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Studies on the morphs, life history and behaviour of green apple aphid, *Aphis pomi* DE GEER on apple host in India

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ABSTRACT. The morphs of green apple aphid occurring on apple host in Himachal Pradesh, which is the main apple growing state of India, were ascertained and their life history was studied on the apple nursery plants from 2002 to 2006 in Mashobra locality ($31^0$1'N latitude, $77^0$1'E longitude and altitude 2286 m above sea level) of Shimla district and Ner Chowk locality ($31^0$32'N latitude, $76^0$54'E longitude and altitude 878 m above sea level) of Mandi district of Himachal Pradesh. Only two kinds of parthenogenetic morphs i.e. apterous and alate parthenogenetic viviparous females occur in this state. Biological characteristics, life history and behaviour of these morphs were studied in different seasons Heavy infestations of green apple aphid prevent the terminal growth of the plants which show distorted growth. This aphid pest builds up big colonies on twigs, leaf petioles and the underside of the leaves. Its settling behaviour on apple plants allows accommodating large number of aphids in a small area on shoots and leaves. Maximum alate morphs were produced from May to August and number of alates was also more in crowded colonies. The alate aphids infest new plants and build up new colonies there. The populations of this insect pest increase in early May and reach high peaks in July. The effect of aphids' feeding on the growth of nursery plants was also measured.

KEY WORDS: Green apple aphid, *Aphis pomi*, morphs, apple host, infestation.

INTRODUCTION

Aphid pests have adapted their life cycle in different geographic regions according to the availability of the host plants and the prevailing environmental conditions. A species may have holocyclic or anholocyclic, or both life cycles in a given geographic region and thus the biology and behaviour of an aphid pest differs considerably in different regions of the

world. Thus the information on the life cycle of a pest species in a given geographical region is important in order to implement effective management strategies.

Apple plants are attacked by a number of insect pests. Among these, green apple aphid is considered a pest damaging apple nursery plants severely. This aphid is small, yellow green in colour with large black siphunculi and dark cauda. It colonizes young host plants, thus damaging seedling stocks of apple nursery plants (BLACKMAN & EASTOP 1984).

This aphid pest was first reported by DE GEER (1773) who studied the life history of this aphid pest in Sweden. It is a well established fact that this species is now found in whole of the Europe and North America wherever apple plants are grown. Outside Europe and North America, it has also been reported from Asia. This species is typically a nursery infesting species and gets easily transported on nursery stock from one region to other (BAKER & TURNER 1916).

Green apple aphid is monoecious and apple plant is its main host. In summer and autumn seasons, Aphis pomi may reach high densities, depositing honeydew which sometimes causes fruit russet. Honeydew acts as a suitable substrate for sooty mold. High population densities in spring, disfigure fruits and may reduce shoot growth in young plants (OATMAN & LEGNER 1961).

In the regions where this aphid species has holocycle, the eggs are laid by sexual females. These eggs hatch in next spring when environmental conditions become favourable with the rise in temperature. After overwintering as eggs on branches of apple tree or related plants, the stem mothers or fundatrices are produced, which initiate 'fundatrix colonies.' Thereafter, all generations except the last consist of only parthenogenetic females which reproduce vivpariously as clones of the fundatrices. Alates appear generally in the second or later generations (BAKER & TURNER, 1916). However, in many parts of world, the behaviour and biology of this aphid pest changed considerably due to adaptations to the different prevailing environmental conditions.

In India, this insect pest has been reported to infest apple plants in Himachal Pradesh (BHALLA 1972). This aphid pest damages the foliage and fruits of apple all over the state. The worst affected are the apple nurseries where this pest is controlled by the use of insecticides. GAUTAM & KUMARI (2004) reported preliminary studies on the life history of apterous parthenogenetic morph of green apple aphid during the autumn season. However, no other no details are available on different morphs, life history and behaviour of green apple aphid occurring in Himachal Pradesh, India. The present studies were undertaken to study detailed biology of different morphs of green apple aphid *Aphis pomi* DE GEER in different seasons and to ascertain life cycle adaptations of this species on its apple host in Himachal Pradesh which is primarily the apple growing state of India.

MATERIALS AND METHODS

The present investigations on the morphs, life history and behaviour of *Aphis pomi* were started in the second half of 2002 and were carried out through 2003 to 2006. The detailed biology of this aphid species was studied on apple nursery plants maintained in the clay pots in the laboratory. The temperature and humidity records of these years of studies are given in the table 1. Apterous, parthenogenetic, viviparous females of green apple aphid *Aphis pomi* DE GEER were collected from seedling stocks of apple nursery plants and reared for different studies. Field surveys of apple nurseries in Mashobra locality ($31^0$1'N latitude, $77^0$1'E longitude and altitude 2286 m above sea level) of Shimla district and Ner Chowk locality ($31^0$32'N latitude, $76^0$54'E longitude and altitude 878 m above sea level) of Mandi district were made regularly to observe different aspects of life history of different morphs under field conditions. In these two localities, large number of apple nursery plants are grown**.**

Stock culture

Apple nursery plants infested with green apple aphid were procured from apple nurseries and culture of green apple aphid was maintained on young nursery plants grown in natural field conditions. The aphids were then transferred to uninfested apple nursery plants maintained in the clay pots in the laboratory for different studies. A magnifying lens was used to observe the various stages of green apple aphid.

