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Research Article

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Ecological dynamics and management of citrus psylla Diaphorina citri Kuwayama (Hemiptera: Psyllidae) under semi-arid conditions in India

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Abstract

Diaphorina citri Kuwayama (Hemiptera: Psyllidae) is a key citrus pest in India, and an important vector of Huanglongbing. This study characterized the seasonality and population dynamics of *D. citri* in Kinnow mandarin orchards in south-western Punjab in relation to weather variables and host phenology conducted between 2012-2018. Adults were present almost year-round, surviving winter in the adult stage within the canopy, while nymphs occurred primarily during two major flushing periods: early February to April and August–September, with the first flush supporting the highest populations. Population build-up peaked in the 13th standard meteorological week (56.36 ± 2.05 nymphs and 32.46 ± 2.49 adults per 10 cm twig). Optimal conditions for proliferation were maximum temperatures of 21.69-37.87 °C, minimum temperatures of 7.30–20.53 °C, and relative humidity of 63.90–92.66% (maximum) and 19.53–54.22% (minimum). A multiple-regression prediction model incorporating temperature, humidity, radiation and wind speed explained 67% of the variation in *D. citri* populations ($R^2 = 0.67$). Among citrus cultivars, lemon, sweet lime and Kinnow mandarin were the most preferred hosts, whereas Early Gold and Mosambi were moderately infested. Chemical control trials achieved 30.72-82.90% nymph reduction 14 days after treatment, with thiamethoxam (12.6%) + lambda-cyhalothrin (9.5%) most effective, followed by beta-cyfluthrin (8.49%) + imidacloprid (19.81%), flonicamid, thiamethoxam and imidacloprid. Biopesticides including *Beauveria bassiana* (1.15%, 1×10^8 CFU mL^{-1}), *Verticillium lecanii* (1.15%, 1×10^8 CFU mL^{-1}) and horticultural mineral oil provided 47.86–52.23% reduction while remaining relatively safe to natural predators. Overall, *D. citri* population dynamics were strongly shaped by climatic conditions and host phenology, and both newer insecticides and biopesticides offer effective management options compatible with natural enemy conservation.

Keywords: Citrus, kinnow mandarin, *Diaphorina citri,* abundance, population dynamics, Weather, Management, entomopathogenic fungi, HMO, insecticides.

1. Introduction:

Citrus is one of the important, high value fruit crops commercially cultivated in India, which is enjoyed globally for its stimulating scent, appealing taste and richness of vitamin-C. In 2023-24, the gross area and production under this crop was 1.126 million hectares and 14,553,000 MT, respectively (Anonymous, 2025b). In Punjab the agroclimatic conditions are well suited for citrus cultivation which was envisaged from the facts that the state has recorded an increase of 18.05 Per cent in area (46.29 thousand hectares in 2011-12 to 56.49 thousand hectares in 2023-24) and 31.73 Per cent in production (942.75 thousand MT in 2010-11 to 1380.87 thousand MT in 2023-24) from 2011 onwards (Anonymous, 2025a & 2025b). Under field conditions, the citrus plants are being attacked by different insect pests which influence the productive health of the plant. Globally 823 species of insect and mites was associated with citrus, of which, 165 species are important in India, causing an estimated yield loss of 30 per cent (Butani, 1979). Among different insect-pests, Asian citrus psylla, *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), is the most important and damaging pest of citrus worldwide (Sule et al., 2012; Rao and Pathak, 2001). It causes severe damage to citrus plants initially by direct feeding and sucking sap from new flush leading to plant decline while the other and most important is that it transmits bacteria (*Candidatus liberibacter asiaticus*) causing Huanglongbing (HLB) disease, which is the most serious and vulnerable disease of citrus (McClean & Schwartz 1970; Halbert and Manjunath, 2004; Bove 2006; Hall et al., 2013; Gottwald 2010).

Congregation of nymphs and adults of *D. citri* on tender shoots, buds, leaves, developing fruits results in massive quantitative and qualitative losses. Both nymphs and adults feed by sucking sap and severe infestation may lead to stunted growth, drying of tender parts and death of terminal portion (Halbert and Manjunath, 2004; Bove, 2006; Rogers et al., 2014). Besides this psyllid also secretes honey dew on the leaf surface, the accumulation of which promotes development of sooty mould, thus inhibiting the photosynthetic activity. This results in growth disruption, and the affected plant parts dry and wither away, leading to premature fruit drop and the decline of plant health (Shah and Saleem, 2000). The *D. citri* is regarded as the most notorious and devastating pest of citrus in India (Randhawa 1974; Hall et al., 2012; Chauhan & Srivastava 2018), causing severe losses (both in terms of fruit yield and tree health) to the tune of 83 - 95 percent and gained

prominence as a vector of citrus greening disease (Hall et al., 2012; Gravena 2005; Singh and Yadav 2018), particularly in Punjab, Haryana, Himachal Pradesh, Maharashtra states, however the pest is considered as minor in southern regions of the country (Bindra 1970; Randhawa & Srivastava1986). Development and oviposition of *D. citri* needs availability of new flush and young shoots with tender leaves and (Shahid and Khan 1976; Patel 2007; Grafton et al., 2013) initiation of flushing is greatly influenced by local weather conditions, variety and age of plants which ultimately influence the pest dynamics (Tsai and Liu, 2000). Therefore, portraying the patterns of seasonal activity of pests and their abundance forms basis for effective pest management (Pedigo 1999). Moreover, the development of different life stages of insects, their behavior and phenology were directly mediated by the prevailing temperature, which can be estimated by Degree-day accumulation (Cammell and Knight 1992, Nietschke et al. 2007, Jones et al. 2009 and Milosavljevic et al., 2018).

Insecticidal application is a major part of *D. citri* management in orchards. Repeated applications of synthetic insecticides, including neonicotinoids (e.g., imidacloprid, thiamethoxam, clothianidin) and insect growth regulators, are commonly used to control this pest (Boulahia et al., 1996; Shivankar et al., 2000; Qureshi & Stansly, 2007, 2008, 2010; Qureshi et al., 2009, 2010, 2011, 2012; Rogers, 2008; Rogers et al., 2012; Setamou et al., 2010; Tiwari et al., 2011). Repeated applications of these insecticides have led to many problems including insecticide resistance (Tiwari et al., 2011), negative impacts on natural enemies' populations (Grafton at al., 2013), and effects to human health. (Kuhns et al. 2016; Hussaina & Siddique, 2010). Therefore, it is imperative to develop eco-friendly alternatives and green chemistry-based insecticides to supplement existing insecticide-based management programs for phytophagous pests (Ismaan, 2000; Heinrichs, 1998; Tengerdy & Szakacs, 1998; Rausell et al., 2000). In concern to this we tried to determine the patterns of seasonal dynamics and phenology of citrus psyllids and the strategies for its management in orchards.

2. Materials and methods:

The study was performed at the experimental farm of the Punjab Agricultural University Regional Research Station, Abohar, which is located in the municipality of district Fazilka, Punjab, India (30°08'N; 74°12'E & altitude: 185.78 above mean sea level) during 2012-2018 (Fig. 1). The

location was characterized by hot and dry weather besides semi-arid climate. It receives 75-300 mm of annual rainfall occurring mostly during July to September. According to Koppen-Geiger system of classification, this type of climate has been symbolized as BWh. The study was conducted in 15-year-old kinnow mandarin orchard planted at a spacing of 6 x 6 metres. Cultural and nutritional management practices in the Kinnow orchard were maintained in accordance with the recommendations of Punjab Agricultural University, Ludhiana. (Anonymous 2012 & 2016). Daily meteorological observations of temperature, humidity, precipitation, etc. were recorded using an Automatic Weather Station (Model No. DCPAW502, BioScientific Limited, UK) installed at the experimental farm.

2.1 Dynamics of *Diaphorina citri* on kinnow mandarin:

Population dynamics of *D. citri* were studied in a 15-year-old Kinnow mandarin orchard maintained in accordance with the recommended practices of Punjab Agricultural University (Anonymous, 2012), except for pesticide sprays. No harsh pesticide sprays were applied against any insect pests during the season. For this study, fifteen Kinnow mandarin plants were selected and marked for taking observations. Data on *D. citri* adults and nymphs were recorded at weekly intervals from January 2012 to December 2018. Over the seven-year period, trees that showed severe decline or mortality were replaced with immediately adjacent trees of the same age and vigour to maintain a consistent sample size. The experimental block was otherwise maintained without any insecticide applications to allow for the natural fluctuation of the pest population. Samples were taken around the tree canopy, covering all four directions (one sample from each direction) of the tree, 1 - 2 m above ground. The number of *D. citri* adults was counted from 10 leaves from each direction of the plant, while *D. citri* nymphal counts were taken from 10 cm apical twigs from all directions. Mean numbers of nymphs and adults were calculated each week. The phenology of *D. citri* on Kinnow mandarin was depicted graphically by plotting mean numbers of nymphs and adult psylla per week over time. Air temperature data for each Standard Meteorological Week (SMW) were used to calculate weekly Growing Degree Days (GDD)/heating units for *D. citri* using a base temperature of 11°C. For each SMW, GDD was computed as:

$$Growing\ Degree\ Days\ = \frac{(T\ max + T\ min)}{2} - T\ base$$

Where: *T* max = daily maximum air temperature: *T* min = daily minimum air temperature; and T base = base temperature. The base temperature for the growth and development of *D. citri was taken as* 11°C as per Liu & Tsai (2000), Hall et al. (2008) and Grafton-Cardwell et al. (2013).

