange leaves were superior to the lower surface. Damavandian (2008) reported that the aphelinid parasitoids prefer to parasitize adult female scales. The results of the present study are in agreement with the results of the above study.

Draz et al. (2011) stated that the population distribution pattern of *L. beckii* differs significantly from one direction to another. They reported that the highest average population of this pest in the two consecutive years was counted in the south direction, while the lowest in the first and second years were in the east and north directions, respectively. In the present study, the highest number of *L. beckii* was counted in 5 of 10 trees in the north direction, and the highest number was counted in the south directionin two of 10 trees. In half of the studied trees (5 trees), the lowest number of *L. beckii* was counted in the west direction, which differs from the results of the above study. As it mentioned, in the present study, statistical analysis of data indicated the highest number of *L. beckii* settled on the leaves and in the north and east directions of the trees. The observed difference between the above study and the present research can be due to the geographical location that influenced on the direction of sunlight and shadow and the average temperature of the two studies. Damavandian (1994) reported that *Chrysomphalus dictyospermi* (Morgan) prefers shady areas of the tree and they can not activate in sunny areas of the tree. El-Amir et al. (2012) reported that Both north and east directions harbored the heaviest infestation of *L. beckii*, which is in the agreement with the results of the present study. Drazet al.(2011) also stated that the preference of these insects settled on the leaves on the branches located in the south and west direction of the tree is due to the direction of the wind from north to south, which carries newly hatched crawlers and shelters them on those leaves. Therefore, the direction of the wind in the study area can also be effective in settling the direction on the tree. The difference in the results of the above studies may be due to differences in the direction of the wind and sunlight in the area.

The results of this study showed that in the 5 of 12 dates, the highest number of parasitized scales was observed in the north direction of the trees. Also, the lowest number of parasitized scales counted in the 6 of 12 sampling dates was related to the west direction. Taghipour et al. (2019) evaluated the effect of cardinal direction on the rate of *L. beckii* parasitism on citrustrees and their report was same to this research.

In summary, the results of the population fluctuations of *L. beckii* showed that this pest has three complete generations per year in the climate of Mazandaran province. In the present study, the infestation peak was on late May, mid June, mid August, and mid October. Also, the population density of different developmental stages of *L. beckii* on the upper of the leaves was higher compared to density on the lower of the leaves. In the present study, most of the parasitized specimens were adult females and the parasitism percentage on the upper surface was higher than that on the lower surface. The important point is that the time of maximum parasitism is obtained in late summer, which coincides with spraying the gardens, which can have a very negative effect on the activity of parasites, so non-chemical control is strongly recommended. In addition, because the activity of *L. beckii* is reported in all cardinal directions and is somewhat the same, it is better to sample the whole tree for controlling. The results showed that overwintering of this insect was in the form of second instar nymphs and an adult female.

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