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Population dynamics of aphid and coexisting predators in tomato agroecosystem

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ABSTRACT

Aphids generally attack vegetative plant parts, preferably leaves, and devitalize the plant by sucking the cell sap. Thorough knowledge of pest-predator ecology and their interaction is requisite to initiate timely pest management strategies. Therefore, we aimed to study the population dynamics of aphids and their predators on tomato in Hisar, Haryana during *Rabi,* 2016-17 and 2017-18. We observed two dominant aphid species viz., *Aphis gossypii* and *Myzus persicae* and three aphidophagous predator groups *viz.,* coccinellids, spiders and syrphid fly maggots in the tomato agroecosystem. Aphid infestation started during the 9th standard meteorological week (SMW) and attained a peak during the 12th SMW (22.65 aphids per three leaves per plant). Aphid population exhibited highly significant negative correlation with minimum temperature (r= -0.917**), maximum temperature (r= -0.895**) and wind speed (r= -0.809**). However, it was positively correlated with morning relative humidity (r= 0.933**) and evening relative humidity (r= 0.856**). We used Principal component analysis (PCA) to reduce the dimensions of data and variables were transformed into principal components (PC) to explain the nature and extent of the relationships among different variables. PC1 and PC2 capture 57.6 and 20.3% of the variability in the data, respectively. Aphid predators exhibited a significant positive correlation with the prey population suggesting a positive density-dependent response.

Key words: *Aphis gossypi,* coccinellids, *Myzus persicae,* predators, regression, tomato

Tomato (*Solanum lycopersicum* Mill) is the second most important vegetable crop after potato (FAOSTAT, 2018). Globally, tomato production stands at 182.26 million tonnes (mt) from 4.76 million hectares (mha) (FAOSTAT, 2018). India is the second-largest producer of fresh tomatoes after China (61.63 mt) and ensures a total production of 19.37 mt from 0.79 mha (FAOSTAT, 2018). Tomato productivity is hampered by several abiotic and biotic stressors such as unfavourable environment, degraded soils, weeds, insect-pests and diseases (Osei *et al.,* 2010). Global crop losses owing to pest infestation are appraised to be around 34.4% of attainable tomato yield and without crop protection measures losses would escalate to 77.7% (Zalom, 2003). Aphids generally attack all the vegetative plant parts in larger numbers, settle down on the underside of leaves and suck the cell sap from phloem sieves (Watt & Hales, 1996). Outrageous aphid population often results in stunting and curling of leaves, reduces plant vigour rendering the plant more susceptible to secondary infestation which may exterminate the plant completely (Berlandier and Sweetingham, 2003).

Population dynamics studies are imperative for proper knowledge of pest ecology in key agricultural crops. Aphids as well as their predators are affected by prevailing weather factors *viz.,* temperature, relative humidity, rainfall, sunshine, and wind speed. Favourable weather conditions help in population build-up and ultimately increases pest infestation. (Khokhar *et al.,* 2019). Aphids are being widely studied in several crops, but little is known about population dynamics and its predatory complex in tomato. An exact determination of changes in aphid and its predators' population with meteorological factors is a prime requisite for Integrated Pest Management (IPM). We aimed to utilize these research gaps and study the population dynamics of the aphid complex and its predators in tomato. Based on the literature review, we hypothesized that prevailing weather conditions greatly influence the aphid population which in turn might affect its predators and their feeding rates. This study explains the trends in aphid and their predators' population and helps us to predict the crop stages when pest management tactics can be initiated.

