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IMPACT OF INDIGENOUS FARMING SYSTEMS ON ARTHROPOD DYNAMICS, SOIL FAUNA AND QUALITY OF TOMATO UNDER NORTH- INDIAN CONDITIONS

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ABSTRACT

The impact of different crop production systems on arthropod diversity, enzymatic activity, soil microflora and fruit quality on winter planted tomato crop was studied during 2017-2019 at Ludhiana. Highest populations of *Aphis gossypii* (2.15/3leaves) and *Helicoverpa armigera* (1.31%) were observed in organic fields followed by IPM and conventional fields during 2017-18. Correlation analysis between aphids and meteorological parameters revealed a negative correlation of aphid with maximum and minimum temperature while tomato fruit borer population showed a positive trend. The mean fruit yield in the farming system following Good Agricultural Practices (GAP) was maximum (592.4 q/ha). The mean spider population (no.) was found to be significantly higher under organic conditions (0.56) in contrast to conventional (0.11) and IPM (0.35). Analysis of soil and tomato fruit samples for pesticide residues showed that samples from organic & IPM fields were free from the pesticide residues whereas collected field samples showed the presence of profenophos during 2017 and mancozeb during 2018. The flavonoids, antioxidants, activity of alkaline phosphatase and urease from organic fields was higher in comparison to conventional fields.

Keywords: *Aphis gossypii, Helicoverpa armigera*, Microorganisms, Pesticide residues, Seasonal incidence

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Tomato, *(Lycopersicon esculentum* Mill.) is one of the remunerative vegetable crops grown around the world for fresh market and processing. India is the world's second-largest producer, after China, accounting for about 11 per cent of total global output with annual production of 18.7 million MT on 0.88 million hectares (Mondal *et al.,* 2019). In Punjab, tomato crop is cultivated on 8.06 thousand hectares with a production of 224.18 thousand MT (Anonymous, 2019). Tomato cultivation in India is undertaken under three different farming systems namely; conventional farming wherein farmers usually make blanket application of chemical fertilizers and pesticides; organic farming with use of agri-inputs and farming following good agricultural practices (GAP) whereby integrated pest and disease management (IPM) tactics are followed.

In conventional farming, excessive and indiscriminate use of agrochemicals frequently leads to negative impacts like soil and water pollution, toxic residues in the final product, development of insecticide resistance and induction of resurgence in major insect pests. Organic farming, on the other hand, strives to produce pesticide-residue free food while ensuring good health of soil and water environments. The third system farming following GAP with IPM removes drawbacks of conventional and organic farming. It employs good agricultural practices recommended by the University (Anonymous, 2018) for raising a healthy crop while adopting need based application of agrochemicals and pesticides. IPM, in fact, is an effective and environmentally accessible approach and a feasible alternative to conventional farming.

Tomato productivity is greatly vulnerable to biotic and abiotic factors (Blay, 2005). In India, about 16 pests feed on tomato, initiating from germination stage to harvesting which reduces its yield and degrades its quality (Chavan *et al.,* 2013). The tomato fruit borer, *Helicoverpa armigera* (Hubner) and aphid, *Aphis gossypii* Glover are the major insect-pests causing yield losses to the tune of 85- 93.7 and 34 per cent, respectively (Islam *et al.,* 2017). The weather parameters viz., temperature, rainfall, humidity prevailing during the crop growth period put forth a direct pressure on insect distribution and development (Saxena and Murty, 2014). Modern plant protection products, although, are more specific to the target and somewhat environmentally safe but there is always a risk of a potential danger to human health (Rembialkowska and Badowski, 2011). The present investigation was thus, considered for studying the impact of indiscriminate and excessive use of agrochemicals in three different crop production systems *viz*. conventional farming system; organic farming and farming following GAP with IPM adoption. The arthropod diversity under these different crop production systems and its relation with various abiotic

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factors was studied. The effect of organic and synthetic agri-inputs on soil properties and quality parameters of tomato were also taken into consideration.