Rearing of green apple aphid on apple plants

Adult apterous parthenogenetic viviparous females were taken from the stock culture to obtain young nymphs. When a female gave birth to a nymph, the former was removed from plant. The newly born nymphs were kept on different plants and their development was studied. All the developmental stages were kept under keen observation throughout their life and various aspects of life history such as nymphal instars, pre-reproductive and reproductive periods, progeny born and post reproductive period were studied.

Effect of infestation

The effect of green apple aphid infestation on apple nursery plant growth was studied and measured in terms of shoot growth in infested and uninfested control plants. For life history studies, the months of the year were grouped in seasons such as summer (March to May), rainy (June to August), autumn (September to November) and winter (December to February)**.**

RESULTS

In the present investigations, only two kinds of parthenogenetic morphs of green apple aphid were recorded both on apple nursery plants in fields as well as on apple plants main

Table 1. Temperature (^{0}C) and humidity (%) record of Shimla where biological studies on green apple aphid, *Aphis pomi* DE GEER were carried out from 2003 to 2006.

Months	2003			2004			2005			2006		
	Mean Max.	Mean Min.	Mean% Humidity	Mean Max.	Mean Min.	Mean% Humidity	Mean Max.	Mean Min.	Mean% Humidity	Mean Max.	Mean Min.	Mean% Humidity
March - May	19.39	13.59	16.02	23.41	16.19	60.45	19.13	13.16	67.81	20.04	14.22	70.15
June - August	22.76	19.46	83.09	22.21	18.68	83.60	23.32	19.18	79.98	24.03	18.57	71.78
September - November	20.14	15.40	74.56	20.45	14.69	69.32	21.33	16.11	66.11			
December – February	14.16	08.14	68.49	12.03	06.37	71.00	16.54	7.83	56.48			

tained under laboratory conditions. These morphs are apterous and alate parthenogenetic viviparous females.

The biology of these two kinds of morphs of green apple aphid was studied all through the year and observations on various aspects of their biology are as follows:

APTEROUS PARTHENOGENETIC MORPH

General biological characteristics and duration of different stages of apterous parthenogenetic morphs are as follows:

General biological characteristics

The individuals of this morph undergo four regular moults, resulting in five instar stages. The newly born nymph has green colour on its general body surface. The first instar nymphs are active right from the birth and move around on the surface of apple nursery plants in search of a suitable place and take nutrition from the soft parts of the plants. Most of the first instar nymphs move to colonize the other parts of the plant and settle on the soft parts of the shoots of the plant. Generally, they prefer to colonise the underside of the leaves. The second instar stage is also green in colour and is very active. The second instar nymphs can also be seen moving on plant parts where they establish on the soft parts. The colour of third instar nymph is also similar to that of first and second instar nymphs. However, colour of fourth instar turns light green and develops a yellowish shade.

The general colour of the adult aphid (Fig. 1) varies from light green to a very dark green. Head of adult aphid is orange yellow and sometimes it gives a purplish cast. The thorax has same colour as of the main body with shading off into yellowish green near posterior end. Both head and thorax are covered with a slight bloom. The abdomen of adult is light green. It is also observed that the individuals of green apple aphid which do not get good supply of food on mature plants show stunted growth and their colour is much deeper, the green colour being very dark over the entire body whereas the well fed aphids on young nursery plants are large in size and their colour is light green. The aphids during autumn have a brownish colour. Apterous parthenogenetic morphs occur throughout the year. These individuals form big colonies on the aerial parts of plants. The colonies appear as greenish or purple in colour.

Duration of different instar stages

The duration of first instar ranges from 3 to 3.5 days during summer, 2 to 2.5 during rainy, 4 to 6 days during autumn and 5 to 7 days during winter season. The duration of second instar stage lasts from 2 to 3 days during summer, 1 to 2 days during rainy, 2.5 to 4 days during autumn and 5 to 9 days during winter season. The duration of third instar ranges from 2 to 3 days during summer, 1 to 2 days during rainy, 2 to 3.5 days during autumn and 9 to 14 days during winter season. The duration of fourth instar ranges from 3 to 4 days during summer, 1 to 2.5 days during rainy, 2.5 to 3.5 days during autumn and 12 to 20 days during winter season (table 2). The duration of the period between the last moult

Fig. 1. Adult apterous parthenogenetic morph. (Bar represents 1.8 mm).

and beginning of reproduction ranges from 2 to 3 days during summer, 1 to 2 days during rainy, 1 to 2.5 days during autumn and 2 to 3.5 days during winter season (Table 2).

Total pre-reproductive period

The total pre-reproductive period of apterous parthenogenetic viviparous female of green apple aphid ranges from 12.5 to 14.5 days (mean 13.85 days ± 0.18 SE) during summer, 7 to 9.5 days (mean 8.20 days ± 0.29 SE) during rainy, 13 to 17.5 days (mean 15.25 days ± 0.52 SE) during autumn and 33 to 52 days (mean 43.80 days ± 1.73 SE) during winter season (Table 2, Fig. 2).