MATERIALS AND METHODS

This experiment was conducted at University Research Area of, CCS Haryana Agricultural University, Hisar during *Rabi* seasons of 2016-17 and 2017-18. Seedlings of tomato crop *cv*. Selection-7 were transplanted in a flatbed of 100 m^2 by adopting 60 cm × 45 cm spacing in 2nd week of February 2017 and 2018. The whole bed was divided into 4 quadrats of 25 m^2 representing four replicates. The crop was raised as per the standard practices, recommended by CCS Haryana Agricultural University, except for the plant protection measures. Nymphs and adults of aphids were observed and counted at a weekly interval on three leaves per plant *i.e.,* one leaf each from the top, middle and bottom of crop canopy, starting from 15 days after transplanting (DAT). Aphid population data were recorded on 10 randomly selected plants per quadrat during morning hours (06:30 to 08:00 AM) and expressed as aphids per three leaves per plant, irrespective of their species (Chavan *et al* 2013). Different spiders, maggots of syrphid fly and grubs and adults of coccinellids were counted at a weekly interval from each quadrat irrespective of their species and expressed as spiders, syrphid fly maggots and coccinellids per plant, respectively. Relation between aphids and their predators and different weather parameters were worked out by Pearson correlation coefficient, regression and PCA. Data on different weather parameters [maximum and minimum temperatures (˚C), morning and evening relative humidity (%), wind speed (km/hr), bright sunshine hours and total rainfall (mm)] were obtained from nearby Agrometeorological Observatory. Data under different heads were pooled for both seasons, *Rabi* 2016-2017 and 2017-2018. Correlation and regression analysis were done with IBM SPSS and PCA was plotted by R software (IBM SPSS, 2017; R core Team, 2017).

RESULTS AND DISCUSSION

Aphid population in relation to weather parameters

The tomato crop was infested by two dominant aphid species *viz., Aphis gossypii* and *Myzus persicae*. Aphid infestation started during the first week of March (9th SMW) and attained a peak (22.65 aphids per three leaves per plant) during the 4th week of March (12th SMW) (Table 1). Similar levels of aphid infestation during the early stages of crop growth have been reported earlier (Mandlio *et al.,* 2015; This variation may be attributed to seasonal and environmental differences. Aphids population followed a declining trend during later stages of crop growth, and it was minimum (0.10 aphid per three leaves per plant) during the second week of May (19th SMW). No aphid population was observed afterwards (Table 1). Chavan *et al.,* (2013) too also reported a steady decline in aphid population with crop maturity.

Correlation and principal component analysis

Aphid population exhibited highly significant negative correlation with minimum temperature [r= -0.917**; Bayes factor (BF) = 0.002], maximum temperature (r= -0.895**; BF = 0.005) and wind speed (r= -0.809**; BF = 0.049). However, there was a significant positive correlation between aphid population and morning relative humidity (r= 0.933**; BF = 0.001) and evening relative humidity (r= 0.856**; BF = 0.017) (Table 2). A similar type of correlation was reported in studies from other parts of India (Pavan *et al.,* 2019). For instance, Deb and Bharpoda (2017) reported a significant negative correlation between aphid infestation and maximum temperature (r= -0.699**) and minimum temperature (r= -0.693**). However, Mondal *et al.,* (2018) showed a non-significant correlation between aphid population and rainfall. A multivariate analysis was performed using PCA to reduce the dimensions of data and variables were transformed into principal components (PC) to explain the nature and extent of the relationships among different variables. Principal components are the newly generated variables constructed as linear combinations of the initial variables. These new variables (i.e., principal components) are uncorrelated and most of the information within the initial variables is squeezed or compressed into the first components (PCI and PC2). PC1 and PC2 capture 57.6 and 20.3% of the variability in data, respectively (Fig. 1a). It explains that negatively correlated variables *i.e.,* wind speed, maximum and minimum temperature, rainfall and sunshine hours are positioned on the opposite quadrats whereas positively correlated variables (morning and evening relative humidity) are positioned on the same side of the axis. The distance between each vector component explains the significance of each variable *i.e.* lesser the distance more significant is the relation (Fig 1a). The length of the vector explains the variance due to that vector *i.e.* longer the vector length, the more is the variation caused by the vector (Fig. 1a). According to PC1 And PC2, weather parameters *viz.,* maximum and minimum temperature, morning and evening relative humidity, wind speed, and biotic factors *viz.,* syrphid fly maggots and coccinellids are the most important variables causing significant variability in aphids population (Fig. F1a).