MATERIALS AND METHODS

Study area and data collection

The present studies were conducted on the winter-planted tomato crop during three consecutive years, from 2017 to 2019. Five farmers, each with one acre area, were selected for each of the crop production system; organic, farming following GAP with IPM and conventional farmer's fields. Tomato cultivars *viz*. Golden 575, Punjab Ratta and Hybrid tomato were cultivated under different farming systems. The details of the inputs added under different farming systems are given in Table 1.

Pest population dynamics

The data pertaining to insect-pests, *H. armigera* and *A. gossypii* were recorded at weekly intervals starting from the appearance of pest. Correlation and regression equations were calculated to estimate the effects of abiotic factors viz. minimum and maximum temperature, relative humidity and rainfall, on population counts of insect pests. The data on population dynamics of *A. gossypii* and *H. armigera* recorded from ten plants, selected at random from organic/ IPM and conventional fields, starting from the month of January to June during three years of study (2017-19). Besides, the population of natural enemies (spiders) was also recorded during each year.

Analysis of pesticide residues

Pesticide residues in tomato fruits and soil were analysed using GLC-ECD for organochlorines and synthetic pyrethroids detection and GLC-FPD for organophosphates detection (Anastassiades and Lehotay, 2003). For estimation of pesticide residues, the fruit and soil samples from three different crop production systems were collected. The confirmation of pesticide detected was done on GCMS. For tomato fruits, 500 g representative sample from each crop production system was crushed using high volume homogenizer. A sub-sample of 15 g crushed fruits, obtained from above, was put into a 50 ml centrifuge tube and further homogenized using high speed homogenizer (Heidolph Silent Crusher-M®) for 3 min at 15,000 rpm while adding 30 ml acetonitrile and 7 ml of distilled water to it. For phase separation, 10 g sodium chloride was added. An aliquot of 10 ml acetonitrile layer transferred over 10±0.1 g anhydrous sodium sulfate, was subjected to cleanup by dispersive solid phase extraction (DSPE). An aliquot of 6 ml acetonitrile was taken in a test tube containing 0.15±0.01 g PSA sorbent and 0.90±0.01 g anhydrous $MgSO_4$ and the contents were thoroughly vortex on vortex shaker, followed by centrifugation at 2500 rpm for 1 min. Finally, a 4 ml aliquot was concentrated at Turbo vap till dryness, and final volume made upto 2 ml with acetone for the estimation of pesticide residues. For soil samples analysis, same methodology was followed except a sub-sample of 10 g and addition of 20 ml of acetonitrile to the 50 ml centrifuge tube.

Analysis of soil biological parameters

The surface soil samples (0-15 cm) from all the selected fields (organic, IPM, and conventional fields) were collected before harvesting the crop. The data on soil parameters were interpreted by categorizing the farmers based on the recommended dose of N fertilizer: F(N) = Farmers using the recommended dose of N fertilizer; F(MH) = Farmers using more than 25% of the recommended dose of N fertilizer; F(H) = Farmers using more than 50% of the recommended dose of N fertilizer; F(VH) = Farmers using more than 75% of the recommended dose of N fertilizer. The activity of soil enzymes *viz*. dehydrogenases (Ohlinger, 1996), urease (Alef and Nannipieri, 1998) and alkaline phosphatase (AKP) (Alef *et al*.,1998) was found higher in organic fields.

Analysis of quality parameters in tomato fruits'

The tomato fruits harvested from the selected organic, IPM and conventional farmers' fields were analyzed for flavonoids (Woisky and Salatino, 1998) and anti-oxidants (Kaur and Kapoor, 2002).