Table 2. Duration* of different developmental stages of the progeny of apterous and altate parthenogenetic females of green apple aphid, *Aphis pomi* De Geer on apple nursery plants during different seasons

			Duration of nymphal instars				Total nymphal period	Period between last moult and begining of reproduction	Total prereproductive period	Morph of adult formed
			I	II	III	IV				
Summer	Ap	R	3.0-3.5	2.0-3.0	2.0-3.0	3.0-4.0	10.5-12.0	2.0-3.0	12.5-14.5	Ap
		M	3.15±0.07	2.60±0.01	2.50±0.12	3.25±0.11	11.50±0.16	2.35±0.13	13.85±0.18	
	Al	R	3.0-3.5	2.5-3.0	2.5-3.5	4.5-5.5	13.0-14.5	2.0-3.5	16.0-17.5	Al
		M	3.20±0.08	2.65±0.07	3.05±0.08	4.90±0.10	13.80±0.1	2.90±0.14	16.70±0.13	
Rainy	Ap	R	2.0-2.5	1.0-2.0	1.0-2.0	1-2.5	6.0-8.0	1.0-2.0	7.0-9.5	Ap
		M	2.15±0.07	1.45±0.11	1.30±0.13	2.00±0.16	6.90±0.27	1.30±0.11	8.20±0.29	
	Al	R	1.0-2.5	1.0-2.5	1.5-2.5	2.5-4.5	7.0-10.0	1.0-2.5	9.0-13.5	Al
		M	2.20±0.12	1.45±0.15	1.90±0.10	3.85±0.19	9.20±0.36	1.85±0.16	11.05±0.39	

Autumn	Ap	R	4.0-6.0	2.5-4.0	2.0-3.5	2.5-3.5	12.0-15.0	1.0-2.5	13.0-17.5	Ap
		M	4.95±0.21	3.05±0.13	2.65±0.16	2.90±0.12	13.55±0.43	1.70±0.18	15.25±0.52	
	Al	R	3.5-5.5	2.5-3.5	3.0-3.5	4.5-6.5	13.5-18.5	2.0-3.5	16.0-22.0	Al
		M	4.30±0.24	3.05±0.11	3.02±0.81	5.55±0.21	15.83±0.50	2.60±0.11	18.33±0.48	
Winter	Ap	R	5.0-7.0	5.0-9.0	9.0-14.0	12.0-20.0	31.0-49.0	2.0-3.5	33.0-52.0	Ap
		M	5.90±0.27	7.40±0.42	11.45±0.51	16.55±0.81	41.30±1.67	2.50±0.21	43.80±1.73	
	Al	R	4.0-8.0	6.0-10.0	8.0-16.0	10.0-23.0	28.5-53.0	2.5-4.0	31.5-56.0	Al
		M	6.05±0.41	7.80±0.40	11.10±0.78	15.90±1.33	40.85±2.63	3.45±0.17	44.30±2.67	

* in days , Ap-apterous, Al-alate, R-range in days, M-mean value of duration in days for 10 individuals, ± standard error about the mean.

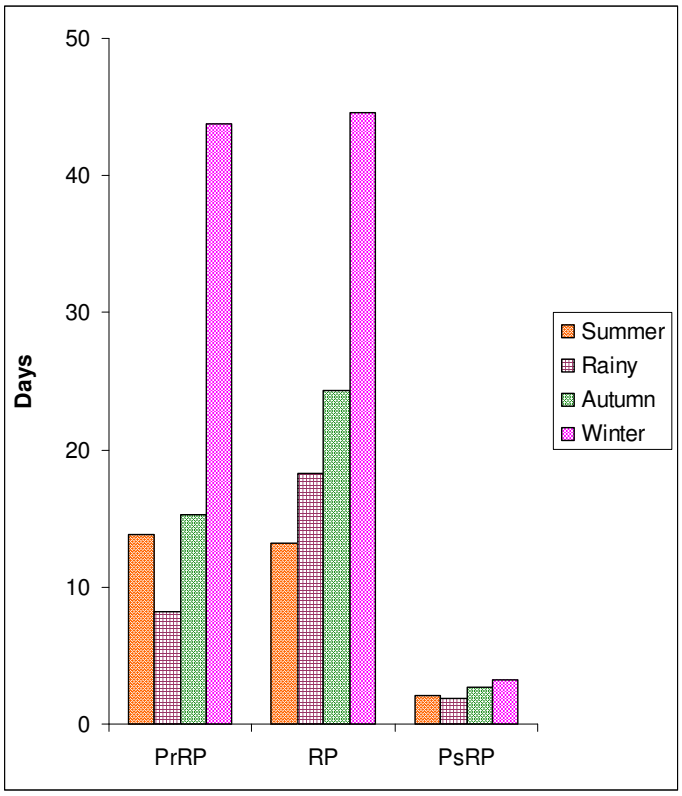

Fig. 2. PrRP: Pre-reproductive period, RP: Reproductive period and PsRP: Post-Reproductive periods of apterous parthenogenetic viviparous female during summer, rainy, autumn and winter season.