Table 1: Population dynamics of aphid complex and coexisting predators on tomato during *Rabi,* 2016-17 and 2017-18 (pooled)

SMW*	Aphid population per three leaves per plant	Predators population per plant			Weather parameters						
		Coccinellids grubs and adults	Spiders	Syrphid fly maggots	Temperature (°C)		RH (%)		Rainfall (mm)	Sunshine hrs./day	Wind speed (km hr^{-1})
					Tmax	Tmin	Morning	Evening			
9	15.75	0.25	0.10	1.85	27.51	10.20	91.71	42.07	0.00	7.45	2.76
10	19.00	0.50	0.60	2.80	27.25	10.12	87.45	40.84	0.55	7.39	3.56
11	21.50	0.61	1.06	3.90	28.46	10.05	85.07	35.43	0.00	7.80	2.60
12	22.65	0.69	1.11	4.35	30.93	13.05	86.00	37.86	0.00	7.95	2.95
13	15.30	0.79	0.93	4.25	35.49	15.25	79.00	28.79	0.00	8.73	3.19
14	10.70	0.72	0.76	3.85	35.74	18.61	64.50	30.43	0.00	6.28	6.55
15	6.40	0.61	0.74	3.10	35.42	16.02	65.72	27.43	1.00	8.64	4.61
16	2.70	0.65	0.60	1.90	40.29	21.08	50.79	25.00	0.00	9.08	4.75
17	1.35	0.46	0.50	0.85	38.89	20.66	52.93	25.36	0.07	8.19	5.12
18	0.50	0.25	0.45	0.45	39.13	23.13	57.00	26.43	0.00	7.50	7.05
19	0.10	0.10	0.37	0.15	40.88	23.61	56.00	23.14	0.10	7.85	5.95
20	0.00	0.05	0.23	0.00	40.54	24.69	56.00	31.57	0.00	6.83	6.15
21	0.00	0.00	0.09	0.00	41.67	24.27	52.43	24.64	0.00	8.42	4.56
22	0.00	0.00	0.05	0.00	40.96	25.57	70.07	41.43	2.20	7.86	8.42

*SMW= Standard Meteorological Week

Table 2: Bayesian inference about Pearson correlation coefficient of aphid complex and coexisting predators with weather parameters

Weather parameters	Aphid population per 3 leaves per plant		Coccinellids per plant		Spiders per plant		Syrphid fly maggots per plant	
	r	Bayes factor$^{\#}$	r	Bayes factor	r	Bayes factor	r	Bayes factor
Maximum temperature	-0.895**	0.005	-0.310^{NS}	2.863	-0.464^{NS}	1.233	-0.547^{NS}	0.967
Minimum temperature	-0.917**	0.002	-0.471^{NS}	1.397	-0.576*	0.493	-0.653*	0.415
Morning relative humidity	0.933**	0.001	-0.434^{NS}	1.707	0.371^{NS}	2.123	0.611*	0.601
Evening relative humidity	0.856**	0.017	0.072^{NS}	4.543	-0.19^{NS}	4.978	0.466^{NS}	1.556
Wind speed	-0.809**	0.049	0.304^{NS}	2.921	-0.511^{NS}	0.875	-0.571^{NS}	0.819
Rainfall	-0.042^{NS}	4.452	0.131^{NS}	4.286	-0.306^{NS}	2.829	0.084^{NS}	4.349
Sunshine hours	-0.206^{NS}	3.714	0.368^{NS}	2.310	0.14^{NS}	4.450	-0.370^{NS}	4.458

r: Pearson correlation coefficient; NS=non-significant*=significant at $p<0.05$; **=significant at $p<0.01$

Bayes factor: null hypotheses (H_0) to alternate hypotheses (H_1); Bayes factor<0.001: Extreme evidence for rejection of H_0; 0.001<Bayes factor<0.03:Very strong evidence for rejection of H_0; 0.03<Bayes factor<0.1: Strong evidence for rejection of H_0; 0.1<Bayes factor<0.33: Moderate evidence for rejection of H_0;0.33<Bayes factor<1: Anecdotal evidence of rejection of H_0; Bayes factor=1: No evidence for rejection of H_0; 1<Bayes factor<3: Anecdotal evidence for acceptance of H_0; 3<Bayes factor<10:Moderate evidence for acceptance of H_0.

