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A review on the seasonal succession and management of key insect pests infesting tomatoes

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Abstract: Tomatoes have become one of the most significant and profitable vegetable crops farmed for the fresh market and processing in tropical and subtropical parts of the globe and they are an important element of human nutrition. Tomatoes, like other vegetables, are more susceptible to insect pests and illnesses than other crops, owing to their sensitivity and softness. Insect pests are among the many causes that cause low tomato yields including the fruit borer, jassid, white fly, aphid and leaf miner. On the other hand, enough understanding about the seasonal abundance of insect pests is required for the formulation and implementation of an appropriate, effective, and timely pest management approach. The current demand focuses not only on the use of various eco-friendly chemical groups, but also the employment of unique modes of action to provide sufficient control of insect pest populations. So, this work reviews and presents a pool of research on the seasonal succession and management of key insect pests of tomatoes.

Keywords: vegetable; seasonal abundance; effective; chemical

The tomato (*Solanum esculentum* Miller) crop is one of the most significant commercial vegetable crops farmed across the world, ranking third in terms of area and output among vegetables (Sharma 2004). It is regarded as a significant commercial and dietary vegetable crop. It is high in vitamins A, B and C as well as potassium, iron, and phosphorus. It is also a strong source of lycopene (Khanam et al. 2003). Because it is utilised in salads, various culinary preparations, juices, or processed into purees, concentrates, condiments and sauces, it is widely employed in the Indian culinary culture (Razdan, Mattoo 2007). The United States of America, Mexico, Spain, Brazil, China, Egypt, India, Iran, Italy, and Turkey are among the major tomato-growing countries. Over an area of 809 000 ha, India produces roughly 19 697 (000'MT) of goods (Anonymous 2017). A total production of 177 mil. tonnes of tomatoes was recorded in the year 2016 while India ranks second with a total production of 18.4 mil. tonnes. The area under tomato cultivation in India was estimated to be 789 000 ha in 2017–2018, with a production and productivity of 19.7 million tonnes and 25.0 t/ha, respectively (NHB 2018). West Bengal, Karnataka, Maharashtra, Uttar Pradesh, Haryana, Odisha, Andhra Pradesh, Madhya Pradesh, and Bihar are the top tomato-producing states. Tomatoes are grown in Haryana over an area of 29.03 thousand ha with a yield of 675.38 (000'MT) (Anonymous 2017). Over a hundred species insect pests have been identified that affect tomato crops across the world. Insects not only degrade the quality and amount of food, but they also serve as disease vectors (Dharumarajan et al. 2009). The major insect pests of tomato crop in

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India are the tomato fruit borer (*Helicoverpa armigera*), jassid (*Amrasca biguttula biguttula*), white fly (*Bemisia tabaci),* mite (*Tetranychus urticae*), aphid (*Aphis gossypii*), leaf miner (*Liriomyza trifolii*) and tobacco caterpillar (*Spodoptera litura*) (Lal et al. 2008). In addition to providing hazards to humans, the soil and the environment, the use of conventional pesticides has produced a dramatic fall in the population of natural enemies as well as increasing the threats, such as insecticide resistance, pest revival, secondary pest breakout, and so on (Kumar, Sarada 2015). As a result, the careful use of safer and more effective pesticides in the management of these pests that leave less residue and pose less of a hazard to the environment is required. To manage insect pests, new molecular structures with unique modes of action have recently been created. As a result, in order to improve management, it is required to determine the efficacy of these sprayed pesticides. It is also possible to build forecasting modes for them with the assistance of their population dynamics and their link to the weather conditions so that the management action can be made on time. The current review paper has been written with all these considerations in mind.