2.2 Infestation of *D. citri* in different citrus cultivars:

Nine plants (3 plants/ replication) of each cultivar were randomly selected, marked and tagged for taking insect observations. The sampling unit was a 10 cm apical twig (4 shoots/tree) randomly covering all the four directions *viz.,* East, South, West and North of the plant canopy (Ahuja et al., 2015). Thus, 36 terminal shoots were sampled per variety at weekly interval during February, March, August and September at weekly interval for their reaction to *D. citri* infestation during the years 2015 - 2017. The time chosen for screening the cultivars is based on major activity period of *D. citri*. The sampling involved visual *in situ* field estimation of *D. citri* nymphal counts. Also, to study the effect of major nutrient elements on the population build-up of *D. citri* the leaf samples from new flush were taken during April. Samples were prepared and analysed for N, P and K content as per the method standardised by Jackson (2005). Also, the phytochemical properties of these citrus cultivars *i.e.* total soluble sugars (Dudois et al., 1951; Nelson 1944; Malhotra and Sarkar, 1979), total phenols (Singleton and Rossi, 1965; Singleton et al., 1999; Chandler and Dodds, 1983) and flavonoids (Waage and Heddin, 1984) were worked out as per standard protocols.

2.3 Management of *D. citri*:

The experiment was carried out on 15-year-old Kinnow mandarin trees grafted on Rough Lemon (*C. jambhiri*) planted at 20 x 20 ft spacing. Experiment was conducted in RBD (Randomized Block Design) with three replications of each treatment. There were two experiments conducted during the month of March. There was a total of seventeen treatments with five trees in each replication. Spraying of trees was done using a 15-litre power operated knapsack sprayer (Mohindra GA-914) @ 5 litre of spray solution to each tree (Pathania et. al., 2019). In control treatment kinnow trees were sprayed with water only. Sampling was performed 1 day before spraying, and at 3, 7, 10 and 14 days after spraying. For sampling, 5 twigs of 10 cm length on each direction of the tree were randomly picked. The numbers of *D. citri* live nymphs on each twig were counted. Also, the effect of spray solutions on the activity of its predator's *viz*. coccinellids, *Chrysoperla carnea* and spiders was also recorded in terms of counts, one day before and 14 days after the spray. The corrected efficacy percentage was calculated as per Henderson and Tilton's (1955):

$$\text{Corrected Mortality \%} = \left(1 - \frac{\text{N in control before treatment} * \text{N in treatment after treatment}}{\text{N in control after treatment} * \text{N in treatment before treatment}}\right) \times 100$$

Where: N = number of nymphal populations

2.4 Chemical and biopesticides

Five commercial formulations of insecticides, three commercial formulations of entomopathogenic fungi, two botanicals and one mineral oil was accessed to control *D. citri* outbreak in kinnow mandarin. The different formulation used were flonicamid (Ulala 50 WG, United Phosphorus Limited), imidacloprid (Confidor 17.8% SL, Bayer Crop Science), thiamethoxam (Actara 25% WG, Bayer Crop Science), beta-cyfluthrin 8.49% + Imidacloprid 19.81% (Solomon, Bayer Crop Science), thiamethoxam 12.6% + lambdacyhalothrin 9.5% (Alika, Syngenta Crop Protection), *Verticillium lecanii* (Bio-Catch 1.15% WP, T Stanes & Company Limited), *Beauveria bassiana* (Bio-Power 1.15% WP, T Stanes & Company Limited), *Metarhizium anisopliae* (Bio-Magic 1.15% WP, T Stanes & Company Limited), Pongamia Soap (IIHR Natura Crop Care), Neem Soap (IIHR Natura Crop Care) and Horticulture Mineral Oil (MAK All Season HMO 89% EC, Bharat Petroleum Corporation Limited) were used. Based on preliminary trials, different concentrations of each pesticide were prepared with distilled water and sprayed on plants to study their efficacy against *D. citri*.

2.5 Statistical analysis

The pooled data over years were subjected to analysis of variance (ANOVA) and treatment means were separated using the critical difference at the 5% level. *D. citri* nymph counts were square-root transformed, and percentage data were arcsine square-root transformed prior to analysis to stabilize variance and better meet the assumptions of ANOVA. Data on leaf tissue nutrient contents of different cultivars was subjected to analysis of variances (ANOVA). Pearson's correlation coefficients were calculated to describe relationships between *D. citri* populations, abiotic variables and host-plant characteristics, and multiple linear regression was used to develop predictive models; model residuals were examined by normal probability plots and residual-versus-fitted plots, and multicollinearity was checked using correlation matrices and variance inflation factors. All analyses were conducted with SPSS version 20.0 (SPSS Inc., Chicago, IL, USA).

3. Results:

3.1. *D. citri* infestation in Kinnow mandarin

The pooled data revealed that though the adults of *D. citri* existed on kinnow mandarin trees throughout the year, whereas nymphs were present from February to November and mostly absent in December and January months (Fig. 2). The *D. citri* hibernates in citrus plants in adult stage in winter months. However, the population build up and infestation on kinnow mandarin started with the rise in temperature in the last week of January (Fig. 2). The occurrence and further spread of *D. citri* adults and nymphs was mainly triggered by the air temperature and initiation of new growth in kinnow mandarin. Both the nymphs and adults were observed to suck the sap from the new flush, tender leaves, shoots, flower buds etc. from early February to April and again in August-September (Fig. 2). The population of *D. citri* on kinnow mandarin ranged from 6.40 ± 0.44 – 32.46 ± 2.49 and 0.0 – 56.36 ± 2.05 (Mean + S.E.), adults and nymphs, respectively, during the study period *i.e* from SMW (Standard Meteorological Week) 1 to SMW 52 (Fig. 2). The population of *D. citri* peaked during 13th SMW for both nymphs (56.36±2.05 nymphs/10 cm twig) and adults (32.46±2.49 adults/10 leaves). After that the population of *D. citri* start decreasing (Fig. 2). There were two peaks in the dynamics of *D. citri* was observed, first during SMW 7 to 18 and second from SMW 32 to 36 which confirmed to be as the major period of its activity. Furthermore, both the upper and lower boundaries of temperature and humidity greatly influenced the incidence of *D. citri*. When we plotted (Fig. 2) the dynamics data of *D. citri* population against various weather parameters, a typical optimum range of temperature (Tm 21.69°C – 37.87°C; Tmn 7.30°C - 20.53°C) and humidity (RHm 63.90% – 92.66%; RHmn 19.53% – 54.22%) was observed which favoured the build-up of *D. citri* population (Fig. 2). Beyond this range, the population of *D. citri* followed a decreasing trend and reached to minimum level in 23rd SMW, however, the incidence disappeared when maximum and minimum temperature touched 40.63°C and below 6°C, respectively (Fig. 2). Furthermore, an average temperature of 22.68°C and 60.19% relative humidity corresponds to peak of *D. citri* infestation. The year wise data exhibited that the infestation of *D. citri* adults was highest during 2016 ($F_{6,51}$ = 16.74 adults / 10 leaves and $p < 0.05$) and lowest during 2012 ($F_{6,51}$= 12.32 adults / 10 leaves and $p < 0.05$), whereas, the nymphal population was statistically non-significant when compared across the years. Air temperature and time continuously influenced the seasonal dynamics of each pest stage, therefore, cumulative *D. citri* nymph, and adult population build-up recorded over the years was paired with accumulated Growing Degree Days (GDD)/ Heating Units (Fig. 3) over the Standard meteorological Weeks (Base temperature of *D. citri* used was 11°C). The lower threshold

temperature for development of *D. citri* was observed to be 11°C and 151.63 to 952.62 heating units / GDD (cumulative Heating units/SMW) was favourable for population build-up of *D. citri* in kinnow mandarin (Fig. 3).

3.2. Association of abiotic factors with *D. citri* incidence:

The degree of linear association of *D. citri* nymphal and adult population in kinnow mandarin with weather-based observations (Ta: average temperature; Tm: maximum temperature; Tmn: minimum temperature; RHa: average relative humidity; RHmn: minimum relative humidity; RHm: maximum relative humidity; Wd: wind direction, Ws: wind speed, R: rainfall and Rd: radiations) is presented by correlation matrix (Table 1). *D. citri* population was observed to have positive but weak correlation with Tm, Ta, Ws and Rd, whereas, significant negative correlation with RHa and RHm. Due to the strong correlation between Ta and Tm (r = 0.95); between Ta and Tmn (r = 0.84), and between RHa and Rhm (r = 0.82); RHa and RHmn (r = 0.80), Ta and RHa were not considered in regression. Rhm, Ws and Rd were considered due to their better correlation with *D. citri* population. To mitigate multicollinearity among weather parameters, a reduced multiple linear regression model was developed using 75% of the data to predict *D. citri* adult populations. The multi-regression model developed between *D. citri* population and selected weather variables (Tm, Tmn RHm, RHmn, Ws and Rd) was highly significant (F= 27.73; P < 0.001) and is expressed as:

$$\text{No. of } D.\ citi \text{ nymphs/ 10 cm twig} = 5.50\ T\text{m} - 6.71\ T\text{mn} + 0.45\ RH\text{m} + 1.21\ RH\text{mn} + 48.04\ Ws + 0.25\ Rd - 210.82$$

The weather variables collectively explained 67.3% of the variation in the population (R^2 = 0.673; adjusted R^2 = 0.457), with a standard error of 13.25. All evaluated weather parameters (T m, Tmn, RHm, RHmn, Ws and Rd) significantly influenced the population dynamics (P < 0.05 P<0.05) and used for validation on the remaining 25% of observations demonstrated predictive capability (Fig. 4).