Reproductive period

The duration of reproductive period ranges from 8 to 22 days (mean 13.20 days ± 1.46 SE) during summer, 10.5 to 25.5 days (mean 18.30 days ± 1.59 SE) during rainy, 17.5 to 30 days (mean 24.35 days ± 1.43 SE) during autumn and 39 to 55 days (mean 44.60 days ± 1.77 SE) during winter season (Table 3, Fig. 2).

Progeny produced by a apterous female in the whole life period

The progeny produced by an apterous parthenogenetic viviparious female of green apple aphid during the whole life ranged from 18 to 50 aphids during summer, 55 to 72 aphids during rainy, 13 to 31 aphids during autumn and 17 to 32 aphids during winter

season. The maximum number of nymphs laid in a day was 5 during summer, 9 during rainy, 4 during autumn and 3 during winter seasons (Table 3).

Table 3. Reproductive period, post reproductive period and the progeny produced by apterous and alate parthenogenetic females of green apple aphid, *Aphis pomi* De Geer on apple nursery plants during different seasons.

			Reproductive period (in days)	Post reproductive period (in days)	Total life period (in days)	Total progeny produced	Maximum number of births in a day
Summer	Ap	R	8.0-22.0	1.0-3.0	24.0-38.5	18-50	5
		M	13.20±1.46	2.05±0.24	29.50±1.67	30.60±3.26	3.50±0.34
	Al	R	7.0-20.0	1.0-3.5	24.5-40.0	16-38	5
		M	12.55±1.33	2.15±0.33	31.40±1.45	25.80±2.30	3.40±0.30
Rainy	Ap	R	10.5-25.5	1.0-3.5	22.5-36.0	55-72	9
		M	18.30±1.59	1.85±0.28	28.35±1.59	66.10±1.72	6.3±0.51
	Al	R	10.5-23.0	1.0-3.0	23.0-36.5	50-110	7
		M	16.50±1.12	1.50±0.22	29.35±1.18	72.90±0.59	5.10±0.31
Autumn	Ap	R	17.5-30.0	1.0-4.5	36.0-48.0	13-31	4
		M	24.35±1.43	2.75±0.35	42.35±1.37	21.90±1.76	3.10±0.31
	Al	R	15.0-29.5	1.5-4.5	36.5-51.5	17-50	4
		M	19.90±1.48	2.80±0.29	41.40±1.43	34.30±2.77	2.60±0.30
Winter	Ap	R	39.0-55.0	2.0-5.0	76.0-109.0	17-32	3
		M	44.60±1.77	3.20±0.32	91.60±2.80	24.30±1.80	1.90±0.23
	Al	R	35.0-51.0	3.0-4.5	72.5-110.5	10-31	3
		M	42.10±1.87	3.80±0.15	90.20±4.06	21.10±1.93	1.60±0.22

Ap-apterous, Al-alate, R-range, M-mean value for 10 individuals, ± standard error about the mean.

Post-reproductive period

During this period, the apterous parthenogenetic female generally remains at a place and does not move around. The individual then dies and falls down from the plant. The post-reproductive period ranges from 1 to 3 days (mean 2.05 days ± 0.24 SE) during summer, 1 to 3.5 days (mean 1.85 days ± 0.28 SE) during rainy, from 1 to 4.5 days (mean 2.75 ± 0.35 SE) during autumn and 2 to 5 days (mean 3.20 days ± 0.32 SE) during winter season (Table 3, Fig. 2).

Total life period

The duration of total life period of apterous parthenogenetic viviparous female ranged from 24 to 38.5 days (mean 29.50 days ± 1.67 SE) during summer, 22.5 to 36 days (mean 28.35 days ± 1.59 SE) during rainy, from 36 to 48 days (mean 42.35 days ± 1.37 SE) during autumn and 76 to 109 days (mean 91.60 days ± 2.80 SE) during winter season (Table 3).

ALATE PARTHENOGENETIC MORPH

The alate morphs of green apple aphid were recorded throughout the year although their number varied in different seasons.

General biological characterstics

The alate parthenogenetic viviparous female also undergoes four regular moults resulting in the five instar stages. The newly born nymph of this morph is similar to that of apterous parthenogenetic viviparous female. It has also green colour on its body surface. The colour of the second instar is similar to that of first instar. In the third instar, the wing pads start becoming visible. The fourth instar is greenish in colour with yellow green abdomen. The wing pads are prominent in this instar.

The adult alate aphid (Fig. 3) is dark in body colour. The main function of alate morph is dispersal to other host plants. Adult alate aphids start giving birth to nymphs on new host plants and build up big colonies in a short time to exploit the host plant fully.

Duration of different instar stages

The duration of first instar lasts from 3 to 3.5 days during summer, 1 to 2.5 days during rainy, 3.5 to 5.5 days during autumn and 4 to 8 during winter season. The duration of second instar lasts from 2.5 to 3 days during summer, 1 to 2.5 days during rainy, 2.5 to 3.5 days during autumn seasion and 6 to 10 days during winter season. The duration of third instar lasts from 2.5 to 3.5 days in summer, 1.5 to 2.5 days during rainy, 3 to 3.5 days during autumn and 8 to 16 days during winter seasons. The duration of fourth instar lasts from 4.5 to 5.5 days during summer, 2.5 to 4.5 days during rainy, 4.5 to 6.5 days during autumn and 10 to 23 days during winter season (table 2). The duration of the period

between the last moult and beginning of reproduction ranges from 2 to 3.5 days during summer, 1 to 2.5

Fig. 3 Adult alate parthenogenetic morph. (Bar represents 2 mm).

days during rainy, 2 to 3.5 days during autumn and 2.5 to 4 days during winter season (Table 2).