POPULATION DYNAMICS OF MAJOR INSECT PESTS INFESTING TOMATOES

Tomato fruit borer, *H. armigera*

For the timely prevention of sudden epidemic outbreaks and for devising and applying appropriate pest management strategies, the constant monitoring of all the major pests in the field is required. The peak activity of the fruit borer varies in different areas, although it normally occurs between March and June (Hath, Das 2004; Pathania et al. 2009; Kurl, Kumar 2010; Safna et al. 2018b). *H. armigera* was originally recorded on the 35th SMW (Standard Meteorological Week), according to Kamble et al. (2005). The larval population peaked on the 37th SMW, after which it began to decline until the 44th SMW, but according to Kurl, Kumar (2010), the larval population recorded on tomato crops in the second standard week of January and lasted until the 21st standard week, with a peak larval population build-up seen in the 15th standard week. Chakraborty et al. (2012), from their trial, concluded that the infestation started from the 9th SMW to the 17th SMW and the highest occurrence of the insects at the fruiting stage, causing most of the fruit damage. Kumar et al. (2013) examined the highest moth population during blooming, resulting in 40–60% tomato fruit losses. The initial appearance occurred in the 9th standard meteorological week (SMW) period which was in March and the peak population occurred in the 16th SMW with a max.–min. temperature (35.0 to 18.2 °C), morning-evening relative humidity (72 to 30%), rainfall, sunshine (10 hours/day) and wind (8.9 km/h), which was in April as per Bisht (2014), while Meena and Bajwa (2014), from their research, revealed that the larval population peaked during the first week of February. According to Selvaraj and Bisht (2014), the pest first appeared in the 7th and 9th SMW, *i.e.,* (February and March), and reached a peak population in the 16th and 15th SMW, *i.e.,* (April) recording a temperature of 35 to 18.2 °C, relative humidity of 72 to 30%, the sunshine of 10 hours with no rainfall. The initial emergence of the tomato fruit borer (0.98 larvae/plant) was observed by Kumar and Kharia (2015) during the 11th SMW, with the highest infestation (3.79 larvae/plant) occurring during the 16th SMW. Faqiri and Kumar (2016) stated, from the trial, that the occurrence of the insect started from the first week of October until the middle of November. Mandloi et al. (2015), from the experiment, noted that the insects remain active from the 48th to 12th SW (November–March) with a peak infestation occurring during the 12th SMW, and recorded a max. (33.4 °C) and min. (16.2 °C) temperature, morning (77%) and evening (28%) relative humidity, and no rainfall. In the Northern Plains of India, Singh and Gupta (2017), from their investigation, discovered that the first fruit infestation occurred in November, with a downward tendency occurring over the months of December and January. According to Chula et al. (2017), the fruit borer infection began in the 8th standard week (February third week) and peaked in the 13th standard week (48.14%) (March second week) when the temperature and relative humidity varies from 34.14–18.37 °C and 91.14–44.14%, respectively, with 1.20 mm of rainfall and 10.32 hours of sunshine per day. However, Deb and Bharpoda (2017), from their experiment, recorded three peaks in the 47th SMW (3rd week of November), 50th SMW and 51st SMW (December). As per Singh and Gupta (2017), the fruit infestation initiation was noted during the time period of the 46th–47th standard weeks and there was a gradual increase reaching a max. larval population of 11.93

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and 14.78% fruit damage during the 10th and 11th SMW. Sapkal et al. (2018) recorded that the larval population of *H. armigera* began to grow during the 35th SMW (0.5 larvae/plant), increased to 2.8 larvae/plant in the 47th SMW, and peaked at 4.2 larvae per plant during the crop's fruiting stage. Vikram et al. (2018) noted that first appearance of *H. armigera* started in the 8th standard meteorological week (third week of February) and reached its peak level (6.0 larvae per plant) in the 12th standard meteorological week (third week of March) and recorded a temperature (34.31 to 16.45 °C), a relative humidity (87.57 to 45.71%) and no rainfall, but Harshita et al. (2018) recorded that the peak infestation was during March with a larval population of 6.06 and 6.30 larvae per plant. Safna et al. (2018 b) recorded the initiation of pests in the first week of January with a peak larval population during the 11th SMW (March) with a temperature from 32.02 to 14.91 °C, a relative humidity of 68.28 (morning) and 66.29 (evening). Bhanuparkash et al. (2019) found that the occurrence of *H. armigera* started from the 6th standard week (February) and reached peak level in the 12th standard week (March) with a larval population of 5.98 larvae per plant when the temperature ranges from 34.4 °C (max) to 16 °C (min) and a relative humidity of 88% (morning) and 47% (evening), while Mondal et al. (2019) observed the tomato fruit borer population from the 7th standard week to the 15th standard week having weather parameters, such as the temperature in the range of 36.07 to 18.11 °C, a relative humidity of 49 % and no rainfall. Kachave et al. (2020) recorded the incidence occurence from the 32nd SMW with a larval population of 0.5 larvae/plant to the 47th SMW (1.5 larvae/ plant) and a peak in the 41st SMW with a max. number of 3.7 larvae/plant with a max. temperature of 36 °C, morning relative humidity of 64%, rainfall of 6.5 mm, and 7.5 hours of sunshine per day, while Gandhi et al. (2020) noted the incidence of the fruit borer during the 14th SMW (April) with a total population of 0.21 larvae/plant and attained a max. population during the 18th SMW (April) when the max. (28.1 °C) and min. (15.4 °C) temperature, morning (51.6%) and evening (33.7%) relative humidity, and rainfall of 9.2 mm were recorded. Wade et al. (2020) first observed the larvae of the fruit borer in the tomato crop during the 5th SMW with the larval peak in the 13th SMW having a 43.13% fruit infestation. According to Singh et al. (2021), in 52th standard week, the initiation of the infestation was recorded and the highest fruit damage occurred during the 14th standard week with a mean larval population of 2.88 larvae/plant having a min–max. temperature, relative morning-evening humidity, and sunshine of 36.70 to 16.70 °C, 69.20 to 34.70% and 10.2 hours per day, respectively.