3.3. Screening of citrus cultivars to *D. citri*

The different citrus cultivars screened against *D. citri* were lemon (*Citrus limon*), sweet lime (*Citrus limetta*), Kinnow mandarin (*Citrus nobilis* × *Citrus deliciosa*), *Citrus reticulata* cv. Mosambi (sweet orange); Daisy mandarin, *Citrus reticulata* Blanco; and *Citrus reticulata* cv. Early Gold (sweet orange), and the data are presented in Figure 5. The incidence of *D. citri* was recorded during the peak activity periods, *i.e.* in February, March, April, August and September.

Infestation was initiated from the last week of January in all cultivars, but noticeable nymphal abundance was recorded from February onward and screening was therefore initiated in the first week of February (Fig. 5). None of the cultivars was found free of *D. citri* infestation. Pooled data over three years revealed that, irrespective of cultivar, nymphal infestation was highest during March (43.42 ± 4.56 – 65.53 ± 5.25 nymphs per 10 cm twig) and lowest during September (4.72 ± 1.02 – 13.21 ± 2.31 nymphs per 10 cm twig) (Fig. 4). Lemon ($F_{5,11}$ = 36.88 nymphs per 10 cm twig, $p < 0.01$) had the highest field infestation by *D. citri* and was statistically at par with sweet lime ($F_{5,11}$= 34.19 nymphs per 10 cm twig, $p < 0.01$), followed by Kinnow mandarin ($F_{5,11}$= 28.72 nymphs per 10 cm twig, $p < 0.01$). However, Early Gold ($F_{5,11}$= 20.58 nymphs per 10 cm twig, $p < 0.01$), Mosambi ($F_{5,11}$ = 21.13 nymphs per 10 cm twig, $p < 0.01$) and Daisy ($F_{5,11}$ = 22.71 nymphs per 10 cm twig, $p<0.01$) did not differ significantly from each other in terms of nymphal density. Thus, under the field conditions of the present study, lemon, sweet lime and Kinnow mandarin supported the highest *D. citri* populations and appear to be the most preferred hosts in this region.

3.4. Biochemical profile of different citrus cultivars

Nutrients status (N, P, K) and biochemical properties of leaf tissues, *viz*. total soluble sugars, starch, sucrose, proteins, free amino acids, total phenols and flavonoids, showed significant variability across the citrus cultivars (Fig. 5)**.** Among the cultivars tested, greater percentage of N, P and K in leaf tissues were observed in Mosambi, Lemon and Mosambi & Lemon ($F_{5,8}$ = 2.79%, 0.60% and 1.74%, respectively, $P < 0.05$). The corresponding values for total soluble sugars, sucrose and starch activities were higher in cultivar Mosambi, Daisy and Mosambi ($F_{5,8}$ = 0.82%, 4.26 mg/g DW and 0.35 mg/g DW, respectively, $P < 0.05$) as compared to Kinnow. Sweet lime had significantly greater activities of free amino acids and proteins ($F_{5,8}$ = 3.51 mg/g DW and 2.56 mg/g DW, respectively, $P < 0.05$) than Mosambi, Lemon and Kinnow. The number of total phenols and flavonoids were found highest in lemon and Early Gold ($F_{5,8}$ = 370 mg/g DW and 645 mg/g DW, respectively, $P < 0.05$) as compared to other cultivars (Fig. 5). When the corresponding data was correlated with the incidence of *D. citri*, a negative correlation between to Flavonoids ($r= 0.45^{*}$), sucrose content in leaves ($r= 0.57^{**}$) and K ($r= 0.45^{*}$) and a positive correlation to leaf Nitrogen ($r= 0.42^{**}$), Leaf phosphorus ($r= 0.49^{**}$), proteins ($r= 0.55^{**}$) and Free amino acids ($r= 0.68^{**}$) was observed. Total soluble sugars, starch and total phenols content of

leaf tissues were found to have non-significant association with *D. citri* infestation in different citrus cultivars (Table 2).

3.5. Management of *D. citri* under field conditions:

The pooled data from two experiments on percent reduction in *D. citri* nymph population at 3, 7, 10 and 14 days after treatment with different pesticides is presented in Table 3. Significant differences were observed among the treatments after 3 ($F_{16,34}$ = 22.93, $p < 0.05$), 7 ($F_{16,34}$ = 48.89, $p < 0.05$), 10 ($F_{16,34}$ = 46.80, $p < 0.05$) and 14 ($F_{16,34}$ = 65.19, $p < 0.05$) days of spray application. All the treatments reduced the number of *D. citri* nymph population when compared to untreated control (Table 3). Before treatment the average numbers of *D. citri* nymphs per 10 cm twig were ranged from 28.70 - 37.40 (Table 3). After 3 days, thiamethoxam 12.6% + lambda-cyhalothrin 9.5% @ 0.7 ml/l was most effective in reducing the *D. citri* nymph population and was statistically at par with beta-cyfluthrin 8.49% + imidacloprid 19.81% @ 0.7 ml/l followed by beta-cyfluthrin 8.49% + imidacloprid 19.81% @ 0.5ml/l, flonicamid 50 @ 0.5g/l and thiamethoxam @ 0.32g/l (Table 3). Entomopathogenic fungi *B. bassiana* 1.15% @ 7 ml/l bring forth 54.75 per cent reduction in nymph population and was at par with flonicamid 50% @ 0.5, 0.7g/l and beta-cyfluthrin 8.49% + imidacloprid 19.81% @ 0.5 ml/l and followed by HMO @ 12.5 ml/l ($F_{16,9}$ = 47.86% reduction, $p < 0.05$) and *M. anisopliae* 1.15% @ 7 g/l ($F_{16,34}$ = 45.28% reduction, $p < 0.05$). However, neem soap and pongamia soap revealed 20.28 - 33.94 % mortality of *D. citri* nymphs (Table 3). Significant differences among different treatments after 7 days were noticed (Table 3). Maximum reduction (range: 31.47 - 88.94%) in *D. citri* population was obtained after 10 DAS (Table 3). The treatment with thiamethoxam 12.6% + lambda-cyhalothrin 9.5% @ 0.7 ml/l was found best in reducing *D. citri* population ($F_{16,34}$ = 88.94% reduction) but significantly at par with beta-cyfluthrin 8.49% + imidacloprid 19.81% @ 0.7 ml/l ($F_{16,34}$ = 85.52% reduction, $p < 0.05$) and flonicamid 50% @ 0.7g/l ($F_{16,34}$ = 83.32% reduction, $p < 0.05$) after 10 DAS as compared to standard checks thiamethoxam and imidacloprid (Table 3).

Among biopesticides, *M. anisopliae* 1.15% @ 7 g/l made 60.16% population reduction and was found at par with *B. bassiana* 1.15% @ 7 g/l ($F_{16,34}$ = 54.70% reduction, $p < 0.05$). HMO was found to have 53 per cent reduction in *D. citri* nymph population. Thiamethoxam 12.6% + lambda-cyhalothrin 9.5% @ 0.7 ml/l was found significantly superior over all the treatments with 82.92% reduction of *D. citri* population after 14 days of spray application and was at par with

thiamethoxam 12.6% + lambda-cyhalothrin 9.5% @ 0.5 ml/l, beta-cyfluthrin 8.49% + imidacloprid 19.81% @ 0.5, 0.7 ml/l and flonicamid 50% @ 0.7 g/l (Table 3). Flonicamid 50% @ 0.5 g/l was the next superior treatment (73.33% reduction). Previously recommended imidacloprid and thiamethoxam was found less effective as compared to these insecticides with 65.69 and 61.61 per cent reduction in *D. citri* nymph's population, respectively after 14 days of spray application (Table 3). Among biopesticides, *M. anisopliae* 1.15% @ 7 g/l yielded 60.16% reduction of *D. citri* nymph population after 14 DAS and was at par with *B. bassiana* 1.15% @ 7 g/l ($F_{16,34}$ = 52.23% reduction) and standard check imidacloprid @ 0.4 ml/l ($F_{16,34}$ = 61.61% reduction) followed by *V. lecanii* 1.15% ($F_{16,34}$ = 49.36% reduction) and HMO ($F_{16,34}$ = 47.86% reduction). Both the pongamia and neem soap formulations was found ineffective in reducing *D. citri* population in kinnow mandarin.

