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ORIGINAL RESEARCH ARTICLE

Seasonal patterns of insect pest in major pigeonpea and chickpea growing agro-climatic zones of India and their management inferences

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Abstract

A pest scout data in pigeonpea (leaf webber, plume moth, pod borer) and chickpea (pod borer) crops including daily insect pest counts for three successive seasons (2015/16—2017/18) at western and eastern plateau hills (agro-climatic zones) of India was analysed for spatio-temporal dynamics. Longer infestation (different crop phenological growth stages) behaviour of leaf webber and pod borer in pigeonpea and chickpea, respectively influenced their increased mean counts (incidence). Weekly mean counts of leaf webber, plume moth and pod borer in both the crops varied significantly between the seasons. Linear incremental change in mean counts of leaf webber and pod borer on pigeonpea and chickpea, respectively was observed across the seasons (inter-seasonal). Intra-seasonal built-up of plume moth (pigeonpea) and pod borer (pigeonpea and chickpea) mean counts was also noticed. On pigeonpea, leaf webber and plume moth mean counts never reached an economic threshold level (3 larvae/plant), but crossed the advisory level (1.5 larvae/plant). It was observed that there was incremental rise in pod borer mean counts and crossing economic threshold level over seasons in chickpea (1 larvae/m row length), while it was not the case in pigeonpea (1 larvae/ plant). Furthermore, survival and management strategies of leaf webber, plume moth and pod borer in pigeonpea and pod borer in chickpea were discussed.

Keywords Leaf Webber · Pod borer · Population dynamics · Plume moth · Spatial maps · Spatio-temporal · Threshold level

Introduction

The projected India population of 1.67 billion in 2050 (World Population Prospects 2015) will require the overall pulses production to increase 50% relative to levels in 2015 (ICAR-IIPR Vision 2050 2015). Pigeonpea [*Cajanus cajan* (L.)] and Chickpea (*Cicer arietinum* L.) are the major produced pulses in India. The Maharashtra province (comes under western and eastern plateau hills agro-climatic regions of India) positioned at first and second place in production of pigeonpea (30.69%) and chickpea (18.33%), respectively (Directorate of Economics and Statistics 2018). Pulse crops are highly vulnerable to pest attack, which claim for 30% losses annually (ICAR-IIPR Vision 2050 2015). More than 200 insect species feed on pigeonpea and chickpea crops. Most of these insects show sporadic or restricted distribution, or are seldom present at high densities to cause economic losses. Leaf webber, *Grapholita critica* (Lepidoptera:Torticidae), plume moth, *Exelastis atomosa* (Lepidoptera:Pterophoridae) and pod borer, *Helicoverpa armigera* (Lepidoptera:Noctuidae) are major biotic constraints responsible for heavy production losses in pigeonpea (Sujithra and Chander 2014; Kumar and Nath 2003; Sahoo and Senapati 2000). A monetary loss in chickpea and pigeonpea worldwide due to pod borer, *H. armigera* alone was estimated at more than US$600 million annually despite several plant protection interventions (Rao et al. 2013).

Climate (including temperature and rainfall) is considered as one of the parameters to divide the India into 15 agro-climatic regions. Climate change phenomenon is an evident and global average surface temperature is likely to reach 1.5 °C between about 2030 and 2050 (IPCC 2018). In future climate change scenario, insects being poikilotherms and

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possessing short lifecycle may complete more generations per season; and outbreaks are apparent. Scherrer et al. (2016) found climatic seasonality determines the variation in the spatial and temporal availability of the resources (e.g., food and water) and thus generates changes in the abundance, richness, composition, and interactions of the species. Therefore, studies on seasonal presence patterns of the insect pest including identification of seasons maxima and their temporal dynamics over the crop season, provide figures to develop a management initiative. Based on above mentioned reasons, our assumption is to access the impact of different major pulses production regions/ agro-climatic regions (spatial variation) and seasons (temporal variation) on aforesaid insect pest in pigeonpea and chickpea crops.

In the current study, we compiled insect pest scout data of *G. critica, E. atomosa, H. armigera* over three successive growing seasons (2015/16—2017/18) from fifteen major pulse growing districts of Maharashtra province in pigeonpea and chickpea crops. A time to time management advisories were advocated through Crop Pest Surveillance and Advisory Project (https://cropsap.maharashtra.gov.in/) to the local agricultural administration based on temporal and spatial patterns of insect pests activity. Analysing intra-and inter seasonal patterns of insect pests activity over different districts was our objective. Our findings were also discussed in relation to insect pest management in pigeonpea and chickpea.