RESULTS AND DISCUSSION

Insect pest population dynamics

Aphis gossypii

The analysis of pooled data on aphid incidence for 2016-17, 2017-18 and 2018-19, revealed higher aphid infestation in the organic fields during all the years, followed by the IPM fields and conventional farmers' fields. The aphid population was higher during 2nd year (2.15 in organic, 1.64 in IPM and 0.91 aphids/3 leaves in conventional fields, respectively) as compared to first year (0.80 in organic, 0.51 in IPM and 0.39 aphids/3 leaves in conventional fields) and 3rd year (2.14 in organic, 1.65 in IPM and 0.85 aphids/3 leaves in conventional fields, respectively) (Table 2). The aphid population and meteorological parameters showed a negative correlation with maximum and minimum temperature but a positive correlation with relative humidity (Table 3). The maximum value of regression coefficient (R^2) of aphid population was 0.902, 0.445 and 0.300 with maximum temperature in organic, IPM and conventional fields, respectively (Fig. 1). The

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Table 1. Details of inputs/chemical fertilizers/ synthetic pesticides used under different crop production systems

Organic	• 10 tons of farm yard manure (FYM) of desi cows per acre • Soil Treatment for enhancing soil productivity: Organic material for soil treatment was prepared by mixing 10 kg cow dung with 1500 g jaggery, 1500 g gram flour in 100 L water, followed by incubation of the mix material for 3 days at 35°C to allow fermentation. The final product, so obtained was added to irrigation water once in a month. • Seed treatment: Organic material for seed treatment was prepared by mixing 5 litres cow urine in 5 kg cow dung and 5 g lime soda in 20 litres of water, followed by incubation for 30 hours, filtration and final treatment of seed with the filtrate. • Insect pest and disease management: Spray of sour Butter milk (*Khatti lassi)* alone or after mixing turmeric and jaggery for insect pests and viral diseases control; Spray of *Brahma Astra* prepared by mixing 2 kg each of neem (*Azadirachta indica*), Akk (*Calotropis* sp.), Dhatura (*Datura stramonium*) and castor (*Ricinus communis*) leaves in 20 litres of cow urine; and Spray of *Neem Astra* prepared by mixing 2 kg each of neem leaves and cow dung in 200 litres of water.
IPM	• 10 tons of farm yard manure • 130 kg Urea (55 kg at planting and 75 kg in mid-February); 155 kg SSP (at planting) and 45 kg Muriate of Potash (at planting) • Seed treatment with Captan @ 3g per kg of seed • Need based spray of Malathion @ 400 ml/acre for aphids, and Flubendiamide 39.35 SL @ 30 ml/acre for tomato fruit borer, and Mancozeb 75% WP @ 600 ml/acre for early blight of tomato.
Conventional	• Synthetic fertilizers: 50-200 kg Urea (split in 2-3 doses) along with 50-100 kg DAP and 50 kg Muriate of Potash • Insect pest and disease management: Insecticides in varying dosages used indiscriminately by conventional farmers included Malathion 50 EC, Emamectin benzoate 5% SG, Chlorantraniliprole 18.5 SC, Flubendiamide 39.35 SL, Chlorpyriphos 20 EC, Profenophos 50EC, Imidacloprid 17.8 SL, Regent 5 SC, Profenofos 40% + cypermethrin 4% EC, β-cyfluthrin+ imidacloprid while fungicides used were Ridomil MZ, Sectin 60 WG, Mancozeb 75% WP, Mancozeb (64% w/w)+Metalaxyl-M (4% w/w), and mixture of Fenamidone 10% + Mancozeb 50%

Table 2. Seasonal incidence of *A. gossypii* and *H.armigera* and abundance of natural enemies (spiders) under different crop production systems

A. gossypii (Number/3 leaves)									
Standard Meteorological Week	**2016-17**			**2017-18**			**2018-19**		
	Org	**IPM**	**F Field**	**Org**	**IPM**	**F Field**	**Org**	**IPM**	**F Field**
SMW5	0.30	0.13	0.04	0.33	0.30	0.33	0.43	0.33	0.30
SMW6	0.53	0.27	0.14	1.30	1.37	1.42	1.33	1.47	1.40
SMW7	0.67	0.40	0.34	3.10	3.50	0.65	3.07	3.50	0.60
SMW8	1.70	1.23	1.06	3.87	1.37	1.25	3.73	1.30	1.09
Mean	0.80	0.51	0.39	2.15	1.64	0.91	2.14	1.65	0.85
H. armigera (%)									
SMW5	0.50	0.44	0.33	0.64	0.45	0.52	0.52	0.39	0.44
SMW6	0.75	0.62	0.65	0.92	0.80	1.06	0.67	0.74	0.88
SMW7	0.97	0.71	1.81	1.5	1.05	0.92	1.31	0.86	0.84
SMW8	2.25	1.73	0.74	2.20	0.86	1.35	2.15	0.80	1.29
Mean	1.12	0.87	0.88	1.31	0.79	0.96	1.16	0.70	0.86
Spiders (Number)									
SMW5	0.48	0.39	0.07	0.57	0.29	0.08	0.53	0.35	0.09
SMW6	0.39	0.31	0.02	0.61	0.32	0.02	0.53	0.37	0.12
SMW7	0.43	0.35	0.03	0.52	0.23	0.03	0.52	0.29	0.10
SMW8	0.45	0.37	0.02	0.53	0.24	0.03	0.54	0.31	0.12
Mean	0.44	0.35	0.04	0.56	0.27	0.04	0.53	0.33	0.11