Aphid, *A. gossypii*

Kumar (2008) found the aphid emergence in January, whereas Hath and Das (2004) and Chakraborty (2011) recorded the highest aphid population on tomatoes in March. Chakraborty (2011) reported the incidence of the *A. gossypii* population on tomato crops started emerging at a temperature (26.81–13.34 °C), relative humidity (96.01–48.41%), with 8.51 hours of sunshine and 1.42 mm of rainfall, lasting until the 11th SMW. The aphid population started to show after transplanting with 1.35 aphids/leaf and reached its max. level (7.31 aphids/leaf) at the 11th SMW as per Chavan et al. (2013), whereas Shakeel et al. (2014) concluded that higher aphid population emerged during the third week of February when the max.–min. temperature (27.83–18.33 °C), relative morning-evening humidity (92.39–47.85%), and rainfall ranged from 0–63.4 mm. The aphid infestation documented by Mandloi et al. (2015) noted the incidence from October to March, with a peak activity in February and March with a max. temperature of 31.60 °C, a min. temperature of 14.70 °C, 84% morning and 39% evening relative humidity with no rainy days. According to Ghosh (2017), the aphid infestation was observed from the last week of July to the second week of August (18th to 22nd SMW), with a population of 0.19 to 0.50 aphids per leaf. Deb and Bharpoda (2017) noticed the aphid population from the 42nd SMW with the highest population in the 52nd SMW while Ghosh (2017) demonstrated a high population (0.62–2.69 aphids/leaf) during the 41st standard week (2nd week of October) to the 51st standard week (3rd week of December) along with two more peaks in the 6th SMW (2nd week February) to 17th SMW (4th week of April). According to Mondal et al. (2019), the aphid infestation started in the 2nd week of January along with a peak population of 9.58 aphids/leaf/plant during the 4th week of February having a temperature in the range of 30.17 to 18.14 °C, a relative humidity of 73.71% and a rainfall of 0.91 mm and disappeared from the field at the end of March. However, the results of Pavan et al. (2019) revealed that the aphid incidence commenced from the 48th standard week with a pop-

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ulation of 2.50 aphids/3 leaves followed by max. population during the 7th standard week having a population of 12.19 aphids/3 leaves (top, middle and bottom leaves) and reported a temperature of 21.9 °C, relative humidity of 66.83%, and sunshine of 5.6 hours per day. As per Wade et al. 2020, the period of activity of *A. gossypii* was recorded from the 2nd SMW (8th of January) to the 16th SMW (23rd of March) with a peak population of 4.53 aphids/three leaves in the 7th SMW. The population of aphids was recorded from the 29th SMW to 47nd SMW, *i.e.,* the 18th of July to the 25th of November with a peak in the 41st SMW with a temperature range from 36.0 to 17.2 °C, relative humidity of 64 to 16%, rainfall of 6.5 mm and sunshine of 7.35 h/day having a population of 8 aphids/3 leaves, as per Kachave et al. (2020). However, Khokhar and Rolania (2021) stated, from their experiment, that the incidence of aphids started during the 9th SMW having a peak population of 22.65 aphids/three leaves/plant during the 12th SMW when the temperature was 30.93 °C (max.)–13.05 °C (min.), with a relative humidity of 86 to 37.86%, no rainy days and sunshine of 7.95 hours per day.