Regression analysis

Analysis of variance suggests significant individual effect of maximum temperature (R^2=0.80; F1,11=36.25; p=0.0002***), minimum temperature (R^2=0.84; F1,11=47.43; p<0.0001***), morning relative humidity (R^2=0.87; F1,11=60.37; p<0.0001***), evening relative humidity (R^2=0.73; F1,11=24.77; p= 0.0007***), wind speed (R^2=0.65; F1,11=17.07; p= 0.003**) towards aphid population changes (Table 3). Additionally, rainfall (F1,11= 0.016; p= 0.903) and sunshine hours (R^2=0.04, F1,11=0.399, p= 0.543) had minimal and non-significant individual effect (Table 3). However, the stepwise regression analysis was carried out to ascertain contribution of most significant weather variables. Morning relative humidity was the most

Table 3: Linear model describing the effect of individual weather parameter on aphids and their predator complex population

Weather parameters	Aphid population per 3 leaves per plant			Coccinellids per plant			Spiders per plant			Syrphid fly maggots per plant		
	t stat	F value	Pr (>|F|)	t stat	F value	Pr (>|F|)	t stat	F value	Pr (>|F|)	t stat	F value	Pr (>|F|)
Maximum temperature (℃)	-6.02	36.25	0.0002***	-1.032	1.06	0.33	-1.83	3.33	0.09	-1.96	3.85	0.08·
Minimum temperature (℃)	-6.89	47.43	<0.0001***	-1.687	2.85	0.12	-2.45	6.02	0.03*	-2.58	6.68	0.03*
Morning relative humidity (%)	7.77	60.37	<0.0001***	1.015	1.03	0.33	1.39	1.94	0.19	2.32	5.37	0.04*
Evening relative humidity (%)	4.98	24.77	0.0007***	0.234	0.05	0.82	-0.063	0.004	0.95	1.58	2.50	0.15
Wind speed (km/hr)	-4.13	17.07	0.003**	-1.518	2.31	0.16	-2.077	4.31	0.06·	-2.08	4.36	0.07·
Rainfall (mm)	-0.125	0.016	0.903	0.42	0.17	0.69	-1.12	1.24	0.29	0.25	0.06	0.81
Sunshine hours	-0.632	0.399	0.543	1.24	1.54	0.24	0.5	0.25	0.62	-0.11	0.01	0.91
0	t_{10}=2.228	$F_{1,11}$= 4.84		t_{11}=2.201	$F_{1,12}$= 4.75		t_{13}=2.160	$F_{1,14}$=4.60		t_{10}=2.228	$F_{1,11}$= 4.84	

Significant levels: $p<0.001$‘***’; $p<0.01$‘**’; $p<0.05$‘*’; $p<0.1$‘.’

$P<0.001$: extreme evidence against H_0;$p< 0.01$: very strong evidence against H_0; $0.01<=p< 0.05$: moderate evidence against H_0; $0.05<=p< 0.10$: suggestive evidence against H_0; $p>=0.10$: little or no real evidence against H_0

significant factor contributing 87 per cent variability (Table 4). Likewise, significant contribution of weather parameters has also been reported (Sharma *et al.,* 2013).

Predators population in relation to weather parameters

Coccinellids : Three species of coccinellids *viz., Brumoides suturalis, Cheilomenes sexmaculata, Coccinella septempunctata* were observed feeding on aphids. Initially, the predator population was low but increased sustainably with an increase in the aphid population. Coccinellids were first observed during the first week of March (9th SMW) (0.25 grubs and adults per plant) and thereafter, attained peak during the first week of April (13th SMW) (0.79 grubs and adults per plant) (Table 1). Afterwards, coccinellids populations decreased gradually due to a reduction in prey density which continued up to 20th SMW (0.05 grubs and adults per plant) (Table 1). A similar period of activity was also recorded by Saljoqi *et al.,* (2009). Coccinellids exhibited a non-significant correlation with all the weather parameters under study (Fig 1b & Table 2). Kalasariya and Parmar (2018) and Subba (2013) as well recorded a non-significant correlation between coccinellids and weather parameter. Regression model suggests that maximum temperature and minimum temperature were primarily responsible for changes in coccinellids population (Table 4), however, the contribution was non-significant (F1,12=1.06; p=0.33 & F1,12=2.85; p=0.12) (Table 3).