*Mean of 10 plants per replication; No. of replications/treatment: 5
SMW1-SMW5=Standard Meteorological week 1 to 5; Org-Organic, IPM= Integrated Farmer’s Field, F=Farmers’ Field

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Table 3. Correlation coefficient between insect pests of winter tomato and weather parameters

Correlation coefficient (r)	Max temp (˚C)	Min temp (˚C)	RH (%)	Rainfall (mm)	Aphid	Fruit borer
Organic Farming						
Max temp (˚C)	1					
Min temp (˚C)	0.925	1				
RH (%)	-0.925	-0.778	1			
Rainfall (mm)	-0.486	-0.431	0.215	1		
Aphid (*A.gossypii*)	-0.949	-0.841	0.957	-0.417	1	
Fruit borer (*H.armigera)*	0.908	0.949	-0.836	-0.319	0.868	1
Farming following GAP with IPM adoption						
Max temp (˚C)	1					
Min temp (˚C)	0.925348	1				
RH (%)	-0.92552	-0.778	1			
Rainfall (mm)	-0.48699	-0.431	0.215	1		
Aphid (*A.gossypii*)	-0.667495	-0.715	0.498	-0.439	1	
Fruit borer (*H.armigera)*	0.449914	0.647	-0.212	-0.240	0.630	1
Conventional farmers' field						
Max temp (˚C)	1					
Min temp (˚C)	0.925348	1				
RH (%)	-0.92552	-0.778	1			
Rainfall (mm)	-0.48699	-0.431	0.215	1		
Aphid (*A.gossypii*)	-0.547981	-0.692	0.379	-0.242	1	
Fruit borer (*H.armigera)*	0.381595	0.681	-0.21743	0.049	0.752	1

Significant at 5% level

lowest value of R^2 was- worked out for rainfall in organic, IPM and conventional fields (0.1747, 0.1932 and 0.05, respectively) (Fig. 1).

Helicoverpa armigera

The population of tomato fruit borer was highest (2.25%) in 8th SMW during 2016-17, while it was 2.20 per cent in 8th SMW during 2017-18 and 2.15 per cent in 8th SMW during 2018-19 in the respective organic fields (Table 2). The fruit borer population was higher during the 2nd year in contrast to 1st and 3rd year. *H. armigera* incidence during 1st year of study (2016-17) was 1.12 % in organic, 0.87% in IPM and 0.88 % in conventional fields as compared to 2nd year (2017-18) in which it increased to 1.31% in organic, 0.79% in IPM and 0.96% in conventional fields and 3rd year (2018-19), it was (1.16% in organic, 0.70% in IPM and 0.86% in conventional fields). Correlation analysis showed a positive correlation between fruit borer population with maximum and minimum temperature but a negative correlation with relative humidity (Table 3). The value of regression coefficient (R^2) was highest with minimum temperature (0.902, 0.419 and 0.47 for organic, IPM and conventional fields, respectively) while lowest with rainfall (0.102, 0.058 and 0.003 in organic, IPM and conventional fields, respectively) (Fig. 1).