Methods

Study locations and sampling

The study was conducted in three major pulses growing regions viz., Madhya Maharashtra, Marathwada and Vidarbha, which comes under western and eastern plateau hills agro-climatic zones of India (http://mowr.gov.in/agro-climatic-zones). Districts Ahmadnagar, Jalgaon and Nasik were selected from Madhya Maharashtra region. Aurangabad, Nanded, Osmanabad, Parbhani districts were selected from Marathwada region and from Vidarbha region Akola, Amravati, Buldhana, Chandrapur, Nagpur, Washim, Wardha, Yavatmal districts were selected (Fig. 1). Geographical map of India and Maharashtra province were obtained from Global Administrative Maps (GADM) ver. 3.6 (https://gadm.org/index.html). A fixed plot survey was conducted in fifty randomly selected villages in each district and designated one plot (one plot = 4000 m^2) from each village. The selected plots were farmers owned; therefore, mixture of crop varieties and staggered sowing dates was observed in both pigeonpea and chickpea crops. The crop duration of pigeonpea and chickpea in selected plots was averaged to 170 days and 120 days, respectively for analyses purpose. All agronomic practices were followed according to local recommendation except for insecticidal application. Day-to-day observations were taken in selected plots for incidence of leaf webber, plume moth, pod borer in pigeonpea and pod borer in chickpea. In pigeonpea, randomly ten plants were selected from each plot, and from each plant three branches located in different directions from middle portion of the plant were selected and larval count per 3 branches was ascertained. Whereas in chickpea, randomly five distantly located one metre row length of crop from each plot were selected and, all the chickpea plants (entire plant) present in one meter length were observed to take larval count. Even though, incidence of leaf webber in pigeonpea noticed much earlier than other insect pests, observation on all target insect pest count was started on 41st Standard Meteorological Week (SMW) i.e. October to obtain equal number of observations across test insect pests. Daily observations on target insect pest (LW- Leaf Webber, PM – Plume Moth, PbPp – Pod borer in Pigeonpea, PbCp – Pod borer in Chickpea) was documented as 'daily insect count'. Further, daily insect count was averaged for each SMW and was denoted as 'mean insect count', which was used for analyses in this study. Pigeonpea and chickpea crops grown in *kharif* and *rabi* seasons (yearly once), respectively in the present study regions. In pigeonpea, insect pest (all larval instars of *G. critica*, *E. atomosa* and *H. armigera*) incidence were counted during October, November, December months (from 41 to 52 SMW) for 2015, 2016 and 2017 crop seasons. Likewise, in chickpea incidence of insect pest (all larval instars of *H. armigera*) was enumerated during November, December, January, February months (from 46 to 7 SMW) for 2015/16, 2016/17 and 2017/18 seasons. 'Mean insect count' data was categorised and arranged by seasons (three seasons), month [(three months in pigeonpea) and (five months in chickpea)], regions (three regions) and districts (fifteen districts) for further statistical analysis.

Incidence and threshold levels of insect pests

The mean insect count data was tested for normality, and based on descriptive statistics (skewness = 2.659 and kurtosis = 9.269) and Shapiro-Wilk test significance (df = 1634, $p < 0.05$), the mean data was transformed ($\log_{10}$) before statistical analysis. After data transformation, values of descriptive statistics (skewness = −0.413 and kurtosis = 0.111) and Shapiro-Wilk test significance (df = 1634, $p > 0.05$) witnessed the mean insect count data normalization. Missing observation of insect pest incidence during particular SMW was taken as zero and after transformation of the data those values were denoted as missing values. Incidence of insect pest among seasons, months, regions and districts was compared using Univariant Test (UT) analysis. The mean of ranks for four different insect pests were compared using Tukey's HSD