Leaf miner, *L. trifolii*

The onset of the leaf minor differed with the region, with the peak activity generally occurring in February and March (Reddy, Kumar 2004; Kharpuse 2005; Kumar 2008). Saradhi and Patnaik (2004) found that the *L. trifolii* incidence on tomatoes was highest between the second and third weeks of February while a higher occurrence of the leaf miner on tomatoes was recorded from late March to early May by Chaudhuri and Senapati (2004). According to Hemalatha and Maheswari (2004), leaf miners initially emerged on tomatoes in the first week of July (27th standard week), with peaks in the population in the first weeks of October and January (40th and 1st standard weeks). Reddy and Kumar (2005) investigated the seasonal abundance of *L. trifolii* on tomatoes and they found that the incidence of *L. trifolii* was highest in March–April, when the crop was in its vegetative and reproductive phases, while Chakraborty (2011) investigated the availability and the incidence of leaf miners and found that the infestation began in the 46th SMW and peaked at the 8th SMW. Variya and Bhut (2014), on the other hand, reported a leaf miner peak infestation of 10.26 mines/leaf in the third week of January. From the investigation of Sharma et al. (2014), it was concluded that the pest initially appeared in the 14th standard week (1.10 miners/plant). The population peaked during the 22nd standard week (7.80 miners/plant). The leaf miner incidence was also reported by Mandloi et al. (2015) from October to March, with the peak activity occurring around the 10th, 11th and 12th SMWs having a temperature, relative humidity, and rainfall of 31.6- 14.7 °C, 84 to 39% and 2 mm, respectively. Selvaraj et al. (2016) investigated into the population dynamics of the tomato leaf miner and found that the first signs of the pest appeared in the 8th and 9th SMW, *i.e.,* (February and March), and the population peaked in the 14th and 17th SMW, *i.e.,* (April). Throat et al. (2017) recorded that the leaf damage from the leaf miner peaked during the 11th SMW with damage of 11.03%/plant whereas the minimum leaf damage was reported during the 1st SMW, *i.e.*, 0.03%/plant. A correlation study shows that the population of the leaf miner positively correlated with the minimum temperature and sunshine hours and negatively correlated with the rest of the factors. However, according to Singh et al. (2018), the presence of the tomato leaf miner began on January 16th, with 1.05 live miners per leaf. The pest's activity peaked during the fruiting stage, with 31.25 mines per leaf. Wade et al. (2020) reported that *L. trifolii* first appeared during the 2nd SMW on tomato plants and the max. leaf miner infestation was recorded in the 12th SMW. Khaliq and Shankar (2020), from their experiment, found that the pest incidence commenced from the 10th to 26th standard week and attained the max. population during the 15th standard week and recorded a temperature of 32.5–14.1 °C, relative humidity of 74–34.5%, rainfall of 1.9 mm, and sunshine of 8.45 hours per day, while Dibbad et al. (2020) noted the *L. trifolii* incidence started from the 5th SMW and reached the highest population of 4.70 live mines/ leaf during the 16th SMW with an average temperature of 28.46 °C and average relative humidity of 70.84%. As per Ravipati et al. (2020), the incidence of leaf miners was first observed during the 44th standard week and attained a peak during the 1st SMW and the correlation studies showed that the population of the leaf miner exhibited a negative correlation with the temperature, evening relative humidity and rainfall.

Whitefly, *B. tabaci*

According to an experiment performed by Sarangdevot et al. (2010), the incidence of *B. tabaci* was first noticed in the 14th standard meteorological week and peaked in the 22nd standard meteorologi-

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cal week. Jha and Kumar (2017) also investigated the population dynamics of the whitefly and found that the whitefly population counts began 30 days after transplanting. The max. population of the whitefly (42.4/three leaves) was reported on the 70th day after transplantation having a temperature of 23.50–10.40 °C, relative humidity of 95–74%, and sunshine of 3.30 hours per day. As per Sharma et al. (2017), the peak population of the whitefly on tomatoes was attained during the 21st standard meteorological week and the correlation studies showed that the whitefly population was positively correlated with the temperature and sunshine, while a negative correlation was observed with the humidity and rainfall. Subba et al. (2017) concluded, from a trail, that the peak level was found during the 11th to 18th standard week with the highest population of (0.47/leaf) recorded at a temperature of 28.80–27.42 °C, a relative humidity of 92.46 to 75.59% and rainfall of 8.80 to 240.00 mm, whereas Deb and Bharpoda (2017) recorded that the incidence started from the 39th SMW (4th week of September) and the population represented peaks during the 45th SMW (1st week of November) with a population of 2.72 whiteflies/3 compound leaves and 48th SMW (4th week of November). Wade et al. (2020), from the research, revealed that the whitefly was first noted during the 2nd SMW on tomatoes along with a peak population level of 7.83 whiteflies per three leaves during the 16th SMW, while, according to Kachave et al. (2020), the whitefly population commenced from the 31st SMW to the 47th SMW (30th of July to 22th of November) and recorded a maximum and minimum temperature of 34.4 and 18.00 °C, morning and evening relative humidity of 74% and 27%, 6 mm of rainfall and 7.4 hours of sunshine. Mondal et al. (2019), from their investigation, found that the incidence of whiteflies initiated in the first week of February with a peak population during the 2nd week of March with 6.21 whiteflies/leaf/plant having a temperature of 33.96 to 21.21 °C, a relative humidity of 68.43% and a rainfall of 0.10 mm.