Tomato yield

The mean tomato fruit yield in the farming following GAP with IPM adoption was maximum (592.4 q/ha) followed by conventional farmers' fields (554.9 q/ha) and organic field (510.7 q/ha). The conventional tomato growers obtained the mean tomato fruit yield in the range of 528.1 to 569.3 q/ha. The yield trends observed in the study showed that lower rates of application of pesticides in IPM may be more desirable for environment safety and to reduce the cost of cultivation.

Natural enemies

The mean spider population was found to be substantially higher under organic conditions (0.44, 0.56 & 0.53 spiders/plant, respectively during 2017, 2018 and 2019) followed by farming system following GAP with IPM adoption (0.35, 0.27 & 0.33 spiders/plant, respectively during 2017, 2018 and 2019) while least in conventional farmers' fields (0.04, 0.04 & 0.11 spiders/plant), respectively during 2017, 2018 and 2019) (Table 2).

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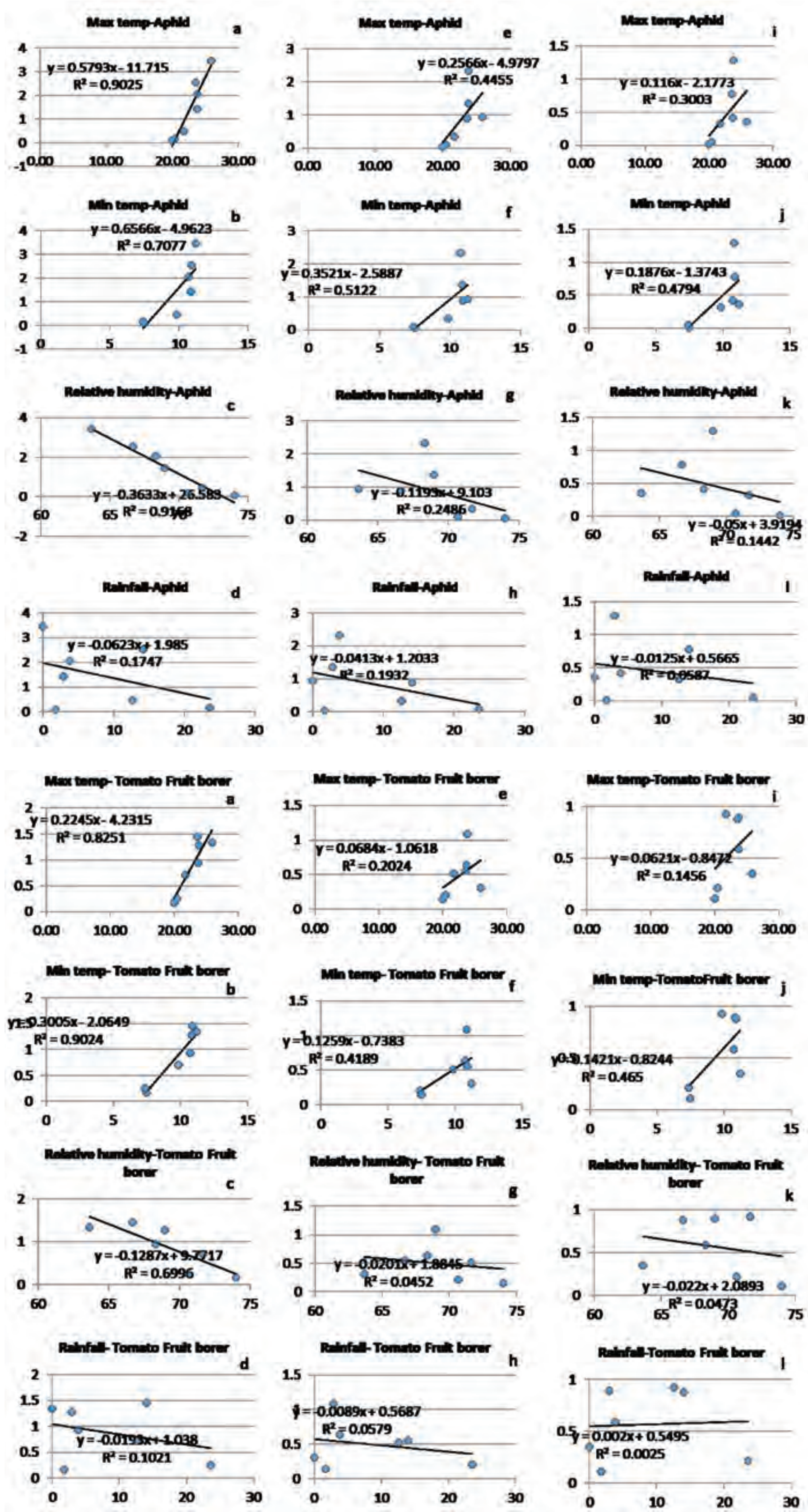