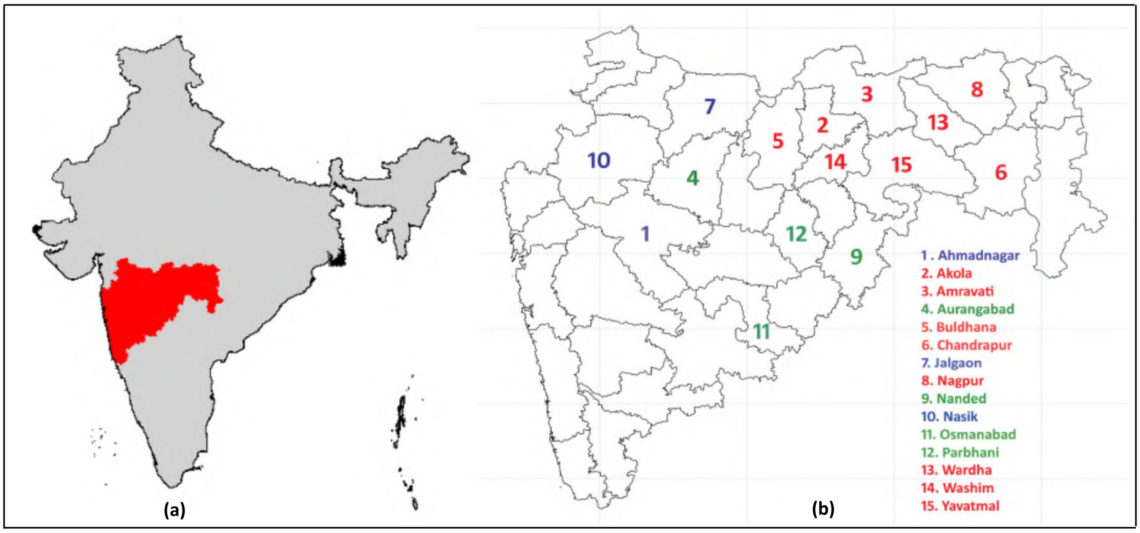


Fig. 1 (**a**) Geographical administrative map of India highlighting the Maharashtra Province (**b**) Map of Maharashtra Province illustrating surveyed districts. Districts with red, blue, green coloured texts belong to Vidarbha, Marathwada, Madhya Maharashtra regions, respectively

post hoc test. Distribution and association of insect pest between seasons, months and regions was illustrated in box plots. The computer software SPSS ver. 25.0 was used for aforesaid analyses (IBM Corp 2017). In this study we followed Economic Threshold Levels (ETL) and Advisory Levels (AL) recommended for test insect pest by Crop Pest Surveillance and Advisory Project (https://cropsap.maharashtra.gov.in/) for timely monitoring and deciphering an advisory to the local farmers. The ETL (LW and PM – 3 larvae/plant; PbPp – 1 larvae/ plant; PbCp – 1 larvae/ m row length) of target insect pests were observed in each SMW across regions and districts during three consecutive seasons (2015, 2016, 2017). Since the mean counts of LW (1.5 larvae/ plant) and PM (1.5 larvae/plant) never reached ETL, so AL was observed for these insect pests.

Time series and geographical maps of insect pests

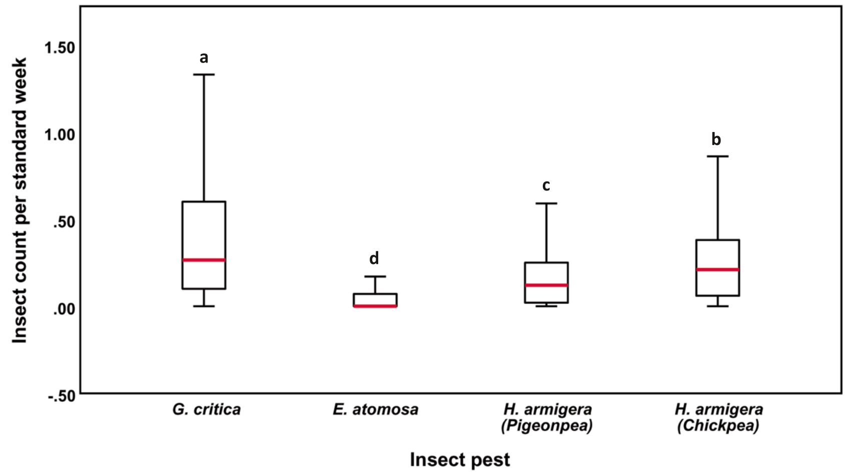
Temporal dynamics of target insect pest in different districts over three successive seasons across the regions and months was explained. Geographical distribution and incidence of test insect pests on pigeonpea and chickpea was illustrated on geographical map of Maharashtra province. To map the geographical distribution of target insect pests, mean insect count data was standardised ($(x-\mu)/\sigma$) to avoid missing values and also to attain equal number of distribution class intervals (4 no.) over the seasons. Shape file (level = 2) of Maharashtra province was obtained from GADM ver 3.6 data. To develop a geographical distribution and incidence maps of insect pests for different seasons further the Maharashtra province shape file was used as an input file to GADMTools package (Jean Pierre 2020) in R Studio (RStudio team 2019). The graphs in this study were developed using ggplot2 package (Wickham 2016) in RStudio.