Total pre-reproductive period

The total pre-reproductive period of alate parthenogenetic morph ranges from 16 to 17.5 days (mean 16.70 days ± 0.13 SE) during summer, 9 to 13.5 days (mean 11.05 days ± 0.39 SE) during rainy, 16 to 22 days (mean 18.33 days ± 0.48 SE) during autumn and 31.5 to 56 days (mean 44.30 days ± 2.67 SE) during winter season (Table 2, Fig. 4).

Reproductive period

The duration of reproductive period ranges from 7 to 20 days (mean 12.55 days ± 1.33 SE) during summer, 10.5 to 23 days (mean 16.5 days ± 1.12 SE) during rainy, 15 to 29.5 days (mean 19.90 ± 1.48 SE) during autumn and 35 to 51 days (mean 42.10 days ± 1.87 SE) during winter season (Table 3, Fig. 4).

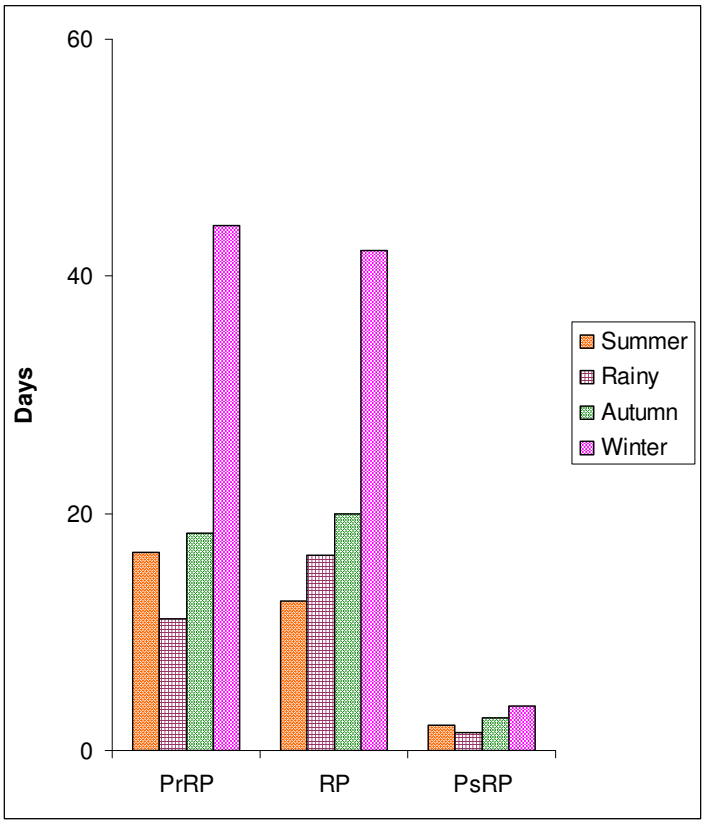

Fig. 4. PrRP: Pre-reproductive period, RP: Reproductive period and PsRP: Post-reproductive periods of alate parthenogenetic viviparous female during summer, rainy, autumn and winter season.

Progeny produced by alate female in the whole life period

Total progeny produced by a alate female of green apple aphid during whole life period ranged from 16 to 38 nymphs during summer, 50 to 110 nymphs during rainy, 17 to 50 nymphs during autumn and 10 to 31 nymphs during winter season (table 3). Maximum number of nymphs laid by a alate female in a day was 5 during summer, 7 during rainy, 4 during autumn and 3 during winter season (Table 3).

Post-reproductive period

The duration of post-reproductive period of alate morph ranged from 1 to 3.5 days (mean 2.15 days ± 0.33 SE) during summer, 1 to 3.0 days (mean 1.50 days ± 0.22 SE) during rainy, 1.5 to 4.5 days (mean 2.80 days ± 0.29 SE) during autumn and 3.0 to 4.5 days (mean 3.80 days ± 0.15 SE) during winter seasons (Table 3, Fig. 4).

Total life period of alate parthenogenetic female

The duration of total life period ranged from 24.5 to 40 days (mean 31.40 days ± 1.45 SE) during summer, 23 to 36.5 days (mean 29.35 days ± 1.18 SE) during rainy, 36.5 to 51.5 days (mean 41.40 days ± 1.43 SE) during autumn and 72.5 to 110.5 days (mean 90.20 days ± 4.06 SE) during winter season (Table 3, Fig. 4).

Alate morph production in green apple aphid

Alate morphs occur throughout the year. It was noted that the greatest numbers of alate morphs were produced from May to August and during this period the population density of alate aphids was high. Number of alates was more in crowded colonies. The alate aphids infest new plants and build up new colonies there. The percentage of adult alate morphs in green apple aphid colonies ranged from 18.80 to 50 (Table 4) and percentage of alatoid nymphs ranged from 55.90 to 89.9 (Table 5).