Fig. 1. Scatter plot and regression equation of insect pests and weather parameters in winter tomato during 2017-2019

Pesticide residues in soil and tomato fruits

Analysis of crop, soil and tomato fruits for pesticide residues from organic and IPM fields showed that all tested samples were pesticide-free. However, the soil samples collected from conventional fields revealed the presence of chlorpyriphos while the tomato fruit samples of conventional farmers' fields showed the presence of profenophos during 2017 and mancozeb during 2018. During 2019 crop season, all samples of crop soil and tomato fruits were free from any pesticide residues. This may be the result of consistent efforts made to educate the conventional farmers regarding ill effects of excessive or indiscriminate use of pesticides on fruit quality, natural enemies' diversity and ill effects on human health.

Biological properties

The soil samples from organic fields showed relatively higher number of earthworms, higher population of fungi, bacteria and actinomycetes and enhanced activity of enzymes, dehydrogenase, alkaline phosphatase and urease as compared to soil samples from IPM and conventional fields (Table 4). Actinomycetes count in soil of organic and IPM field was 1.6 x 10^7 and 1.3×10^7, respectively during 2016-17, 7 x 10^6 and 5.8 ×10^6 cfu/g soil during 2017-18 and 8.7 x 10^6 and 6.3×10^6 cfu/g soil during 2018-19. The count for fungal colonies recorded using 10^{-3} and 10^{-4} dilutions was observed to be 2.4×10^4cfu/gm soil in organic field and 2.0×10^4 cfu/g soil in IPM field in 2016-17, which decreased to 1.3×10^4 cfu/gm in organic field and 1.6×10^4 cfu/gm in IPM field in 2017-18 and again increased to 9.7×10^3 cfu/gm in organic field and 8.4×10^3 cfu/gm in IPM field in 2018-19 season, respectively. The bacterial, actinomycetes and fungal count in conventional field was lower than both organic and IPM fields in the final season. The soil samples from organic fields showed relatively higher population of fungi, bacteria and actinomycetes as compared to soil samples from IPM and conventional fields in all the three growing seasons (Table 4). Activity of dehydrogenase enzyme ranged from 3.08-8.61, 3.10-13.21 and 4.86-11.18 µg TPF g^{-1} dry soil h^{-1} in 2016-17, 2017-18 and 2018-19 respectively. The activity of alkaline phosphatase was highest in organic fields (70, 82 and 74 µg PNP/g/hr in 2016-17, 2017-18 and 2018-19, respectively) followed by IPM field (58, 67 and 71 µg PNP/g/hr in 2016-17, 2017-18 and 2018-19, respectively). The activity was lower in all the fields following conventional practices throughout the study period. Similarly, urease enzyme activity was higher in soil under organic practices (635, 520 and 486 µg/g/hr in 2016-17, 2017-18 and 2018-19, respectively) than those under IPM and conventional practices.

Quality of tomato fruits

The flavonoid content of produce from organic field (2.03 mg RE/g) was highest in contrast to IPM field that recorded 1.58 mg RE/g and the fruits from conventional farming ranging from 0.83- 1.19 mg RE/g during 2018-19 (Table 5). The percent antioxidant activity in the produce harvested organic fruits was higher during 2018-19.