Results

Seasonal means of target insect pest counts and their thresholds

Insect pests (LW, PM, PbPp, PbCp) in this study differed significantly with each other over their weekly mean counts (UT = 129.06, $P = 0.00$, $df = 3$) across the districts, regions, months and seasons (Fig. 2). Inter-seasonal profiling of target insect pests demonstrated considerable differences for their mean counts (LW: UT = 32.43, $P = 0.00$, $df = 2$; PM: UT = 44.75, $P = 0.00$, $df = 2$; PbPp: UT = 16.68, $P = 0.00$, $df = 2$; PbCp: UT = 30.50, $P = 0.00$, $df = 2$). Similarly, intra-seasonal mean insect pest counts of target insects revealed significant differences (LW: UT = 32.80, $P = 0.00$, $df = 2$; PM: UT = 3.08, $P = 0.04$, $df = 2$; PbPp: UT = 35.66, $P = 0.00$, $df = 2$; PbCp: UT = 25.02, $P = 0.00$, $df = 3$). Except LW, other three insect pest (PM, PbPp, PbCp) demonstrated no significant differences for their mean counts (LW: UT = 12.66, $P = 0.00$, $df = 2$) between regions (Fig. 3). Throughout the seasons it was noticed that LW and PM mean counts never reached ETL i.e. ≥3 larvae/plant, but crossed AL i.e. ≥1.5 larvae/plant for multiple times that was illustrated in Fig. 4 by encircling. Among three seasons, LW mean counts crossed AL (1.5 larvae/plant) for multiple times starting from 41 to 48 SMW during 2017. Whereas, mean counts for PM crossed the AL (1.5 larvae/plant) only for twice during 2016 in 50th and 51st SMW. The PbPp mean counts crossed an ETL (≥1 larvae/plant) once (during 2015 and 2017) and

Fig. 2 Weekly mean counts of insect pest



thrice (during 2016) in the entire period of observation. During 2015, 2016 and 2017, PbCp mean counts crossed an ETL (≥1 larvae/m row length) in one, two and seven occasions, respectively across the period (Fig. 4).