Table 4. Appearance of alates in colonies of green apple aphid, *Aphis pomi* De Geer on apple nursery plants.

Number of aphids in a colony		Alate (adult)	Per cent alate
Range	80-350	16-102	8.80-50.0
Mean*±SE	184.60±32.23	59.70±9.05	34.24±2.94

* Mean of 10 values, ± standard error about the mean.

Table 5. Appearance of alatoid nymphs in colonies of green apple aphid, *Aphis pomi* De Geer on apple nursery plants.

Number of aphids in a colony		Alatoid nymphs	Per cent alatoid
Range	101-452	60-385	55.90-89.90
Mean*± SE	242.30±36.58	179.50±35.50	71.26±3.52

*Mean of 10 values, ± standard error about the mean.

INFESTATION OF APPLE PLANTS

Symptoms of infestation

The populations of this insect pest increase in early May and reach high peak in July (Table 6). There is sharp decrease in number of aphids at the end of July month but thereafter further build up of aphid populations occurs in August month followed by a gradual decrease which continues through September to November till December.

Table 6. Low and high infestation of green apple aphid on apple nursery plants.

	Low infestation (<than 500 aphids per apple nursery plant)	High infestation (>than 500 aphids per apple nursery plant)
Range	100-375	550-1500
Mean*±SE	243.60±29.51	845.50±85.36

Mean of 10 values, ± standard error about the mean.

Figs 5-8. 1 – Build up of population of green apple aphid on apical parts of apple nursery plant, 2 – Severe infestation on twig of apple nursery plant, 3 – Heavy infestation of green apple aphid on twig of apple plant, 4 – Establishment of new infestation.

With infestation on the apical parts of the apple nursery plant, green apple aphid builds up population rapidly (Figs 5-8). The effect of feeding on the growth of nursery plants was measured in two sets of 10 plants each.

After four weeks, linear growth of terminal shoots of plants was recorded in both sets. It was observed that the apple nursery plants which were heavily infested with green apple aphid show shorter shoot growth (1.2 to 13.8% (mean 5.83% ± 1.24 %) whereas the plants

which were not infested by these aphids remain healthy and their shoots attained normal height (4.2 to 16% (mean 8.15% ± 1.25 SE) (Table 7).

Table 7. Effect of high infestation of green apple aphid, *Aphis pomi* De Geer on the growth of shoots of apple nursery plants.

	Length of infested shoot			Length of uninfested shoot		
	Length of infested shoot (in cms)	Length of whole plant in cms)	% length of shoot	Length of uninfested shoot (in cms)	Length of whole plant (in cms)	% length of shoot
Range	2.54-11.43	81.28-101.60	1.2-13.8	..5.08-22.86	16.84-152.40	4.2-16.0
Mean*± SE	5.96±1.28	101.09±4.47	5.83±1.24	11.17±1.78	136.14±4.20	.15±1.25

Mean of 10 values, ± standard error about the mean.

When the population of green apple aphid is high, it prevents the terminal growth of the plants by hardening off and curling of the leaves (Figs 5, 6). Several affected plants are found to show distorted growth. The aphids excrete honeydew that coats the leaves. Thus, honeydew coating of leaves helps in rapid growth of sooty mould (fungus) that causes hardening of the leaves. It was observed that the leaves of apple nursery plants which are not covered with honeydew begin hardening later than those covered with honeydew. Therefore, aphid populations declined concurrently with the cessation of terminal growth. It is also observed that if the aphid population is extremely high, the plant show stunted growth. Infestations of green apple aphids on apple plants in nurseries and orchards were more intense in successive years lasting longer each season.

Settling behaviour of green apple aphid

It was observed that green apple aphid builds up big colonies (Figs 6, 7, 8) on twigs, leaf petioles and the underside of the leaves. The settling behaviour of green apple aphid on shoots and leaves is in such a way that the head of the lower aphid is situated underneath the tip of the abdomen of the anterior one (Fig. 6).

In the nursery fields, the aphids are found settled in rows on the shoots and leaves of the apple nursery plants. It is observed that maximum number of aphids occur on the lower side of the leaves. Only one or two aphids were found feeding on the upper surface of the leaves.

It was observed that quality of apple nursery plants also has great effect on the size, colour and growth of the green apple aphid. When the nymphs of this species feed on healthy well developed shoots, twigs and juicy parts of the apple nursery plants throughout nymphal period, the adults are generally large, plump with light green colour. If the host quality is poor, the adults are small in size with dark green body colour and these aphids also require a considerably longer period to attain maturity.

It was also observed that in the cold part of the year, smaller forms of aphids appear and when the season is favorable (such as from May to August), the size of the aphid is large. The reproductive rate of green apple aphid decreased as the quality of apple nursery plants decreased.

DISCUSSION

Aphis pomi DE GEER is monoecious on apple plants as its main host. In Europe and North America, this aphid has a holocyclic life cycle (BLACKMAN & EASTOP 1984). However, in the present investigations, it was found that in Himachal Pradesh, India this species living on apple nursery plants has anholocyclic life cycle. The factors that have influence on holocyclic or anholocyclic development are photoperiod, temperature and food quality (age of plants) (DIXON 1998).