The present studies on the abundance of *A. gossypii* in tomato are in conformity with Mahmood *et al.*(1990) who reported mean temperature to have a negative and non-significant correlation with the density variation of aphids, *Lipaphis erysimi* (Kalt) in tomato. Kaushik (2011) reported initiation of *A. gossypii* population increasing slowly upto the 6^{th} SMW and attaining the maximum population at about 8^{th} SMW and the present results are in full agreement with their findings. A negative correlation was observed between tomato fruit borer population and relative humidity by Kachave *et al.* (2020) which are in line with the present findings. Kharpuse (2005) also supported the present findings where peak fruit borer population was observed in 8^{th} SMW (2.6%). In contrast to present study, Harshita *et al.* (2018) observed maximum temperature, minimum temperature to have a positive correlation and a negative association with average relative humidity. These results are also supported by Khan *et al.* (2003) who reported mean temperature to be positively correlated with fruit borer infestation in tomato. Sharma *et al.* (2010) also reported tomato fruit borer to have a negative significant correlation with mean relative humidity which is in coherence with the present observations. The findings by Wakil *et al.* (2010) are also in line with our studies, who reported temperature to have a positive correlation while, relative humidity a negative interaction with the larval population and fruit infestation in tomato. Zafar *et al.* (2013) also reported that maximum temperature exhibited significant and positive correlation with the egg counts of *H. armigera* in tomato whereas, relative humidity and rainfall had negative and significant correlation with the egg count. The mean spider population was found to be significantly higher under organic conditions followed by IPM fields and conventional farmers' fields, during all the three years of experimentation are in line with Miranda *et al.* (2005) who observed that indiscriminate use of insecticides reduced the population of natural enemies. Drinkwater *et al.* (1995) also observed higher population of natural enemies and predators under organic field conditions in case of organic tomato in California, USA.

The maximum mean tomato fruit yield of 592.4 q/ha in the crop production system with IPM adoption followed by conventional farmers' field (554.9 q/ha)

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Table 4. Impact of different crop production systems on soil biological properties

Season	2016-17				2017-18				2018-19				
Field	*Org	*IPM	*$F_{(MH)}$	*$F_{(VH)}$	*Org	*IPM	*$F_{(N)}$	*$F_{(VH)}$	*Org	*IPM	*$F_{(N)}$	*$F_{(MH)}$	*$F_{(H)}$
Earthworms													
Mean	2-4	0-1	Nil	Nil	3-4	1-2	Nil	Nil	2-3	1-2	Nil	Nil	Nil
Bacteria													
Mean	5.8×10^7	4.5×10^7	3.1×10^7	3.3×10^7	8.2×10^7	7.6×10^7	4.6×10^7	6.9×10^7	8×10^7	6.5×10^7	4.4×10^7	4.3×10^7	4.7×10^7
Actinomycetes													
Mean	1.6×10^7	1.3×10^7	5.2×10^6	5.9×10^6	7×10^6	5.8×10^6	1.9×10^6	2.1×10^6	8.7×10^6	6.3×10^6	4.8×10^6	4.0×10^6	4.0×10^6
Fungi													
Mean	2.4×10^4	2.0×10^4	7.2×10^3	6.5×10^3	1.3×10^4	1.6×10^4	6.2×10^3	5.3×10^3	9.7×10^3	8.4×10^3	5.0×10^3	7.2×10^3	3.5×10^3
Alkaline phosphatase (µg PNP/g/hr)													
Mean	70	58	54.2	39.2	82	67	53.3	63	74	71	50.7	52.5	59
Dehydrogenase (µg TPF/g/hr)													
Mean	8.61	7.64	3.65	3.08	12.76	13.21	3.10	5.73	10.23	11.18	5.71	7.91	4.86
Urease (µg/g/hr)													
Mean	635	510	389.4	354	520	490	353.1	360	486	394	353.7	288	323

$F_{(MH)}$ = Farmers using more than 25% of recommended dose of N fertilizer
$F_{(VH)}$ = Farmers using more than 75% of recommended dose of N fertilizer
$F_{(N)}$ = Farmers using recommended dose of N fertilizer
$F_{(H)}$ = Farmers using more than 50% of recommended dose of N fertilizer
*Mean value of 05 replications for each treatment

Table 5. Tomato fruits quality parameters following organic, IPM and conventional practices