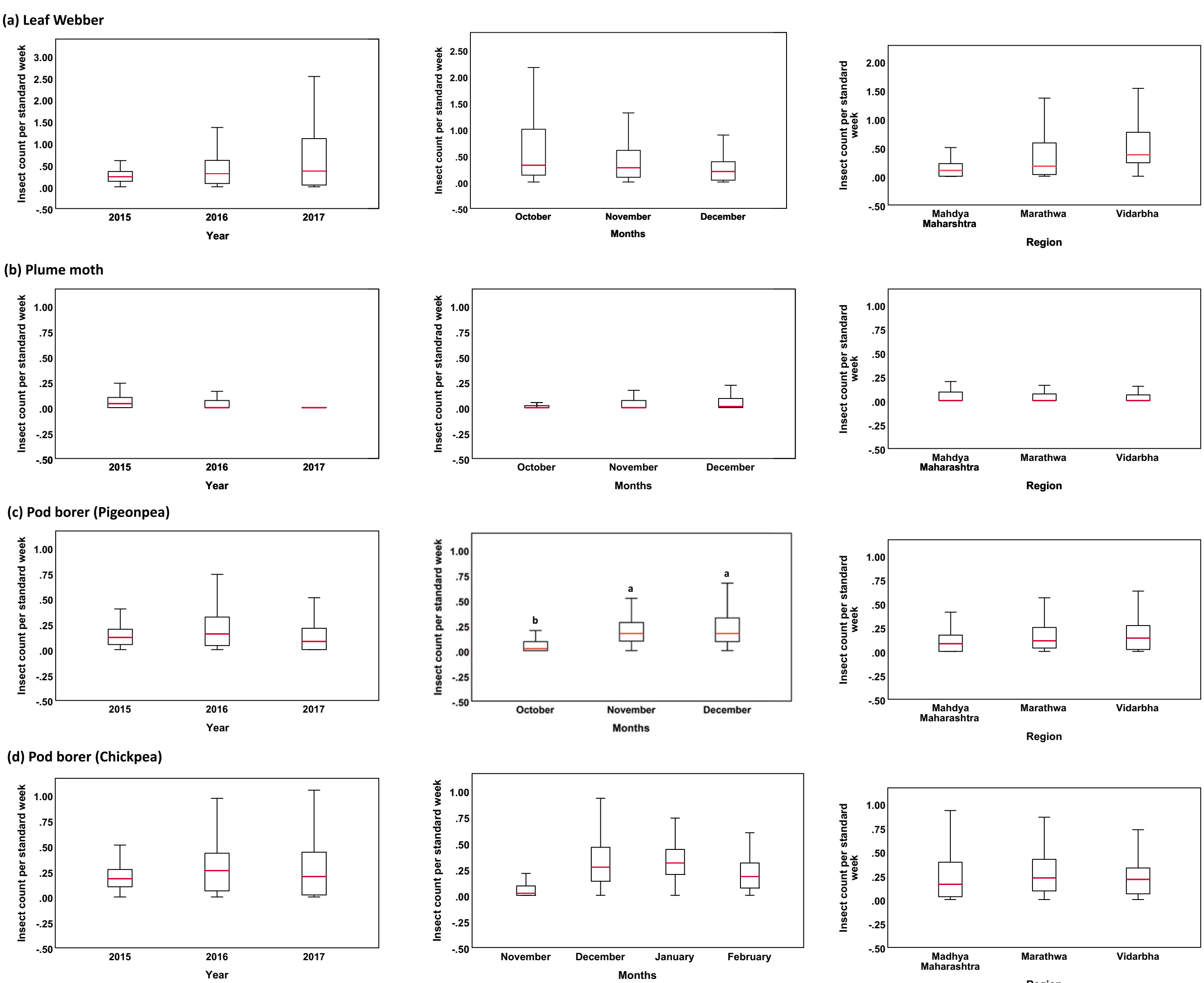


Fig. 3 Distribution of weekly mean insect pest counts over different crop seasons, months and regions

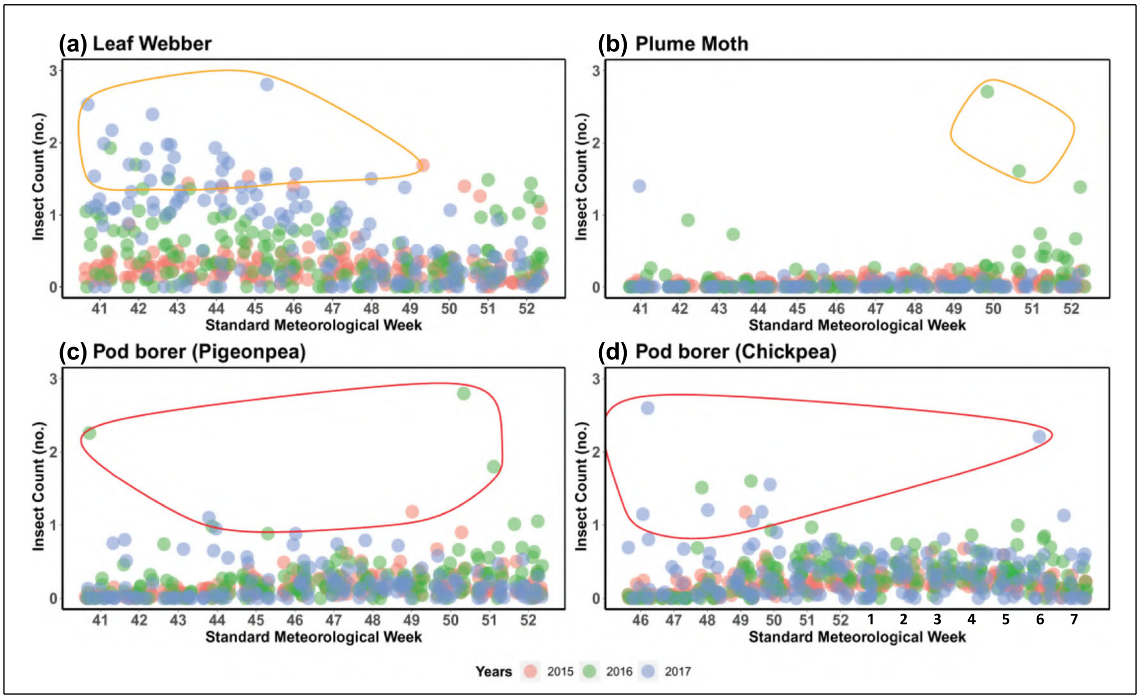


Fig. 4 Encircled insect pest counts crossing the advisory and economic threshold levels over different weeks