Spiders : Spiders are generalist predators which largely feed on sucking pests such as aphids as well as various lepidopteran pests recorded in the tomato ecosystem. Spiders were present during the entire crop period starting from 9th SMW to 22nd SMW (Table 1). The population started increasing from 9th SMW (0.10 spiders per plant) and peaked during the 4th week of March (12th SMW) (1.11 spiders per plant) which are in accordance with previous findings (Subba, 2013). It showed a significant negative correlation with minimum temperature (r= -0.576*; BF = 0.493) but it was non-significantly correlated with all the other weather parameters (Fig 1c & Table 2) (Subba, 2013). In contrast, a positive correlation with temperature and sunshine hours; negative correlation with minimum relative humidity, average relative humidity and rainfall has been reported (Patel *et al.,* 2005).

Syrphid fly maggots : Syrphid fly maggots are important predators in tomato crop and actively feed on nymphs of aphid. The initial population was recorded during the first week of March (9th SMW) (1.85 syrphid fly maggots per plant) and attained a peak (4.35 syrphid fly maggots per plant) during the last week of March (12th SMW). Afterwards, it showed a declining trend with a decrease in aphid population and no population was recorded after the second week of May (19th SMW) (Table 1). Syrphid fly maggot population was significantly and negatively correlated with minimum temperature (r= -0.653**; BF = 0.415) whereas it exhibited a significant positive correlation with morning relative humidity (r= 0.611*; BF = 0.601) (Fig 1d & Table 2). Literature concerning population dynamics of syrphid fly maggot in tomato crop is scarce. However, maggot population was