EFFICACY OF NEW INSECTICIDES FOR MANAGEMENT OF KEY PESTS ON TOMATOES

H. armigera

The efficacy of several pesticide compounds, such as acephate, fenvalerate, permethrin deltamethrin, cypermethrin, and acephate, have previously been studied in several studies (Mehta et al. 2000). Murugaraj et al. (2006) discovered that emamectin benzoate and emamectin are highly effective against the *H. armigera* larval population with an increased yield. Spraying with indoxacarb produced considerable control of the fruit borer with minimal fruit loss, according to Shivalingaswamy et al. (2008), while Kuttalam et al. (2008) found that flubendiamide 480 SC at 48 g a.i./ha had considerable field effectiveness against *H. armigera*, reducing the larval population and fruit damage. As per Kumar and Shivaraju (2009), beta cyfluthrin 9% + imidacloprid 21% 300 OD at 18+42 g a.i./ha was the most potent in controlling the larval population of *H. armigera* (75.95%), accompanied by monocrotophos 36 SL at 450 g a.i./ha, beta cyfluthrin 2.5 SC at 18 g a.i./ha. Ghosh et al. (2010) found that spinosad 45% SC @ 73 and 84 g a.i./ha was effective against *H. armigera* with the least amount of tomato fruit loss. Mandal (2012) found that a novel insecticide, cyazypyr 10% OD (anthranilic diamide group) at 90 and 105 g a.i./ha, had great effectiveness against *H. armigera* and increased the yield of the marketable fruits. Kumar (2013) investigated several pesticide treatments and discovered that profenophos 50 EC at 1 000 g a.i./ha, emamectin benzoate 5 SG at 22 g a.i./ha, and bifenthrin at 100 g a.i./ha decreased the fruit borer populations and reduced the fruit damage by a factor of 100. Babu and Singh (2015) demonstrated the efficiency of chlorantraniliprole 18.5 SC in the management of *H. amigera* when compared to other compounds. Mourya et al. (2015) found that spinosad and imidacloprid were the most and least effective insecticides against the tomato fruit borer, respectively. Among nine novel insecticides investigated by Abbas et al. (2015) treatment with chlorantranliprole + thiamethoxam and spinetoram resulted in max. mortalitity of 89.36 and 85.09%, respectively against *H. armigera*. According to Jat (2016), the novel insecticide propargite 50% + bifenthrin 5% SE at 621 + 62.1 a.i./ha was found to be the most effective against the fruit borer. Chlorantraniliprole + thiamethaxim and spintoram were found to have the highest percent mortality 89.36% and 85.09%, respectively. Patel et al. (2016) found that chlorantraniliprole 35 WG at 30 g a.i./ha efficiently reduced the larval population of *H. armigera* and caused the least amount of fruit damage when compared to conventional controls. Kooner et al. (2016) found that treatment with chlorantraniliprole