Temporal and spatial dynamics of target insect pests

Insect pest counts demonstrated considerable differences over three seasons (Fig. 3) and fifteen districts (Suppl. Table. 1). Time series graph showed Akola (1.05), Nanded (0.73) and Yavatmal (1.18) districts with high LW mean counts per plant during 2015, 2016 and 2017 crop seasons, respectively. Mean counts of PM per plant reached peak in Nasik during 2015 (0.11) and 2017 (0.14), while Jalgaon witnessed an abnormal high mean counts (0.44) for PM in 2016. Amravati (1.41) and Osmanabad (0.58 and 0.4) districts were observed with elevated PbPp mean counts for 2015, 2016 and 2017, respectively. Inflated mean counts of PbCp was noticed in Nagpur (0.4), Nanded (0.48) and Ahmadnagar (0.64) districts during 2015, 2016 and 2017, respectively (Fig. 5). The spatial maps illustrated the distribution of target insect pests over different districts based on four distribution class intervals. The distribution class interval values (transformed mean insect counts) varied among target insect pests (Fig. 6). In four different distribution class intervals, first class interval indicated higher values (high mean insect counts) and followed by decreased values (low mean insect counts) in subsequent class intervals. Leaf webber distribution under first class interval was observed in only one district (Akola) during 2015, later on in 2016 and 2017 (subsequent seasons) the distribution was escalated to three (Amravati, Nanded, Osmanabad) and seven (Akola, Amravati, Chandrapur, Nagpur, Nanded, Wardha, Yavatmal) districts, respectively under first class interval. Four (Ahmadnagar, Aurangabad, Nasik, Yavatmal), one (Jalgaon) and one (Nasik) districts were detected with PM distribution in first class interval during 2015, 2016 and 2017 seasons, respectively. In 2015, 2016 and 2017 seasons, distribution of PbPp was noticed in one (Amravati), two (Jalgaon, Osmanabad) and one (Osmanabad) districts, respectively under first class interval. While, PbCp distribution was descended to first class interval in one (Nagpur), four (Ahmadnagar, Nanded, Washim, Yavatmal) and three (Ahmadnagar, Nanded, Osmanabad) districts during 2015, 2016 and 2017, respectively (Fig. 6).

Discussion

Leaf webber larvae were small (10mm) but their damage symptoms were conspicuous (webbed leaflets/flower buds). Infestation of LW begin as early as the seedling stage and continue till flowering and podding stages. In general, pod borer and plume moth infestation were limited to flowers, buds and pods in pigeonpea. In chickpea, foliar damage was most common along with pod damage by pod borer (Ranga Rao and Shanower 1999). In present study, mean LW counts were high followed by PbPp and PM in pigeonpea. It can be interpreted from the context of infestation that LW has potential to infest crop at different phenological growth stages i.e. from vegetative to reproductive stage, while PbPp and PM were restricted to few crop phenological growth stages (reproductive stage). Likewise, wider infestation potential on crop (from vegetative to reproductive stage of crop) was also