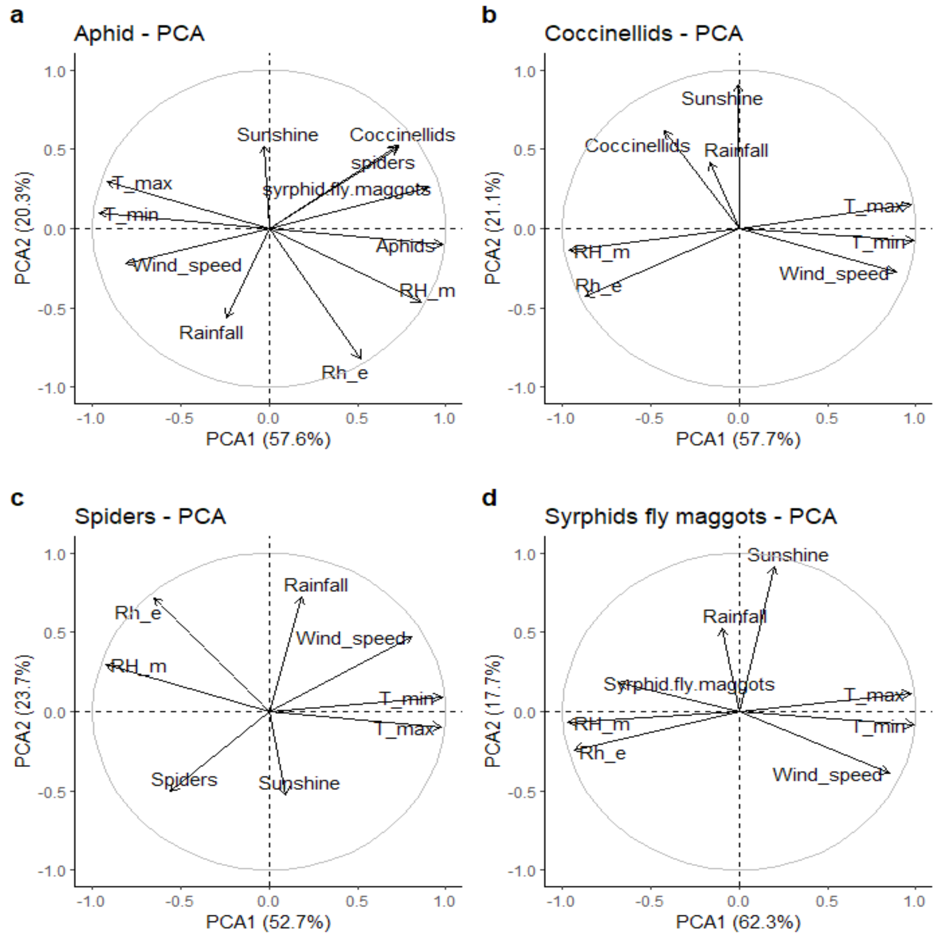

Fig. 1: Loading plots of aphid population with weather parameters and predators (a), coccinellids (b), spider (c) and syrphid fly maggots (d) with weather parameters. The length of vector and angles between the component vectors indicates how a characteristic correlate with another.

Table 4: Stepwise linear regression of aphid and coexisting predators with weather parameters (Pooled)

Stepwise linear regression		
Aphid (Y1)	Y2 = -26.45+0.52X3	0.87
Coccinellids (Y2)	Y2 = -1.49 + 0.12X1 - 0.13 X2	0.59
Spiders (Y3)	Y3= 1.19 – 0.04X2	0.33
Syrphid fly maggots (Y4)	Y4= 5.69 -0.19X2	0.42

X1: Maximum temperature (˚C); X2: Minimum temperature (˚C); X3: Morning relative humidity (%)

Table 5: Correlation coefficient between aphid and natural enemies (Pooled)

Predators	Aphid population per three leaves per plant	
	r	Bayes factor (BF)#
Syrphid fly maggots per plant	0.855**	0.003
Coccinellids grubs and adults per plant	0.682**	0.236
Spiders per plant	0.642*	0.139

positively correlated with temperature on the mustard crop (Dwivedi *et al.,* 2018). Step-wise regression equation shows that minimum temperature was the most significant factor among all (R^2=0.43; F1,11=6.68; p=0.03*) (Table 3 and 4).

Predators population in relation to pest density

The predators' population showed an increasing trend with build-up in the aphid population stating a positive correlation (Table 1). Population of coccinellids, spiders and syrphid fly maggots exhibited highly significant and positive correlation with aphid population with r= 0.642*, r= 0.682**, r= 0.855**, respectively (Table 5). Similarly, a significant positive correlation has been reported between spiders (r=0.786), coccinellids (r=0.933) and aphid population (Nayak *et al.,* 2019). Information about the correlation of syrphid fly maggots with aphid population on tomato crop is scanty while Devi *et al.* (2011) reported a significant positive correlation (r= 0.867) between aphid and syrphid fly maggot population on cabbage. Ranila *et al.,* (2015) too reported a significant positive correlation between aphid population and biotic factors *viz.,* coccinellids and syrphids on coriander.

Predicting pest population

Based on our results, the most important variables contributing significantly towards the variance in the pest population were maximum and minimum temperature, morning relative humidity, wind speed and syrphids accounting for 99 per cent variability in the aphid population (R^2=0.99, F=137.39; $P<0.001$). The linear regression equation thus developed for prediction of pest population is:

Y= 39.21-2.13 Tmax + 2.10 Tmin + 0.16 Morning RH - 2.10 Wind speed + 3.14 Syrphids

CONCLUSION

Aphid population was higher during the early stage of crop growth suggesting the need for pest management during the initial vegetative stage which was largely influenced by prevailing meteorological parameters and predators. Aphid population has a highly significant negative correlation with wind speed, maximum and minimum temperature whereas a highly significant positive correlation with morning and evening relative humidity. Furthermore, the population of predators *viz.,* coccinellids, spiders and syrphid fly maggots exhibit a highly significant positive correlation with prey population suggesting a positive density-dependent response. Thorough knowledge of population dynamic studies of tomato aphid complex in relation to abiotic and biotic factors may strengthen the development of efficient pest management strategies. A holistic IPM program can be designed against aphid complex in tomato where predators can be used in conjugation with other control strategies. This may reduce the dependence on pesticides and may reduce the problems associated with indiscriminate pesticide usage.

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