3.6. Effect of different treatments on natural enemies

The data recorded on the effect of different treatments on predators (*Coccinellid* larvae/adults and *Chrysoperla* larvae) in kinnow mandarin revealed statistically non-significant differences before ($F_{17,36}$ = 1.83±0.06 - 2.01±0.18 (Mean ± S.E.) nos./ plant) and 14 days after ($F_{17,36}$ = 1.22±0.14-2.17±0.13 (Mean ± S.E.) nos./ plant) the treatments (Table 3). Though the effects of different treatments on natural enemies in Kinnow mandarin are statistically not significant, however, the numerical reduction in the population with the use of insecticides cannot be overlooked. The chemical insecticides resulted in 22.54 - 39.35% reduction of coccinellid larvae/adults' population, respectively, however the same with the use of biopesticides ranged between 0.0 - 17.45 percent.

4. Discussions:

This study highlights significant insights into the seasonal dynamics of *D. citri* infestation in Kinnow mandarin, emphasizing the role of weather parameters and plant phenology. The study revealed the year-round presence of *D. citri* adults on Kinnow mandarin, while nymphs were active from February to November, with an absence during colder months (December - January). Infestation began in late January, triggered by rising temperature and the emergence of new plant growth, with two peaks observed: February-April (SMW 7 - 18) and August-September (SMW 32 - 36). These peaks align with periods of new flush development which was also observed by Ehsan and Saeedifar (2013) and Debbarma et al. (2024). During this period, the citrus psylla inflicts maximum damage to new flush of citrus and leads to yield loss, if not controlled. Since, flushing in citrus started during first fortnight of February in semi-arid region of south-western Punjab,

which attracted *D. citri* to colonize, infest and settle down. Because young nymphs and adults are the principal vectors of *C. liberibacter asiaticus* (CLas), these flush periods likely correspond to the highest Huanglongbing disease transmission risk. In practice, this means that vector suppression efforts, including insecticide applications and release of biological control agents, should be strategically concentrated just before and during these peak flushing windows rather than applied uniformly throughout the year. Targeting the phenology-linked peaks minimizes unnecessary sprays outside high-risk periods and may delay the spread of Huanglongbing disease in endemic orchards.

Weather factors, *viz*. temperature, relative humidity play a very crucial role in the initial infestation, further spread and development of different insect-pests (Bale et al., 2000; Tomar, 2010), holds true in our case. However, in contrast to our findings, Atwal et al. (1968) reported four annual population peaks of *D. citri* on citrus which occurred during March, June, July, and August - November from 1965 to 1967 in Ludhiana, India, though the highest population was observed in March. They suggested that both high and low temperatures were detrimental to the psyllid population. However, in the current study there were no population increase in June and October and November months. Population dynamics were significantly influenced by temperature and humidity. The optimal range for *D. citri* development was Tmax 21.69°C - 37.87°C, Tmin 7.30°C - 20.53°C, RHmax 63.90% - 92.66%, and RHmin 19.53% - 54.22%. *D. citri* populations started declining as mercury rises above 40°C or falls below 6°C. These findings align with Tsai et al. (2002), who identified similar thermal thresholds for *D. citri* activity. These thermal relationships have important climate-change implications. Projected warming and altered humidity in north-west India may shift *D. citri* phenology toward earlier spring onset, longer favourable seasons and more intense mid-season peaks, while more frequent heat waves above 40°C could intermittently suppress populations yet, combined with erratic flushing, generate unpredictable outbreaks. Incorporating our locally validated thresholds into regional climate projections would allow forecasting of future *D. citri* risk under different scenarios and support long-term Huanglongbing disease management planning.

Cumulative Heating Units (CHUs) or Growing Degree Days (GDD) were pivotal in explaining population buildup, with 151.63 - 952.62 GDD favourable for infestation. The base developmental threshold for *D. citri* was determined to be 11°C, similar to previous studies indicating the importance of thermal accumulations for psyllid development (Hall et al., 2008). Yearly variability

was observed, with 2016 recording the highest adult population, attributed to favourable weather conditions, while nymphal population differences across years were statistically non-significant. This base temperature is consistent with the developmental physiology of *D. citri*, which is also reported by Grafton-Cardwell et al. (2013) substantiated our findings. The integration of GDD analysis provides a robust framework for anticipating pest outbreaks, enabling growers to implement timely interventions. This study provides critical buildup for developing integrated pest management strategies, emphasizing temperature-based pest prediction models and targeting control measures during peak activity periods for effective management.

Weather variables significantly influenced the population dynamics of *D. citri* in Kinnow mandarin. The correlation analysis showed weak positive associations of *D. citri* population with maximum temperature (Tm), average temperature (Ta), wind speed (Ws), and solar radiation (Rd), but significant negative correlations with average relative humidity (RHa) and maximum relative humidity (RHm), which were consistent with previous studies of Tsai et al. (2002), which identified temperature and humidity as critical factors affecting psyllid populations. Multicollinearity among some weather variables (e.g., strong correlations between Ta and Tm, Ta and Tmn, and RHa and RHm) led to the exclusion of certain parameters from the regression analysis. A multi-regression model developed using Tm, RHm, Ws, and Rd effectively predicted *D. citri* nymph and adult populations, accounting for 67% of the variation ($R^2 = 0.457$) with a root mean square error (RMSE) of 3.357%. This model underscores the dominant influence of temperature and humidity in regulating *D. citri* populations while highlighting the additional roles of wind speed and solar radiation. The model equations indicate that higher Tm and Rd positively influence *D. citri* population growth, while higher Ws and RHm negatively impact it. Similar conclusions were drawn by Hall et al. (2008), who noted that unfavourable wind conditions and high relative humidity suppress psyllid activity. These findings reinforce the importance of integrating abiotic factors into predictive pest management strategies for effective *D. citri* control. More importantly, the model shows that temperature and humidity dominate *D. citri* dynamics, with wind speed and radiation modifying dispersal and activity. Such weather-based models are valuable not only as statistical summaries but as operational forecasting tools.

The three-year screening of citrus cultivars showed clear variation in *D. citri* infestation, with no cultivar completely free from infestation. Infestation peaked in March (43.42–65.53 nymphs per 10 cm twig) during abundant flushing and declined by September (4.72–13.21 nymphs per 10 cm

twig). Lemon and sweet lime were the most preferred hosts, likely due to frequent flush cycles, whereas Early Gold, Mosambi and Daisy sustained moderate infestations, consistent with earlier host-preference studies (Halbert and Manjunath, 2004; Setamou et al., 2016). These patterns support targeted management on highly preferred cultivars and the use of moderately infested cultivars within IPM systems. Marked differences in leaf biochemistry among cultivars appear to modulate *D. citri* susceptibility. Mosambi and lemon had higher nitrogen, phosphorus, potassium, soluble sugars and starch, all positively associated with *D. citri* incidence and probably enhancing leaf palatability and pest development (Setamou et al., 2016). In contrast, sweet lime showed elevated protein and free amino acids, while lemon and Early Gold had the highest phenol and flavonoid levels. Strong negative correlations of phenols ($r = –0.55^{**}$) and flavonoids ($r = –0.68^{**}$) with *D. citri* incidence indicate a defensive role, and the negative association with potassium ($r = –0.45^{**}$) suggests a contribution to plant defence (Kumar et al., 2020; Hafsi et al., 2014). Thus, Mosambi and lemon are nutrient-rich yet highly preferred, whereas phenolic-rich cultivars like Early Gold may aid IPM through inherent biochemical defenses; nutrient management and selection of phenolic-rich types could help mitigate infestation. From an Huanglongbing disease perspective, highly preferred, nutrient-rich cultivars may act as epidemiological hubs, attracting *D. citri* and sustaining high vector reproduction, thereby increasing local pathogen pressure. Cultivars with stronger biochemical defenses and moderate psyllid loads could serve as safer options in mixed plantings or buffer zones. Because our conclusions rely on field infestation and biochemical association rather than controlled choice tests or *C. liberibacter asiaticus* measurements, we refer to these cultivars as “preferred hosts” rather than definitively more or less Huanglongbing disease resistant. Future work should test whether phenolic-rich cultivars reduce *C. liberibacter asiaticus* acquisition and transmission, and whether nutrient management can be adjusted to limit *D. citri* build-up without compromising yield.

When compared with *D. citri* ecology reported from other citrus-growing regions, several consistent themes emerge. Studies from Florida, Texas, Brazil and Southeast Asia also highlight strong coupling between *D. citri* populations, flush availability, and temperature, with optimal development near 25 - 28°C and reduced survival at sustained high (>30 - 33°C) or low (<10 - 11°C) temperatures (Liu & Tsai 2000; Hall 2011; Nava et al. 2007). Our results confirm these broad patterns but refine them for the semi-arid Kinnow production system, where the timing of flushes, heat stress, and humidity differs markedly from humid subtropical or tropical zones. In

many of those regions, *D. citri* management and Huanglongbing disease suppression increasingly rely on coordinated area-wide programs that combine insecticide rotations, biological control, removal of infected trees and regulation of nursery stock. The weather-driven dynamics documented here suggest that similar area-wide approaches in north-west India would benefit from incorporating local phenology and degree-day models to optimize the timing of vector suppression. This study therefore provides a missing ecological link between global *D. citri* biology and region-specific management recommendations for Kinnow-based citrus systems.