The extensive studies on the life history of green apple aphid, *Aphis pomi* DE GEER were reported from the North America by BAKER & TURNER (1916) and these will be considered here for comparison. These workers observed that green apple aphid has a number of stages such as egg stage, stem mother, wingless viviparous females, winged viviparous females, males and oviparous females. The green apple aphid overwinters there in egg stage. The stem mother is wingless and produces summer forms, both winged and wingless. The summer wingless forms and oviparous females, which live longer than the males, remain on the apple tree until the leaves drop, usually till about mid November. Similar findings were reported by subsequent workers from North America (OATMAN & LEGNER 1961, HAMILTON et al. 1986).

In the present investigations, heavy infestation of apple plants was observed in the fields on apple nursery plants. Only two types of morphs i.e. apterous and alate parthenogenetic viviparous females were recorded in the populations of green apple aphid in Himachal Pradesh, India. Observations were made to ascertain the occurrence of sexual forms of this species in these regions from 2003 to 2006 and the regular surveys of the apple orchards and nurseries in Himachal Pradesh revealed that this aphid pest reproduces parthenogentically throughout the year.

Life history of apterous parthenogenetic viviparous female

Life history studies revealed that this aphid species undergoes four regular moults resulting in five instar stages. Same number of moults has been reported in another aphid

species, namely woolly apple aphid *Eriosoma lanigerum* (HAUMANN), infesting apple plants (GAUTAM & VERMA 1982, 1983).

The average nymphal period of apterous parthenogenetic viviparous female is longer in winter as compared to summer, rainy and autumn season (Table 2). Similarly, the average pre-reproductive period of this species is longer in winter as compared to summer, rainy and autumn season (Table 2, Fig. 2). BAKER & TURNER (1916) reported that in North America, due to hot weather in June-July, this period was shortened to 6 days. However, with the beginning of cooler weather, the nymphal period ranged from 8 to 9 days during September and by the end of October, the nymph took 12 to 14 days to become adult.

The reproductive period starts with giving birth of young ones. In this species, the average reproductive period is also longer in winter season as compared to summer, rainy and autumn season. The progeny produced by a female in autumn and winter is lower as compared to summer and rainy season (Table 3).

The maximum number of nymphs born in a day is 5 during summer, 9 during rainy, 4 during autumn and 3 during winter (Table 3) season. BAKER & TURNER (1916) also reported that the wingless viviparous females begin reproduction about 24 hours after becoming mature and the average reproduction varied greatly with season. According to these workers, the maximum reproduction for one day was even more than 16. These variations may be attributed to different prevailing weather conditions in different regions as well as to the quality of host plant in a particular geographical region.

The average total life period was also longer in winter as compared to summer, rainy and autumn season (Table 3). The longer pre-reproductive, reproductive and total life period and low fecundity during winter season may be because of the effect of temperature and nutrition. During summer and rainy seasons, the favourable temperature and nutrition, result in rapid development and high fecundity in aphids. During autumn and winter seasons, the inadequate supply of nutrients and low temperature may slow down the development and result in poor fecundity. Similar findings were reported by BAKER & TURNER (1916) also who noticed that low temperature and the quality of food has a very marked effect upon the size, colour and rapidity of growth of these aphids. These workers also observed that if the temperature is low and the food is poor in quality, the aphids require a considerable longer period to attain maturity.

Life history of alate parthenogenetic viviparous female

The alate morphs were found throughout the year both in Mashobra locality of Shimla district and Ner Chowk locality of Mandi district. So far, these morphs have been reported to appear from June to October only from other regions of the world (BAKER & TURNER 1916). The occurrence of alate morphs throughout the year in these localities may be as a result of high density (Fig. 7).

The average nymphal period of alate parthenogenetic viviparous female is longer in winter as compared to summer, rainy and autumn season (Table 2). The total pre-reproductive period of winged parthenogenetic morph is also longer in winter as compared

to summer, rainy and autumn season (Table 2; Fig. 4). The longer nymphal and pre reproductive period of winged parthenogenetic viviparous female during winter as compared to summer, rainy and autumn season reflect the same pattern as is found in apterous morph.

The average reproductive period of alate parthenogenetic morph is longer in winter as compared to summer, rainy and autumn season (Table 3, Fig. 4). Total progeny produced by a winged female of green apple aphid is lower during winter in whole life as compared to summer, rainy and autumn season (Table 3). In these regions, the maximum number of nymphs born by a female is 3 in winter as compared to 5 in summer, 7 in rainy and 4 in autumn seasons. BAKER & TURNER (1916) reported that the seasonal average production of nymphs in alate morphs was 39 while the daily average was 2.62. The greater number produced in one day was 6 and the maximum number of young ones produced by one individual was 120 in 21 days. According to these workers, average length of the reproductive period for the entire season was 20.75 days.

Similarly, the average life period of alate parthenogenetic viviparous female is longer in winter as compared to summer, rainy and autumn season. BAKER & TURNER (1916) reported that the longest total life for an individual of this morph was 42 days.