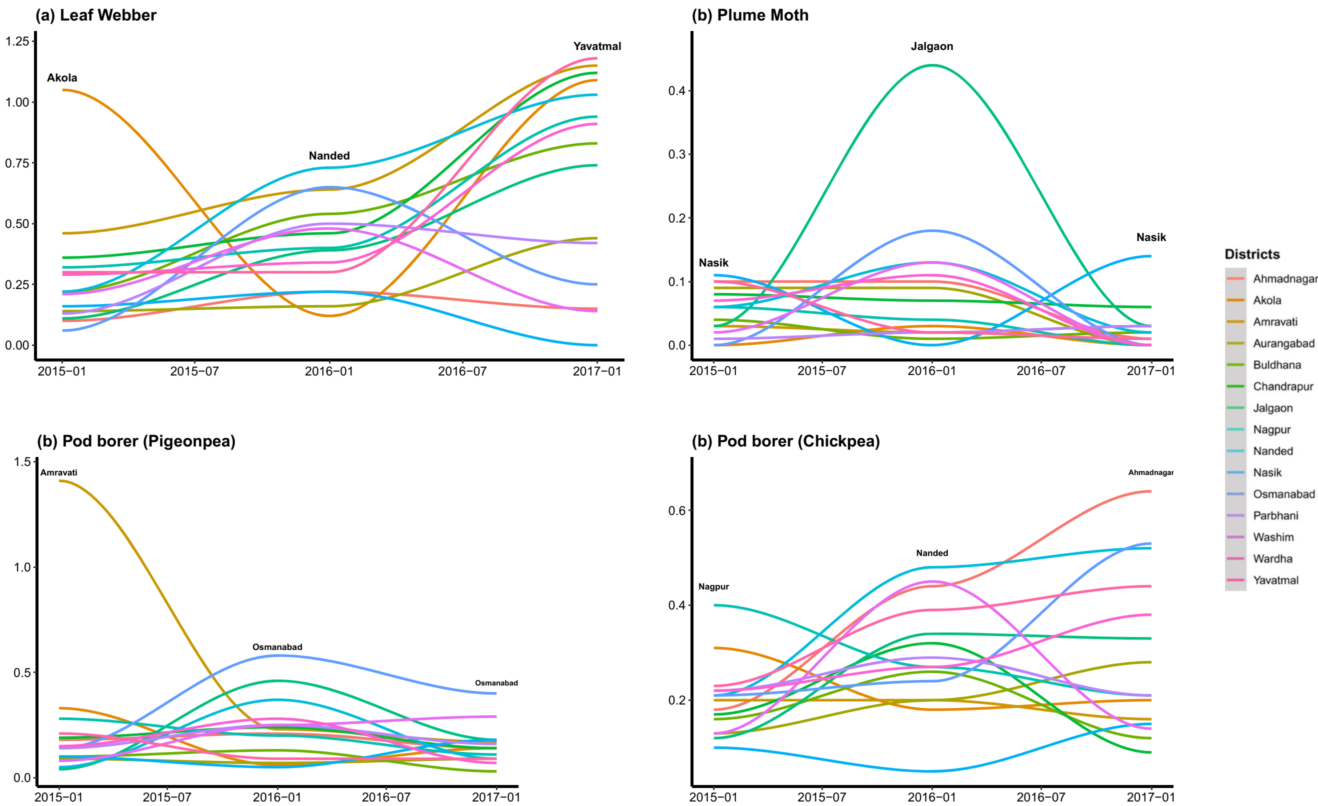


Fig. 5 Temporal dynamics of mean insect pest counts over different crop seasons in fifteen districts

observed with PbCp. An elevated mean count of LW and PbCp in pigeonpea and chickpea, respectively was directly linked to their wider infestation potential on different crop phenological growth stages and availability of the food throughout the crop period (Fig. 2).

Seasonal differences in LW, PM, PbPp and PbCp mean count were observed, whereas mean counts of LW and PbCp increased in pigeonpea and chickpea, respectively and, PM and PbPp mean counts remain stagnant or decreased over seasons (Figs. 3 and 5). It was evident from earlier studies that temperature and wind speed had positive impact on incidence of pod borer and plume moth in pigeonpea (Bhadani and Patel 2019; Rahul Kumar et al. 2017). In present study, changing pattern in mean insect counts between seasons may be linked to one or multiple reasons - crop succession, multiple crops, insecticidal resistance, biotic (predators and parasitoids) and abiotic factors (temperature, relative humidity, rainfall, wind). The possible adaptations of insect pest to the changing cropping systems, weather conditions, crop-pest interactions and improved insect survival strategies favoured an explosion of mean insect counts of LW and PbCp over the course of seasons.

Starting from October to December an increasing larval activity of plume moth and pod borer in pigeonpea was noticed, but an incremental decline in leaf webber mean larval population was observed from August to October within a season (Bhadani and Patel 2019; Ajay Kumar et al. 2018). Gautam et al. (2018) reported that pod borer larval incidence on chickpea started on 46th SMW and continued its presence up to 8th SMW (subsequent year). Therefore, it was not so surprising in present study that mounting intra-seasonal (between months) mean counts of PM and PbPp, and declining LW means counts from October to December months. Mean counts of PbCp began to rise from November and reached to peak on January and flattened during February month (Fig. 3). Staggered sowing dates, variations in plant density, different plant varieties and various plant protection measures in neighbouring plots might influenced the intra-seasonal (within crop season) in-crop recruitment of LW, PM, PbPp and PbCp.

In the present study area i.e., Maharashtra province, chickpea cultivation increased to 14%, whereas pigeonpea growing area declined by 13.8% from 2015/16 to 2016/17 (Directorate of Economics and Statistics 2017 and 2018). Increased chickpea cropping area over pigeonpea in addition to PbCp wider infestation widow in study area might supported the pod borer incidence (mean insect count) on chickpea over pigeonpea. Barton-Browne (1993) stated that the host seeking behaviour of insects can be affected by their physiological state i.e., time elapses since last oviposition, which can control the motivation to oviposition. Plants emit positive and negative cues that