Finally, the evaluation of chemical and biopesticide treatments, together with their impact on natural enemies, underscores the need for balanced IPM strategies. The results indicated significant differences in the effectiveness of various chemical and biopesticide treatments for controlling *D. citri.* Thiamethoxam 12.6% + Lambda-cyhalothrin 9.5% @ 0.7 ml/l of water showed the highest reduction in nymphal populations, with an 82.92% reduction after 14 days, significantly outperforming other treatments. This combination likely offered rapid knockdown and long-lasting effects, a characteristic of broad-spectrum synthetic insecticides that target multiple physiological pathways in the pest. Beta-cyfluthrin + imidacloprid and flonicamid also showed strong efficacy, reducing populations by up to 85%, indicating their value in managing *D. citri* populations in field conditions. Biopesticides like *M. anisopliae* and *B. bassiana* (1.15% @ 7 ml/l) offered moderate but significant reductions (54-60%) and were found comparable to standard insecticides, suggesting their potential as eco-friendly alternatives in integrated pest management (IPM) programs (Tiwari et al., 2011b; Godoy et al., 2018). The moderate performance of biopesticides can be attributed to their slower mode of action compared to chemical pesticides, but their environmental safety and potential for resistance management make them valuable in sustainable agriculture (Garrido-Jurado et al., 2016). However, neem and pongamia soaps were least effective, with only a 20-34% reduction in *D. citri* populations, likely due to their less potent bioactivity against the pest. These results emphasize the importance of combining or alternative use of effective chemical treatments like thiamethoxam + lambda-cyhalothrin, beta-cyfluthrin + imidacloprid, flonicamid for immediate control, with biopesticides for long-term resistance management and environmental sustainability which was substantiated by the findings of Tiwari et al., 2011a.

The study evaluated the effect of different treatments on natural enemies, particularly *Coccinellid* larvae/adults and *Chrysoperla* larvae, in Kinnow mandarin orchards. Although statistical analysis

revealed non-significant differences in predator populations before and after treatment, numerical trends indicated substantial variations, particularly between chemical insecticides and biopesticides. This finding has significant implications for sustainable pest management strategies. Chemical insecticides resulted in a notable reduction in the population of Coccinellid larvae/adults. Such reductions, while they are not statistically significant in the short term but, are ecologically important. Previous studies have documented that chemical insecticides, especially broad-spectrum ones, can adversely impact non-target organisms, including predators and parasitoids, thereby disrupting natural biological control (Desneux et al., 2007; Gurr et al., 2003). The observed numerical decline aligns with these findings, highlighting the potential risk of pest resurgence due to weakened predator populations. Moreover, this reduction could increase reliance on chemical inputs, leading to unsustainable pest management practices. In contrast, biopesticides demonstrated a significantly lower impact, with predator population reductions ranging from 0.0% to 17.45%, which aligns with the growing body of literature emphasizing the compatibility of biopesticides with natural enemy conservation (Lacey et al., 2015; Mandal, 2020; Yadav et al., 2022). The minimal impact on natural enemies underscores their suitability for integrated pest management (IPM) programs, particularly in agroecosystems where biological control is a key component of pest suppression. Natural enemies such as *Coccinellid* and *Chrysoperla* species play a pivotal role in suppressing pest populations in Kinnow orchards. A reduction in their populations, even if statistically non-significant over the short term, can have cascading effects on pest dynamics. The functional roles of these predators, including the consumption of soft-bodied pests like aphids and mealybugs, are essential for maintaining orchard health. Therefore, treatments that minimally impact these natural enemies should be prioritized in Integrated Pest management programmes.

Highly effective insecticide combinations such as thiamethoxam + lambda-cyhalothrin or beta-cyfluthrin + imidacloprid provide rapid suppression during high-risk periods but pose potential risks to predators and long-term resistance management. In contrast, entomopathogenic fungi and other biopesticides offer slower but ecologically compatible control, particularly when applied at times predicted by our weather-based models to correspond to rising *D. citri* populations. The minimal impact of biopesticides on *Coccinellid* and *Chrysoperla* populations reinforces their value in conserving natural enemies and reducing reliance on broad-spectrum chemicals. Taken together, the phenological analyses, thermal thresholds, cultivar preference data

and control evaluations presented here support a more critical and integrated view of *D. citri* management. Effective Huanglongbing disease suppression in Kinnow mandarin orchards will require synchronizing selective chemical and biological controls with weather-based forecasts, exploiting host plant traits that discourage *D. citri* reproduction, and aligning local practices with global knowledge of *D. citri* ecology and climate sensitivity.

5. Conclusion:

This study provides valuable insights into the management of *D. citri* on Kinnow mandarin, highlighting critical infestation periods, particularly SMW 7-18 and SMW 32 - 36 and the importance of environmental factors, cultivar susceptibility, and pest control strategies. *D. citri* nymphs were active from February to November, with peaks coinciding with new flush growth. Temperature and humidity were key factors influencing population dynamics, with optimal conditions for pest development between 21.69°C - 37.87°C and 63.90% - 92.66% relative humidity. A multi-regression model, incorporating temperature, humidity, wind speed, and solar radiation, effectively predicted *D. citri* populations, reinforcing the importance of integrating abiotic factors in formulating pest management strategies. Biochemical profiling of citrus cultivars revealed that Mosambi and Lemon, rich in nutrients, were most preferred to infestation, while cultivars like Early Gold, with high phenolic content, showed potential as part of integrated pest management strategies. The study also compared chemical and biopesticide treatments, finding that thiamethoxam + lambda-cyhalothrin was most effective, followed by beta-cyfluthrin + imidacloprid and flonicamid. Biopesticides, such as *M. anisopliae* and *B. bassiana*, showed moderate effectiveness, offering eco-friendly alternatives for long-term pest management. These findings emphasize the need for a multi-faceted approach, combining environmental monitoring, cultivar selection, and integration of chemical and biological control methods for sustainable *D. citri* management and for possible benefits like insecticide resistance management and for natural enemy/pollinator safety. Monitoring GDD and environmental parameters can guide the application of chemical controls or the release of biological agents thus enhancing pest management efficiency.

Authorship contribution statement

MP and PKA conceived and designed the research. MP, PKA and AV conducted the experiments and recorded data. SP and NK conducted the biochemical analysis of the citrus cultivars. MP and AV analysed data and wrote the manuscript. All authors read and approved the manuscript.

Ethical approval

Not applicable

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The authors received no financial assistance for the research.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data availability

Data will be made available on request.

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Figures: 5

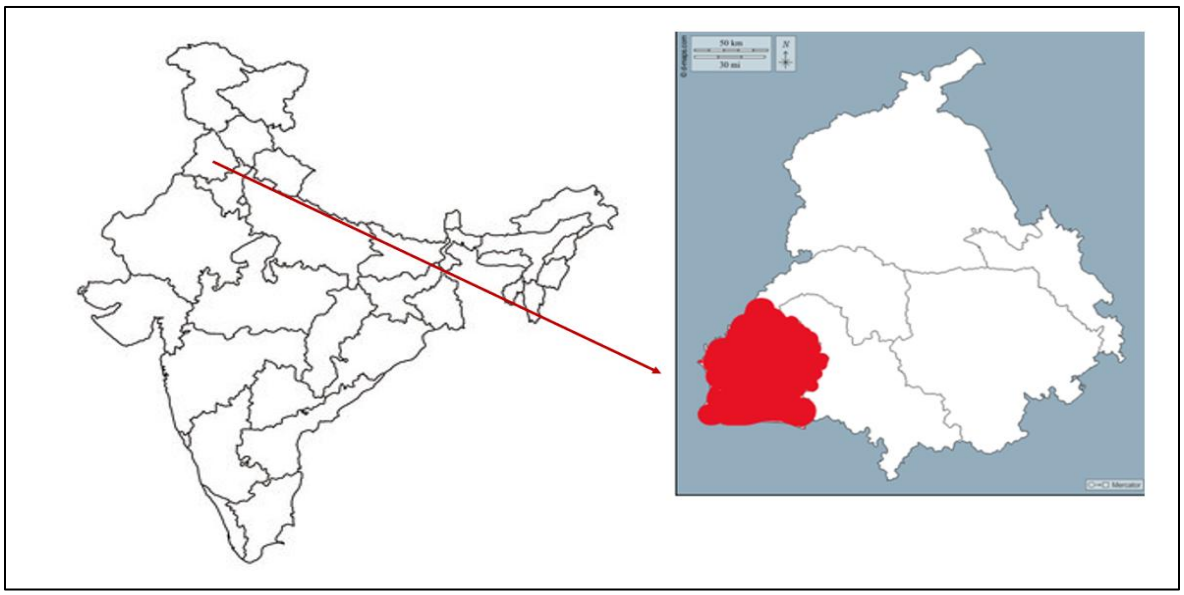


Fig. 1: Study area (South-western Punjab, India)