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18.5 SC at 175 mL/ha resulted in the lowest fruit infestation and mean number of larvae per plant (0.25 larvae per plant and 14.17% fruit damage), followed by treatment with chlorantraniliprole 18.5 SC at 150 mL/ha (0.28 larvae/ plant & 17.25% fruit damage). According to Faqiri and Kumar (2016), the lowest incidence of the fruit borer in different treatments was recorded with profenophos 50% EC, spinosad 45% SC, deltamethrin 2.8% EC, and chlorantraniliprole 18.5% SC. Indoxacarb at 500 mL/ha and spinosad at 150 mL/ha were determined to be the most efficient insecticides for the treatment of *H. armigera* on tomatoes by Chandi and Suri (2016). The highest yield was recorded in chlorantraniliprole 18.5 SC at 175 mL/ha (978.5 q/ha) followed by 830 q/ha in chlorantraniliprole at 150 mL/ha, according to Kooner et al. (2016). Mahla et al. (2017) found that using tetraniliprole SC 200 (w/v) at 300 mL/ha on a treated plot resulted in a significant reduction in the insect population and little fruit loss. According to Singh et al. (2017), indoxacarb 14.5 SC (0.01%) was the most effective and yielded the most fruit, followed by novaluron 10 EC (0.01%) and acephate 75 SP (0.037%). Rajmal et al. (2017), from the research, found that, between the different mixtures and individual chemicals, after the first spray, propargite + bifenthrin 50% + 5% SE with a dose of 594 + 59.4 g a.i./ha was noted of having the min. percent fruit damage (9.63%) and max. reduction in the fruit borer population (69.26%). Satish et al. (2018) discovered that consecutive sprays of chemicals of indoxacarb 14.5 SC with a dose 0.5 mL/L and fipronil 5 SC having a dose of 1.0 mL/L were found to be highly efficient in decreasing the larval population of *H. armigera*. Sandeep and Arunava (2018) among various treatments, *viz*, indoxacarb 14.5 SC (75 and 150 g a.i./ha), pyridalyl 10 EC (75 and 150 g a.i./ha), chlorpyriphos 20 EC (350 g a.i./ha) and chlorfenapyr 10 SC (100 and 200 g a.i./ha), the min. larval population of *H. armigera* of 1.05 larvae/5 plants was noted in the treatment with pyridalyl at 150 g a.i./ha which reduced the damage up to the extent of 84.19%. According to Safna et al. (2018a), chlorantraniliprole 18.5 SC at 0.005% was the best with the least amount of fruit infestation (13.82%), followed by spinosad (17.39%), indoxacarb 14.5 SC at 0.012% (21.64%) and lambda cyhalothrin 5 EC 0.0025% (23.50%). Swodesh and Bhishma (2019) investigated several chemicals and discovered that flubendiamide 40SC at 0.21 mL/L and emamectin benzoate were both efficient against the tomato fruit borer. Kharia et al. (2019), among different tested chemicals, found that decamethrin, novaluron 10 EC, and spinosad 45 SC to be effective in spray planning against the tomato fruit borer. Rasheed et al. (2019), found that the lowest mean of the larval population trends in ascending order was observed in the experimental plots treated with spinetoram followed by emamectin benzoate, cypermethrin and emamectin. As per Hivare et al. (2019), treatment with chlorantraniliprole 18.5% SC recorded the minimum larval population of *H. armigera, i.e.,* 0.59 larvae/plant followed by a larval population of 0.73 larvae/plant in treatment with Indoxacarb 14.5% SC and flubendiamide 39.35% SC having a larval population of 0.80 larvae/plant while Patel et al. (2019) observed that treatment with flubendiamide 20% WDG at 2.5 mL and chlorantraniliprole 8.5% SC at 3.0 ml recorded the min. infestation of the fruit borer. According to Bhanuparkash et al. (2019), plots treated with spinosad 45% SC exhibited a minimum percent fruit infestation of 7.37%, indoxcarb 14.5% SC and chlorpyrifos 20 EC had a percent fruit infestation of 12.54% and 13.76%, respectively. Kumar et al. (2020), from their research, concluded that indoxacarb 14.5 SC recorded highest percent reduction in the fruit infestation to 85.04% over the control and was highly efficient in the management of *H. armigera* followed by fipronil 5 SC, which exhibited an 81.78% reduction in the fruit infestation over control, while Reddy et al. (2021) also found indoxacarb 14.5 SC (65.66%) very effective against *H. armigera* further followed by spinosad 45% SC with a 63.85% fruit infestation reduction over the control.

Leaf miner

Several pesticides had previously demonstrated effectiveness in controlling the leaf minor in tomato fields. Chaudhuri and Senapati (2001) found that avermectin at 0.01% a.i/ha. was the most effective against the tomato pest complex. Ramesh and Ukey (2007) found abamectin 0.002% to be the most effective (13.61 & 16.50%, respectively) at five and seven days after spraying (DAS) followed by cypermethrin 0.01%. However, diafenthiuron 0.05%, emamectin 0.025%, thiamethoxam 0.0125%, and spinosad 0.015% were found to be effective against *L. trifolii* by Variya and Patel (2012). Selvaraj (2013) found that 30 g a.i./ha of chlorantraniliprole 4.3% + abamectin 1.7% SC reduced the population of the leaf miner. Profenophos 40% + cypermethrin