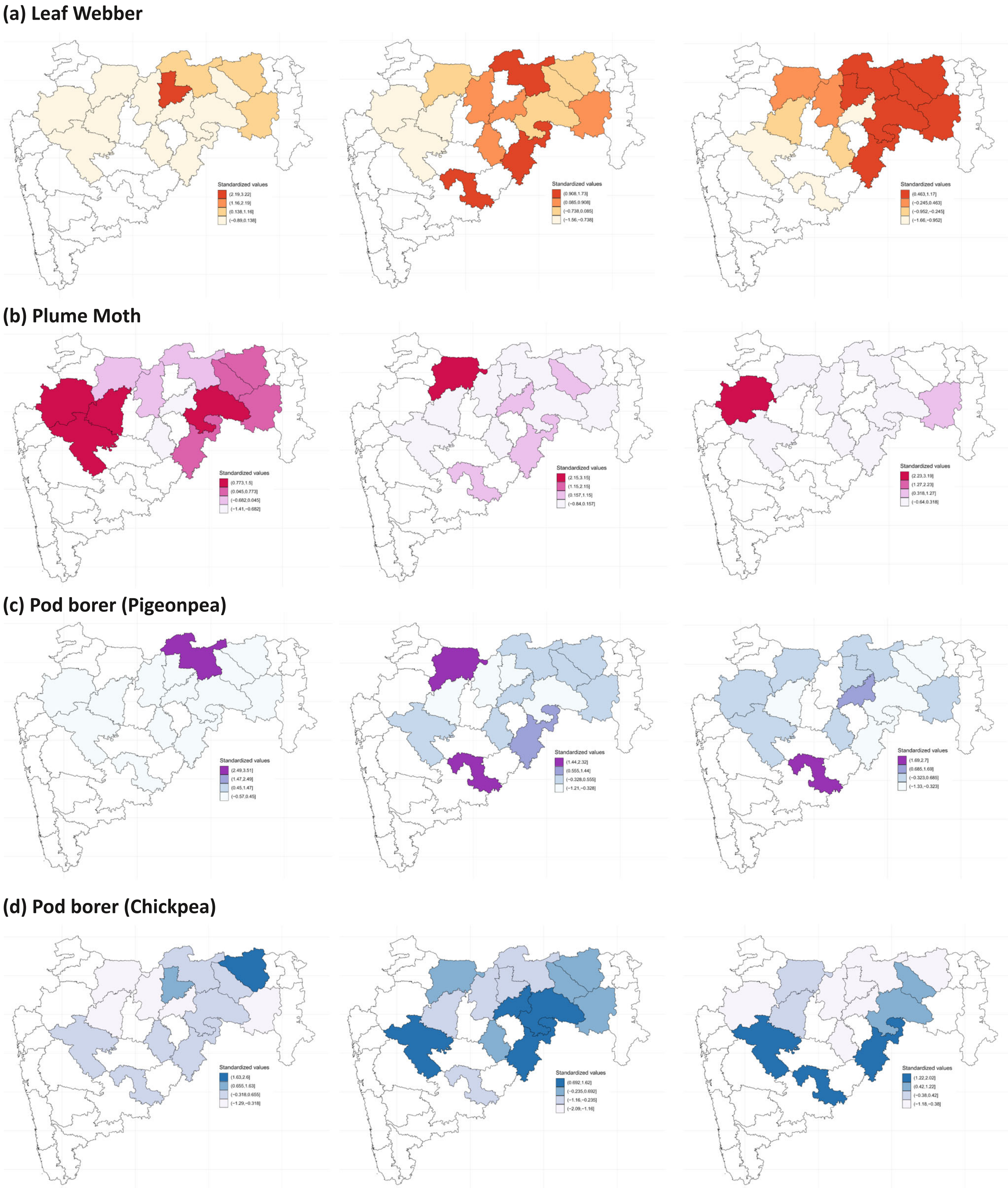


Fig. 6 Maps of insect pest incidence during 2015, 2016 and 2017 in fifteen districts of Maharashtra Province, India. Insect pest incidence illustrated in respect of intensity of the colour

were sensed and processed differently by individual female adult insects; hence, the variation of host plant preference by individual insects (Jallow and Zalucki 2003). Preferential positive chemical cues released by chickpea host may also be a possible factor for more pod borer incidence (mean insect counts).

Symptoms of leaf webber on pigeonpea were conspicuous and visible that encourage farmers to use chemical insecticides. However, plants may produce side branches in compensation to loss; hence leaf webber impact on yield usually negligible (Ranga Rao and Shanower 1999). Bharath Kumar et al. (2014) reported no economic loss was observed on releasing 10 larvae of leaf webber per plant. In present study, LW mean counts never reached ETL (≥3larvae/plant) and moreover an earlier literature reported no significant impact on yield, thus, at this juncture it was not meaningful to discuss on LW control measures. Incidence (mean insect count) of PM in pigeonpea was below the ETL over the seasons during this study, so further management strategies were not discussed hereunder. Increased ETL crossings (numbers) was clearly visible for PbPp and PbCp in pigeonpea and chickpea, respectively as seasons passed. Therefore, an area-wide management (AWM) strategy for PbPp and PbCp in pigeonpea and chickpea, respectively was discussed for locations/districts to avoid the unforeseen losses in near future (Fig. 4). The IPM based AWM program include the following components that could be adopted to manage the pod borer menace in pigeonpea and chickpea; mechanical control method (seasonal traps), wide hybridization (wild derivatives), application of label claimed insecticides (rotation with different mode of actions), site specific pest management (field by field approach), introducing transgenic plants (insecticidal activity), use of biopesticides (Nuclear Polyhedrosis Virus and *Bacillus thuringiensis* bioformulations) and implementing augmentative biological control (*Campoletis chloridae*) (Gupta et al. 2004; Sequeira and Playford 2002; Fitt 2000; Fitt 1994; Tabashnik 1989).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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