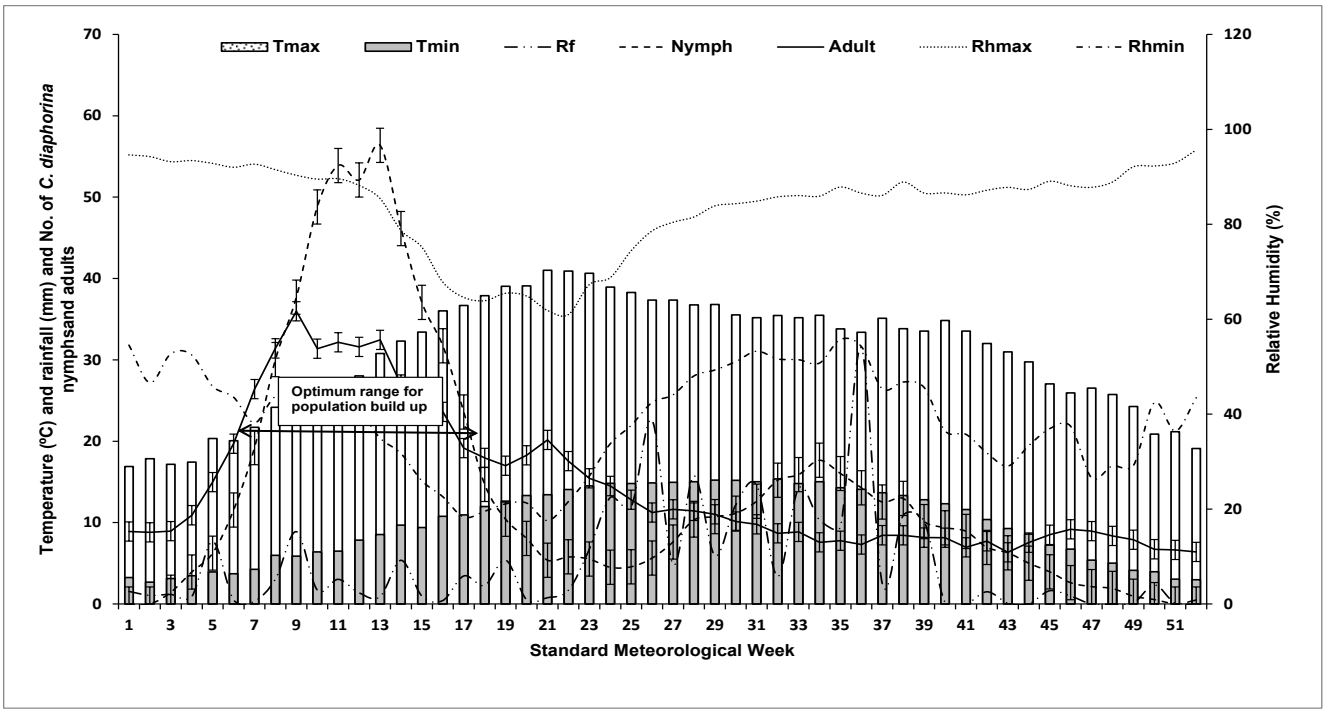


Fig. 2: Population dynamics of *D. citri* on kinnow mandarin in relation to climatic factors (pooled data 2012 - 2018; Tmax: maximum temperature (°C); Tmin: minimum temperature (°C); RHmin: minimum relative humidity (%); RHmax: maximum relative humidity (%); and Rf: rainfall (mm))

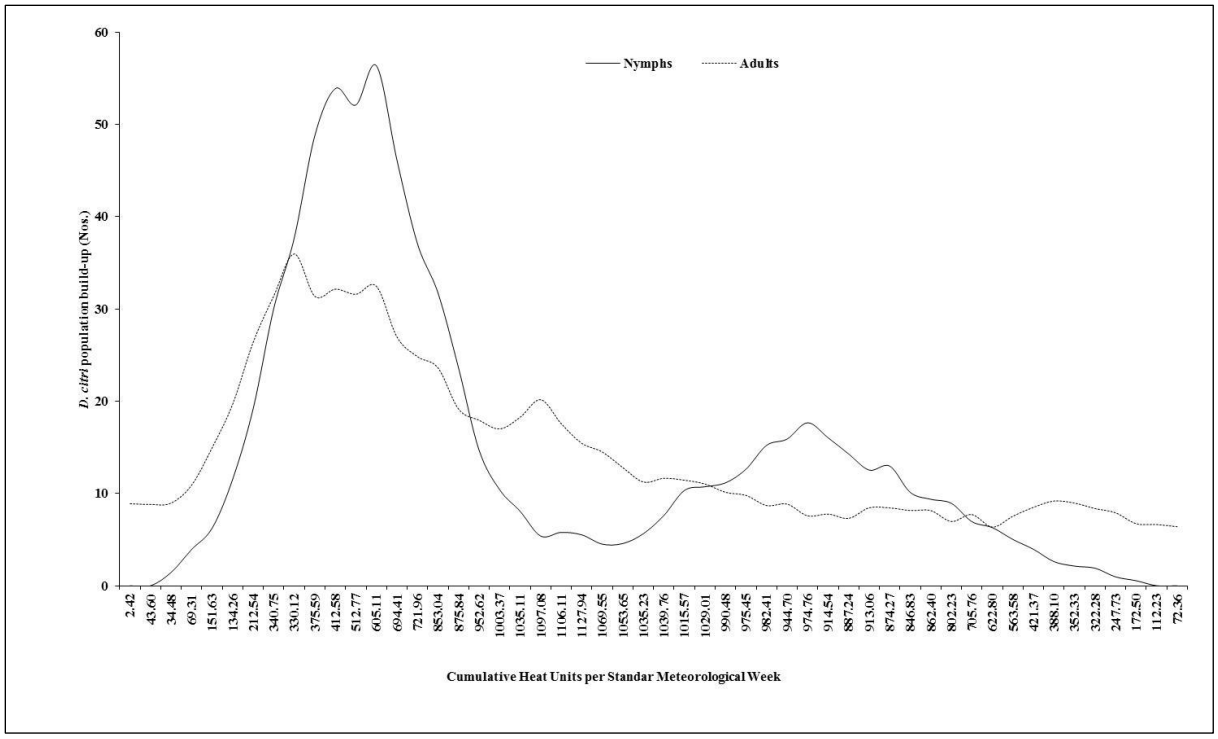


Fig. 3: Cumulative heat units required by *D. citri* on kinnow mandarin across the standard Meteorological Weeks

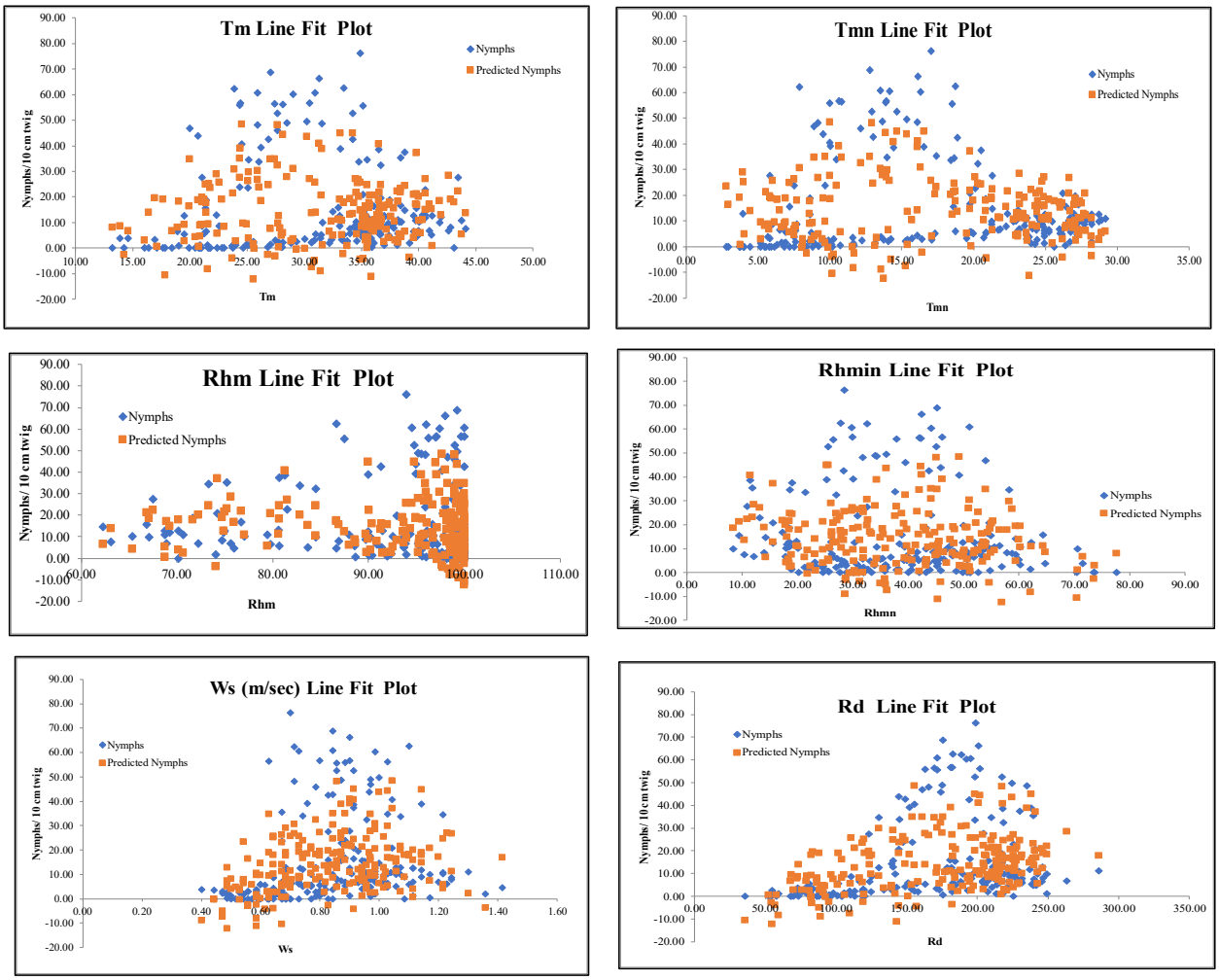


Figure 4: Scatter plots of observed and predicted D. citri nymph populations across key meteorological variables.