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4% was determined to be the most efficient against *L. trifolii* on tomatoes by Deepak et al. (2013) among eight tested pesticides. Gosalwad et al. (2015) found imidacloprid 17.8 SL at 20 g a.i/ha to be the most effective against the leaf miner, followed by acetamiprid 20 SP at 15 g a.i/ha. Gosalwad et al. (2015) also found that spraying emamectin benzoate 5 SG at 9.5 g a.i./ha 65 days after transplanting had the best effectiveness against the leaf miner, followed by spinosad 45 SC at 75 g a.i./ha and chlorpyriphos 20 EC at 525 g a.i./ha. Tarate et al. (2016) found that emamectin benzoate 5 SG at 9.5 g a.i/ha was the most effective against the tomato leaf miner followed by spinosad 45 SC at 75 g a.i/ha and lambda cyhalothrin 5 EC at 50 g a.i./ha. Rajmal (2016) also compared the efficacy of different newer insecticide molecules for the management of the leaf miner and found that cyantraniliprole 10% OD at 105 g a.i./ha (3.83 live mines/plant) was superior to the rest of the treatments, followed by spinosad 45 SC at 56 g a.i. ha^{-1} (5.80 live mines/plant), imidacloprid 17.8 SL at 22.5 a.i./ha (6.88 live mines/plant). Selvraj et al. (2017) found the combination of insecticide chlorantraniliprole 4.3% + abamectin 1.7% SC was highly effective for the management against the incidence of *L. trifoli*. In an effectiveness trial, Mohan and Anitha (2017) discovered that chlorantraniliprole 18.5 SC 0.03% at a 10-day gap was the best therapy for minimizing the leaf damage (percentage), numbers of mines/plant, and number of larvae per plant. Abamectin was the most successful therapy in suppressing the *L. trifolii* population, according to Rai et al. (2017) and Desai et al. (2018). Kotak et al. (2020) found that among the eight tested treatments, chlorantraniliprole 18.5 SC, deltamethrin + triazophos 36 EC, emamectin benzoate 5 SG, thiodicarb 75 WP, diafenthiuron 50 WP dimethoate 30 EC, and control profenofos + cypermethrin 44 EC (0.044%) were more effective in controlling the leaf miner. According to Ravipati et al. (2021), diafenthiuron 50WP decreased it to 40.6%, while spinosad 45 SC was the most effective, reducing it by 58.76 and 54.38%, accordingly. Lalruatsangi et al. (2018) revealed, from the conducted field trails, that the cypermethrin (17.83%) recorded the lowest leaf infestation by the leaf miner, but Kotak et al. (2020) found that, for the management of the leaf miner, the treatment with profenofos + cypermethrin 44 EC (0.044%) was highly efficient. Kousika and Kuttalam (2020) stated that tetraniliprole 200 SC with a dose of 60 and 50 g a.i./ha were significantly effective in minimising the incidence of serpentine leaf miner while Ravipati et al. (2021), among various tested insecticides for efficacy against *L. trifolii*, the treatment with diafenthiuron 50 WP proved highly efficient by reducing damage up to 58.76% followed by spinosad 45 SC with the damage reduction of 54.38% over the control. Solanki et al. (2021), from the trail, concluded that there was a 93% reduction in the population of *L. trifolii* in the plot treated with chlorfenapyr 240 SC with a dose of 480 mL/ha as compared to the plots treated with cynantraniliprole 10.26% OD at 100 ml/ha and dimethoate 30% EC at 150 gm/ha exhibited an 89.70% and 88.43% reduction, respectively.

Whiteflies and aphids

Nicotinoid insecticides, such as thiamethoxam, imidacloprid, and dinotefuran, have been shown to be effective against phloem-feeding insects and can significantly lower whitefly populations in tomato plants (Ahmed et al. 2001). Dimethoate 30 EC (0.03%), imidacloprid 17.8 SL (0.005%), thiamethoxam 25 WG (0.025%), lambda-cyhalothrin 5 EC (0.005%), novaluron 10 EC (0.02%) and fenthion were also effective in controlling whiteflies on tomatoes, according to several researchers (Gupta et al. 2007; Idris and Mandal 2014). It was also discovered that imidacloprid functioned fast and greatly decreased whitefly populations in tomato fields (Thorat et al. 2020; Das, Islam 2014). According to Gosalwad et al. (2015), the most effective whitefly control was induced by imidacloprid 17.8 SL at 20 g a.i./ha, followed by acetamiprid 20 SP. Mandal (2012) also found that cyazypyr 10% OD (anthranilic diamide group) was effective against *A. gossypii* and *B. tabaci* at 90 and 105 g a.i./ha. Imidacloprid 17.8 SL + spinosad 45 SC was shown to be the most successful in managing tomato aphids with the most marketable fruit production and economic returns, according to Sandeep and Subash (2013). Mourya et al. (2015) investigated the efficacy of several pesticides, including imidacloprid, fipronil, profenofos, indoxacarb, novaluron, and spinosad, in suppressing the whitefly and leaf hopper in tomatoes and discovered that imidacloprid and fipronil were the most effective. Sharma et al. (2017) found that seed treatment with imidacloprid followed by the soil application of carbofuran and imidacloprid spray was highly effective in descending order with treatments of imidacloprid (seed treatment) + imidacloprid (spray) > imidacloprid (seed treatment)