Agricultural produce parameters													
Season	2016-17				2017-18				2018-19				
Phenolic compounds (mg GAE/g)													
Field	Org	IPM	$F_{(MH)}$	$F_{(VH)}$	Org	IPM	$F_{(N)}$	$F_{(VH)}$	Org	IPM	$F_{(N)}$	$F_{(MH)}$	$F_{(H)}$
Mean	5.32	3.68	4.25	3.83	4.59	4.27	3.63	4.29	4.85	4.76	3.69	3.82	4.56
Anti-oxidants (% antioxidant activity)													
Mean	94	99	89.1	90.5	99.2	92.3	85.7	82.1	94.7	94.3	90.4	91.6	89.6
Flavonoids (mg RE/g)													
Mean	1.66	1.02	1.36	1.23	1.56	1.23	1.20	0.86	2.03	1.58	1.18	1.19	0.83

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and organic field (510.7 q/ha) in the present study is supported by Gajanana *et al.* (2006) who reported that adoption of IPM technology increased tomato yields on IPM farms by 46 per cent. Contamination of tomato fruits and crop soil samples of conventional farmers' fields with pesticide residues during the first two years of study are in agreement with Zawiyah *et al.* (2007) who reported pesticide residues in tomato and chilli to be 30.00 and 23.3 per cent which is due to the overuse of pesticides in the farmers' fields. The findings are also in line with Miranda *et al.* (2005) who stated that insecticide overuse might reduce natural enemy populations and damage human health, either by contaminating tomato fruits, or water and soil.

Soil enzymatic activity is the indicator of microbial biomass, soil quality, fertility and productivity and enzymes are secreted by floral and faunal organisms, but most often by microorganisms (Winding *et al.,* 2005). The present findings are also supported by the observations of Kumari and Charya (2004) who found a significant positive correlation between soil enzyme activities and microbial population in organic fields. Tiwari *et al.* (2019) also reported significantly greater activities of enzymes *viz*. dehydrogenase, urease and acid phosphatase in organic fields. Fungicide contamination of the soil significantly inhibited the activity of dehydrogenases and urease (Jastrzebska and Kucharski, 2007).

Uthairatanakij *et al.* (2017) stated that tomatoes are a good source of antioxidants, carotenoids, phenolics and phytochemicals. Barron (2010) observed high levels of vitamin C and antioxidant activity in tomatoes grown under organic field conditions. In present studies also, high levels of organic supplements added to the organic fields put a positive influence on the activity of flavonoids and antioxidants in tomato fruits, collected from organic field conditions. Verma *et al.* (2015) reported high level of antioxidant activity in tomatoes under organic conditions as compared to tomato fruits from conventional fields. Rocchetti *et al.* (2022) reported higher flavonoid content of 0.95 mg/g of dry weight from tomatoes grown under organic conditions as compared to 0.74 mg/g of dry weight in tomatoes collected from the conventional fields. Chaudhary *et al.* (2018) recorded high content of flavonoids such as quercetin, rutin, kaempferol and naringenin in tomatoes under organic fields.

The study concluded that different crop management systems i.e. organic farming, farming following GAP with IPM adoption and conventional farming, do affect the population of different insect-pests and their natural enemies. From all abiotic factors, maximum and minimum temperature had much greater impact on the population dynamics of insect pests and amongst biotic factors, organic conditions followed by IPM, greatly influenced the population of natural enemies (spiders). Data on seasonal incidence of insect pests will assist in preparation of a proper schedule for effective management of these pests. From all aspects, IPM model showed promising results and was the most potential module (economical) for management of major insect-pests in addition to additional benefits of higher yields and minimal pesticide residues. Agriculture faces many challenges that require an understanding of the systemic nature of the problems, rather than simply responding to symptoms. Both the organic and IPM approaches can work together to tackle these challenges and develop increased adoption of solutions.

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Authors' contribution

Conceptualization and designing of the research work (KSS, DS); Execution of field and laboratory experiments and data collection (RK, SK); Analysis of data and interpretation, Preparation of manuscript (KSS, DS, RK, SK).

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