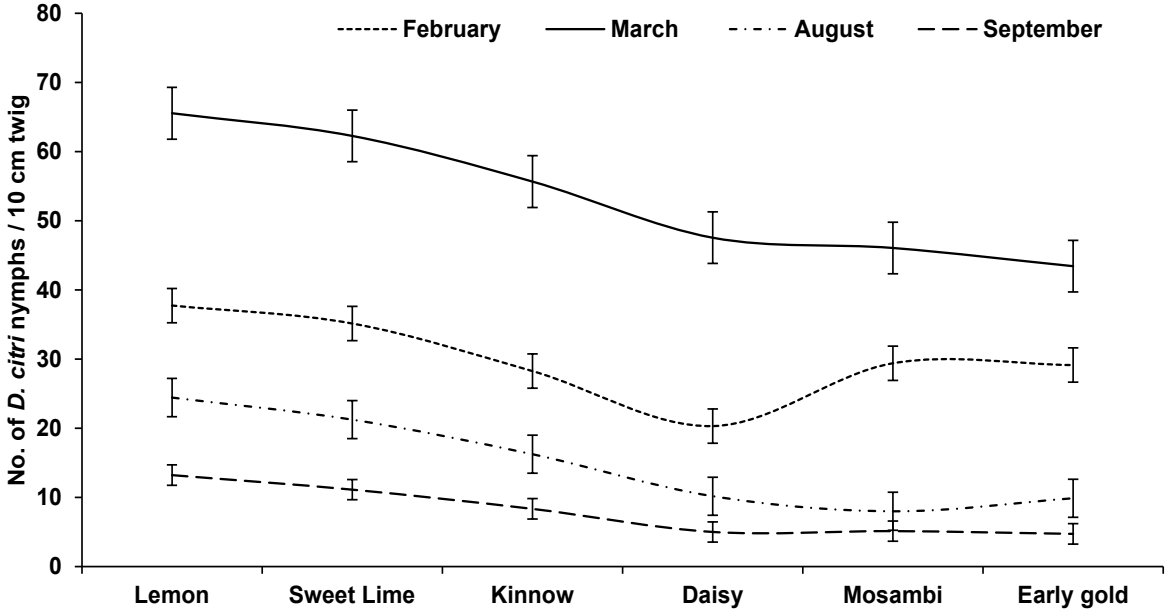
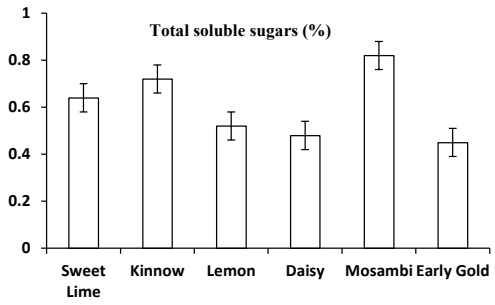
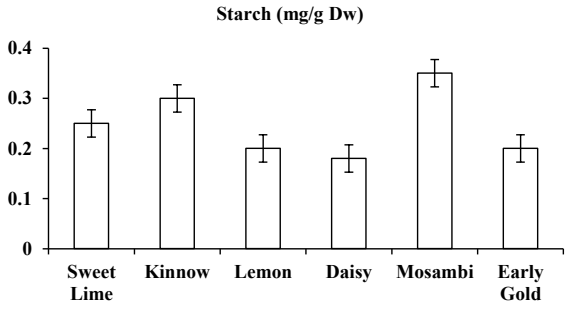


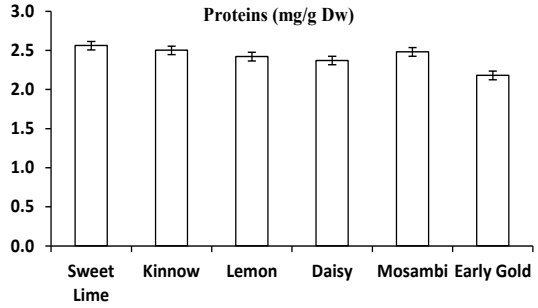
Fig. 5: Infestation of *D. citri* in different citrus cultivars in semi-arid region of south-western Punjab (data pooled for 3 years)



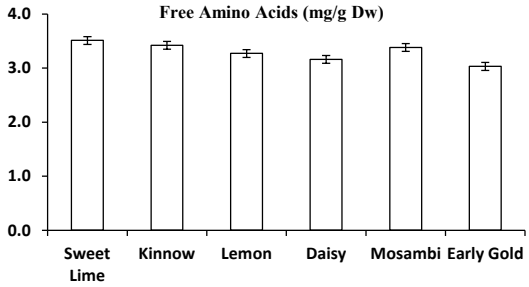
(a)



(b)



(c)



(d)

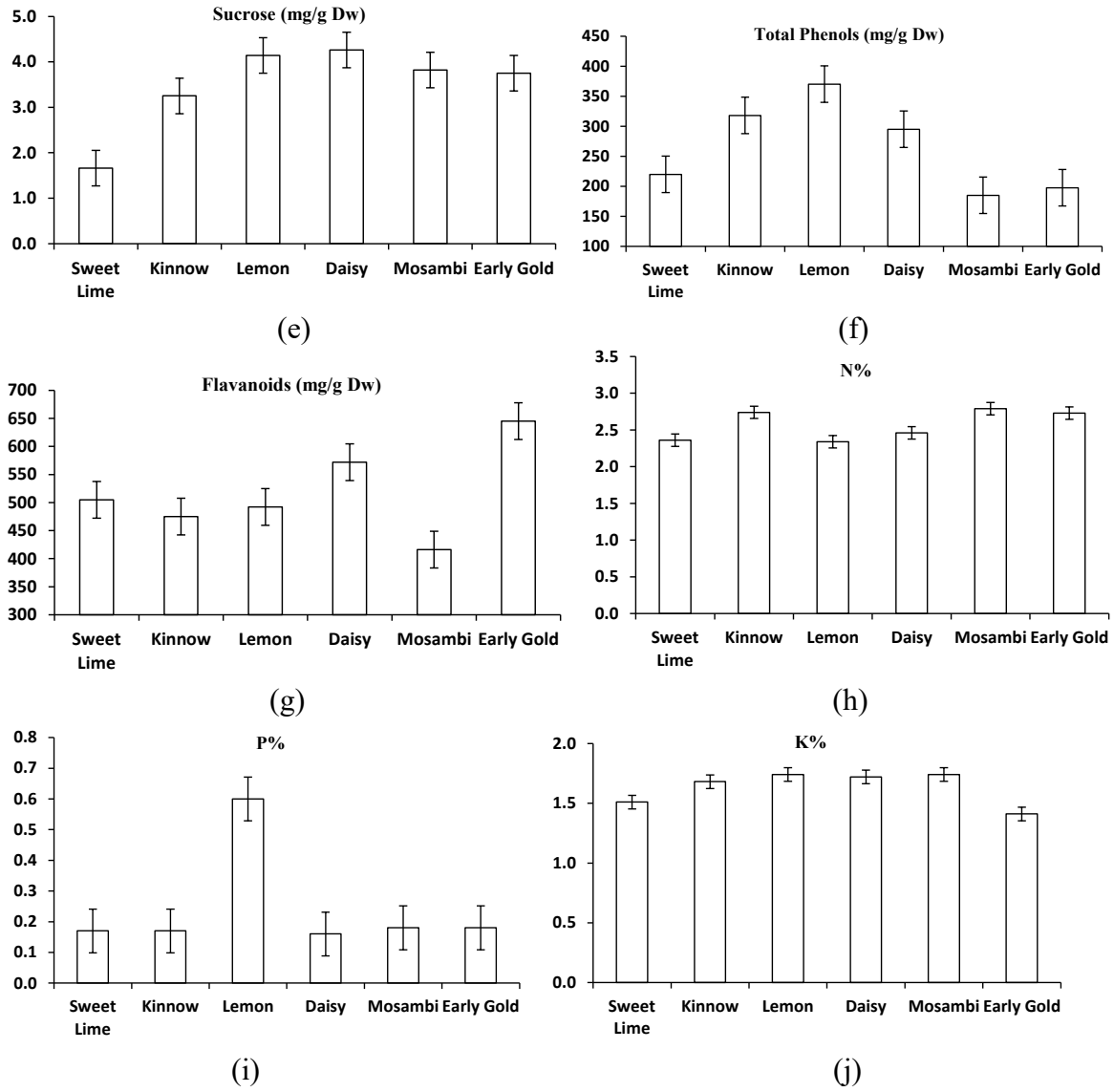


Fig. 5 Concentrations of total soluble sugars (a), starch (b), protein (c), free amino acids (d), sucrose (e), total phenols (f), flavonoids (g), Nitrogen (h), Phosphorus (i), and Potassium (j) in young leaves of different citrus cultivars. Bars represent mean ± SE of three replicates.