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+ thiamethoxam (spray) > imidacloprid (seed treatment) + dimetheoate against the whitefly. According to Bambhaniya et al. (2018), three sprays of flonicamid at 0.015%, imidacloprid at 0.005%, clothianidin at 0.025%, and dimethoate at 0.03% were shown to be successful in regulating aphid populations in tomato fields. Sharma and Kumar (2020) found that thiamethoxam 25 WG at 0.008% and spiromesifen 22.9 SC at 0.028% were both effective in lowering whitefly populations. In their trial, Mohamed et al. (2020) found that abamectin and acetampride were the most significant whitefly treatments in the 2019 and 2020 seasons, respectively. Thorat et al. (2020) found out the lowest whitefly population in imidacloprid 17.8 SC at 0.005% (2.8 mL/10 L of water), which was followed by 2.22 adults/leaf in dimethoate 30 EC at 0.03% (10 mL/10 L of water). Sharma and Kumar et al. (2020) concluded that thiamethoxam 25 WG 0.008% remained the most effective treatment against aphids followed by dimethoate 30 EC 0.03%. Spiromesifen 22.9 SC 0.028% and indoxacarb 14.5 SC 0.005% were ranked the third and fourth effective treatments, respectively. As per Pavan et al. (2019), imidacloprid 30.5 SC at 160 mL/ha and flonicamid 50 WG at 300 g/ha were found to be the most efficient insecticides exhibiting a maximum population reduction of 88.73% and 88.71%, respectively, followed by treatment, with a descending order, of clothianidin 50 WDG at 500 g/ha > dimethoate 30 EC at 1 000 mL/ha > difenthiuron 50 WP at 1 000 g/ha > dinotefuran 20 SG at 500 g/ha (76.14%) and spinosad 45 SC at 100 mL/ha, while Kotak et al. (2020) found dimethoate 30 EC to be a promising insecticide for the management of the whitefly on tomatoes. Balikai (2020) noticed treatments having two sprays of spiromesifen 240 SC with a dose of 150, 120 and 90 g a.i./ha provided the highest protection of whiteflies over the control. There are a number of insecticides and combination of insecticides that are recommended by the Central Insecticide Board & Registration Committee (Tables 1 and 2).

Table 1. List of insecticides recommended against major insect pests of the tomato (CIB&RC)

Insecticide	Insecticide group	Target insect	Formulation	Dose (a.i./ha)	Water required (L/ha)
Carbofuran	Carbamate	whitefly	0.3% CG	1 200	500
Chlorantaniliprole	Diamide	fruit borer	18.50% SC	30	500
Cyantraniliprole	Diamide	leaf miner, aphid, whitefly, fruit borer	10.26% OD	90	500
Deltametri	Synthetic pyrethroids	fruit borer	11% EC	10–12.5	375–500
Diafenthiuron	Thiourea	whitefly	50% WP	300	500
Diamethoate	OP	aphid,whitefly	30% EC	300	500–1 000
Flubendiamide	Diamide	fruit borer	20% WG	50	500
Imidachloprid	Neonicotinoid	whitefly	17.80% SL	30–35	500
Indoxacarb	Oxadiazine	fruit borer	14.50% SC	60–75	300–600
Lambda cyhalothrin	Synthetic pyrethroids	fruit borer	5% EC	15	500
Malathion	OP	whitefly	50% EC	700	500–1 000
Novaluron	Insect growth regulators	fruit borer	10% EC	75	500–1 000
Oxydemeton methyl	OP	whitefly	25% EC	250	500–1 000
Phosalone	OP	fruit borer	35% EC	450	500–1 000
Quinalphos	OP	fruit borer	25% EC	250	500–1 000
Spiromesifen	Titronic acid derivative	whitefly	22.90% SC	150	500
Thiamethoxam	Neonicotinoid	aphid	25% WG	50	500

CG – encapsulated granules; SC – suspension concentrate; EC – emulsifiable concentrates; OD – oil dispersion; WP – wettable powder; SL – soluble liquid; WG – wettable granules; OP – organophosphate; CIB&RC – Central Insecticides Board & Registration Committee, India

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Table 2. List of a combination of insecticides recommended against major insect pests of the tomato (CIB &RC)

Name of insecticides	Target insect	Dose (a.i./ha)	Water required (L/ha)
Flubendiamide 7.5% +Kresoxim methyl 37.5% SC	fruit borer	667	500
Nvaluron 5.25% + indoxacarb 4.50% SC	fruit borer	825–875	500
Propargite 50% + bifenthrin 5% SF	whitefly and jassid	1 100–1 150	500
Thiamethoxam12.60% + lambdacyhalothrin 9.50% ZC	whitefly and fruit borer	125	500
Chlorantraniliprole 8.80% + thiamethoxam 17.50% SC	leaf miner, whitefly and fruit borer	500 (soil drenching)	50–100

CIB&RC – Central Insecticides Board & Registration Committee, India; SC – suspension concentrate; SF – soluble flowable; ZC – combined formulation of CS (capsule suspension) and SC (suspension concentrate)

CONCLUSION

For the development of an efficient management plan to avoid massive production losses and crop damage caused by the insect pest complex of tomatoes, it is necessary to understand the seasonal abundance of insect pests. The relevant literature mentioned studies and overviews presented in this study may assist the end users in the future in successfully implementing chemical controls for the key insect pests of tomatoes.

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