Appearance of alates in natural population

In many species of aphids, the winged morphs develop in response to deteriorating conditions, i.e. when aphids are crowded or feed on plants of declining quality (HILLE RIS LAMBERS 1966, DIXON 1998). Winged morphs can disperse over great distance to colonize new plants to exploit them fully (DIXON & WRATTEN 1971, DIXON 1972, 1998, MACKAY & WELLINGTON 1975). Weisser et al. (1999) reported that the winged morph in aphids is mainly responsible for the colonisation of new plant and in many species of aphids, the alates are produced in response to adverse environmental conditions.

In the present investigations, more alate morphs were produced during the months from May to August when the population of aphids was high. More alatoid nymphs were observed in crowded colonies (Table 5). Appearance of alates is rapid when the aphid population density is very high. Development of alatoid nymph and adult alates among the green apple aphid colonies may be attributed to crowding or change in the quality of host plants in the apple nurseries. Similar findings were reported by (DIXON & LAIRD (1962) and LEES (1967) in other aphid species.

Alate morphs of green apple aphid were found to cause infestation on new plants in both the localities (Mashobra and Ner Chowk) where apple nurseries are grown. The fluctuations in the populations of green apple aphid during different periods of the year were due to favourable or unfavourable environmental conditions, quality of the host as well as dispersal of alates to other new apple plants. WESTIGARD & MADSEN (1965) also reported regular fluctuations in density of *Aphis pomi* in California and opined that alate forms were produced during peaks of population density. According to them, the main factor controlling the production of alates in this species is crowding.

Feeding behaviour of green apple aphid

In the present study, it was found that twigs, leaf petioles and the underside of the leaves were heavily infested by this pest. It was also observed that green apple aphid settled on the shoots and leaves of the plants in such a way that the head of the lower aphid is situated underneath the tip of the abdomen of the upper one (Fig. 6). This facilitates the survival of large number of aphids in a small space since they feed close to one another and thus the sap supply is maintained continuously. Maximum number of aphids was found on the lower side of the leaf. This arrangement of aphids on the tender twigs results in severe damage to host plant. As a result of this, the plant shows symptoms of curling of leaves and there is stunted growth of plant.

It was observed that quality of apple nursery plants has great effect on the size, colour and growth of the green apple aphid. When the nymphs of this species feed on healthy, well developed shoots, twigs and juicy parts of the apple nursery plants throughout nymphal period, the adult aphids are large, plump and light green in colour. But if the host quality is poor, the adults are small, dark green in colour and these aphids require a considerably longer period to attain maturity as compared to those aphids feeding on healthy well developed shoots, twigs and juicy parts of apple nursery plants.

BAKER & TURNER (1916) also reported that the quality of the food has a very marked effect upon the size, colour and rapidity of growth of the aphids. Growth and size of the green apple aphid are affected by change in temperature also. During the cold part of the year, smaller forms of aphids appear, whereas if the temperature is favourable as is from May to August, the bigger forms appear. Low temperature and poor quality of apple nursery plants also decrease the reproductive rate of green apple aphid.

Symptoms of infestation

In the present investigations, it was observed that there is fluctuation in the populations of green apple aphid in different months of the year. The population of green apple aphid increases in early June and reaches at high peak in the month of July. There is sharp decrease in number of aphids at the end of July month followed by further build up of population in August. After August, a gradual decrease in number of aphids in a colony continues throughout winter. High population density of green apple aphid from June to August is due to favourable temperature, good quality of apple nursery plants and favourable environmental conditions as compared to other months of the year. Decline in the population density of green apple aphid from late July to September-October is due to dispersal of alate morphs from the colonies of green apple aphid. Similar findings were reported by OATMAN & LEGNER (1961). According to them, the green apple aphid population reaches a peak on apple trees in the month of July, then decreases slowly and again increases by late August. Later, WESTIGARD & MADSEN (1965) recorded that population trends of the green apple aphid were generally upward during early June and downwards through the remainder of the year.

It was observed that the infestation of green apple aphid was high in the apical parts of apple nursery plants (Fig. 6). The apple nursery plants which were heavily infested with green apple aphid have shorter growth as compared to the plants which were not infested by this pest (Table 7). High population of *Aphis pomi* De Geer prevented the terminal growth of the plants by hardening off and curling of the leaf and affected plants of apple nurseries also showed distorted growth. These aphids also excreted honeydew that coated the leaves. This results in the growth of sooty mould fungus that adversaly affects photosynthesis and causes hardening of the leaves of apple nursery plants. CROSSBY et al. (1938) reported deformation of fruit also as a result of extended feeding.

CONCLUSIONS

Following conclusions are drawn based on present studies:

1. *Aphis pomi* on apple nursery plants is permanent parthenogenetic, only two morphs, aptera and alata occur in the studied regions of India.
2. Temperature and humidity in Shimla district (India) influenced the duration of examined stages of *Aphis pomi.* The duration of nymphal instars, total nymphal period, the period between the last moult and beginning of reproduction and the total pre-reproductive period was shortest during rainy season.
3. *Aphis pomi* is an important pest on apple nursery plants in the studied regions of India

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