Tables:

Table 1: Correlation matrix (Pearson's) of abiotic factors with *D. citri* population build-up in kinnow mandarin

Variables	Adults/10 leaves	Nymphs/ 10 cm twig	Ta	Tm	Tmn	RHa	RHm	RHmn	Rf	Wd	Ws
Ta	0.15*	0.30*									
Tm	0.14*	0.34*	0.95**								
Tmn	NS	0.23**	0.95**	0.84**							
RHa	**0.38****	**0.14****	**0.42****	**0.56****	**0.17****						
RHm	**0.44****	**0.22****	**0.55****	**0.61****	**0.38****	0.82**					
RHmn	**0.29****	NS	**0.12***	**0.36****	0.15*	0.80**	0.48**				
Rf	0.08*	NS	NS	NS	0.13*	0.26**	NS	0.44**			
Wd	0.15*	NS	**0.29****	**0.24****	**0.37****	**0.19****	**0.12***	**0.23****	NS		
Ws	0.44**	0.34**	0.68**	0.58**	0.66**	**0.33****	**0.62****	NS	0.35**	NS	
Rd	0.33**	0.51**	0.85**	0.84**	0.77**	**0.46****	**0.55****	**0.18****	NS	**0.17****	0.68**

Ta: average temperature (°C); Tm: maximum temperature (°C); Tmn: minimum temperature (°C); RHa: average relative humidity (%); RHmn: minimum relative humidity (%); RHm: maximum relative humidity (%); Wd: wind direction (°), Ws: wind speed (m^{-s}); Rd: radiation (W/m^2) and Rf: rainfall (mm)

Bold digits in the table indicate the "–" correlation; data followed by '*' indicates their significant correlation at $P < 0.05$ and data followed by '**' indicate their significant correlation at $P < 0.01$; NS: not significant.

Table 2: Correlation matrix (Pearson's) of leaf nutrient and biochemical components to *D. citri* nymphal population build-up

Variables	*D. citri* Nymphs	TSS	S	Pr	FAA	Sc	Pn	Fl	N%	P%
TSS	0.42*									
S	0.49*	NS								
Pr	NS	NS	NS							
FAA	NS	NS	NS	0.55**						
Sc	NS	NS	NS	0.61**	0.94**					
Pn	**0.55****	NS	NS	0.50*	0.67**	0.66**				
Fl	**0.68****	NS	NS	0.47*	0.76**	0.72**	.921**			
N%	0.57**	NS	NS	NS	NS	NS	**0.52***	**0.69****		
P%	NS	NS	0.64**	NS	NS	NS	NS	NS	NS	
K%	**0.45***	NS	NS	**0.77****	**0.87****	**0.86****	**0.78****	**0.79****	NS	NS

TSS: Total Soluble Sugars (%); S: Starch (mg/g DW); Pr: Proteins (mg/g DW); FAA: Free Amono Acids (mg/g DW); Sc: Sucrose (mg/g DW); Pn: Total Phenols (mg/g DW), Fl: Flavonoids (mg/g DW); N: Nitrogen (%); P: Phosphorus (%); K: Potassium (%);

Bold digits in the table indicate the "–" correlation; data followed by '*' indicates their significant correlation at $P < 0.05$ and data followed by '**' indicate their significant correlation at $P < 0.01$; NS: not significant.

Table 3: Efficacy of different insecticides against *D. citri* and its natural enemies (Pooled data of 2 experiments)

S. No.	Treatments	Dosage g or ml/l	No. of *D. citri* nymphs/ 10 cm twig before treatment	% reduction in *D. citri* nymphal population				Avg. no. of predator larvae / adults per tree (*Coccinellid*, *Chrysopid*, *Syrphid* sp. and spiders)	
				3DAS	7DAS	10DAS	14DAS	1DBS	14DAS
1	Flonicamid 50 WDG	0.5	32.10	58.55±1.48^{b}	69.79±0.61^{c}	79.34±0.84^{bc}	73.33±0.20^{b}	2.13±0.12	1.65±0.11
2	Flonicamid 50 WDG	0.7	30.15	59.64±0.94^{b}	72.27±0.58^{bc}	83.32±0.76^{ab}	77.46±0.18^{ab}	2.07±0.28	1.54±0.07
3	Beta-cyfluthrin 8.49% + Imidacloprid 19.81%	0.5	35.65	61.41±1.79^{b}	71.28±0.69^{c}	80.20±0.83^{b}	77.25±0.20^{ab}	1.99±0.08	1.29±0.17
4	Beta-cyfluthrin 8.49% + Imidacloprid 19.81%	0.7	35.75	67.52±0.85^{ab}	76.92±0.76^{b}	85.52±0.28^{ab}	79.41±0.07^{ab}	1.89±0.07	1.31±0.14
5	Thiamethoxam 12.6% + Lambdacyhalothrin 9.5%	0.5	34.05	56.50±3.09^{bc}	67.34±1.15^{cd}	81.80±1.02^{b}	78.37±0.25^{ab}	1.84±0.21	1.24±0.10
6	Thiamethoxam 12.6% + Lambdacyhalothrin 9.5%	0.7	37.40	70.29±0.99^{a}	82.14±0.65^{a}	88.94±0.15^{a}	82.92±0.04^{a}	2.16±0.18	1.31±0.14
7	*Verticillium lecanii* 1.15% (1X10^{8} CFU's /ml)	5.0	30.10	35.25±3.87^{d}	39.15±2.30^{g}	37.93±2.49^{gh}	35.10±0.60^{fg}	2.35±0.11	1.94±0.09
8	*Verticillium lecanii* 1.15% (1X10^{8} CFU's /ml)	7.0	31.85	48.81±3.60^{c}	54.31±1.86^{e}	50.74±2.34^{f}	49.36±0.57^{e}	2.02±0.16	1.77±0.11
9	*Beauveria bassiana* 1.15% (1X10^{8} CFU's /ml)	5.0	31.10	41.82±3.34^{cd}	46.30±2.79^{f}	40.18±2.03^{g}	37.97±0.49^{f}	2.04±0.09	1.77±0.10
10	*Beauveria bassiana* 1.15% (1X10^{8} CFU's /ml)	7.0	31.60	54.75±1.27^{bc}	53.49±0.86^{e}	54.70±1.79^{ef}	52.23±0.43^{de}	1.98±0.13	1.83±0.06
11	*Metarhizium anisopliae* 1.15% (1X10^{8} CFU's /ml)	5.0	34.35	31.09±4.18^{d}	38.15±2.23^{g}	37.36±2.42^{gh}	35.85±0.59^{fg}	2.01±0.19	1.92±0.14
12	*Metarhizium anisopliae* 1.15% (1X10^{8} CFU's /ml)	7.0	31.00	45.28±2.73^{c}	57.70±1.25^{de}	60.16±1.14^{e}	58.06±0.28^{d}	1.92±0.16	1.92±0.15
13	Pongamia Soap (IIHR Natura Crop Care)	10.0	28.70	33.94±3.53^{d}	36.98±1.93^{g}	33.20±1.58^{h}	30.72±0.38^{g}	2.08±0.12	1.99±0.08
14	Neem Soap (IIHR Natura Crop Care)	10.0	31.25	20.28±2.60^{e}	35.51±2.86^{g}	31.47±2.62^{h}	32.50±0.64^{fg}	2.18±0.09	2.09±0.05
15	HMO	12.5	33.30	47.86±1.92^{c}	56.31±1.04^{e}	53.54±1.29^{f}	47.86±0.31^{e}	2.06±0.19	1.91±0.17
16	Imidacloprid	0.4	33.55	56.67±1.40^{bc}	62.35±0.71^{d}	66.01±1.34^{d}	61.61±0.32^{cd}	1.83±0.06	1.22±0.14

17	Thiamethoxam	0.32	33.05	58.88±0.97[b]	68.94±0.63[c]	73.56±0.92[c]	65.69±0.22[c]	1.91±0.17	1.45±0.12
18	Control	-	-	-	-	-	-	2.01±0.18	2.17±0.13
LSD (p=0.05)				**7.34**	**4.54**	**5.78**	**6.92**	**NS**	**NS**
CV				**16.39**	**8.79**	**10.67**	**13.36**	**-**	**-**
Fstat				**22.93**	**48.89**	**46.80**	**65.19**	**-**	**-**

* values are arcsine transformed; DBS: days before spray; DAS: days after spray; NS: non-significant