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Effect of Weather Factors and Growing Degree day on Population Build up of *Aphis craccivora* and *Empoasca kerri* on *Vigna mungo*

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ABSTRACT: Black gram, *Vigna mungo* (Linn.) Hepper, a short duration pulse crop, which popularly known as urdbean, mash, mashkalai *etc*., belongs to the family Fabaceae; sub family Papilioniaceae are infested by sap feeder, foliage feeder, pollen and tissue borer and fruit feeder. Amongst the pests, sap feeders like aphid (*Aphis craccivora*) and jassid (*Empoasca kerri*) play major role in reducing the yield quality and quantity of the crop. An experiment was thus conducted to assess the influence of weather factors on population build up of *A. craccivora* and *E. kerri* in black gram crop during pre-kharif and post kharif season of two years 2018 and 2019. Pests' data of four crop seasons, when corroborated with weather parameters it was revealed that evening relative humidity and rainfall had a negative significant influence on aphid population in both the seasons. In addition to this maximum and minimum temperature showed significant negative correlation in post kharif season. However, morning relative humidity was negatively correlated with aphid population in pre kharif season, while the opposite trend was observed in post kharif season. Moreover, maximum temperature had a significant positive influence on jassids population in both the season, though minimum temperature showed the same trend only in pre kharif season. Both rainfall and evening relative humidity had a significant negative impact on jassid population in both the season. However, morning relative humidity showed a significant negative effect in pre kharif season. Bright sunshine hours had a significant positive influence on both the pests in both the seasons. The accumulated degree day had a positive influence on both the pests. Nonlinear power and logistic growth models were found best models to predict the aphid and jassid population activities in different phenological stages of black gram crop. Aphid and jassid required 197.20 and 200.96 degree day to reach peak population level in flowering stage of the crop.

Keywords: *Aphis craccivora*, *Empoasca kerri*, Abiotic factors, Growing degree day

INTRODUCTION

Urdbean (*Vigna mungo*) is an important pulse crop used as a whole grain, germinated grain, dal and flour in human diet suffering from and low and erratic rain fall, improper nutrient management number of pests and diseases which ultimately affect the production and productivity. Amongst the pests, sap feeders like aphid (*A. craccivora*) and jassid (*E. kerri*) play major role in reducing the yield quality and quantity of the crop. Black gram, *Vigna mungo* (Linn.) Hepper, a short duration pulse crop, which popularly known as urdbean, mash, mashkalai *etc*., belongs to the family Fabaceae; sub family Papilioniaceae. It contributes 10% of national pulses production (Nene, 2006). India is not only the largest producer of the black gram, but is also largest in the world (Singh and Singh, 1977). As per Fourth Advance Estimates in India, black gram was grown in about 31.92 lakh ha area and production was about 18.3 lakh tonnes in 2011-12 with an average productivity of 485 kg/ha (Anonymous, 2011). India has distinction of being world's largest producer of grain legumes by growing over a dozen pulse crops. Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh and West Bengal are the major black gram growing states in India. They are major source of dietary proteins, essential amino acids, minerals, some vitamins as well as source of energy. The crop is damaged by an array of insect pests from sowing to harvest in the field as well as in the harvested produce in storage (Lal and Sachan, 1987). Nearly twelve species of insects causes considerable yield loss in black gram. Whitefly (*B. tabaci*), aphid (*A. craccivora*), Jassid (*E. kerri*.), flower thrips (*M. thripsdistalis*), gram pod borer (*H. armigera*), spotted pod borer (*M.testulalis*) and hairy caterpillar (*S. obliqua*) were recorded as major pests on black gram (Kumar and Chandra, 2007). *A. craccivora* is one of the major pest of *Vigna* spp. The nymphs and adults cause damage to the leaves by sucking sap from the under surface. It also infests the tender shoots. It marked its appearance at the vegetative stage of crop growth. The pest mostly appeared in last week of October on *V. mungo* and in the first week of October on *V. radiata*. The nymphs and adults of jassid (*E. kerri*) suck the sap from the leaves mostly from under surface which reduce the vigour of the plants. Its appearance was noticed from seedling to pod filling stage of crop growth. An average reduction of yield of black gram to the tune of 20.03%, which varies from 15.62-30.96% depending upon the varieties is caused by the pest complex (Duraimurugan and Tyagi, 2014). However, the annual yield loss due to the insect pests has been found at about 30 per cent in black gram (Gupta and Bhattacharya, 2008).

There present no information's on the occurrence of the sap feeders in black gram crop in terai region of West Bengal. Since both the pests played significant role in plant vigor and thus productivity of the crop, therefore, the present work has been undertaken to study the population dynamics of the pests and their relation to the prevailing climatic conditions in the region concerned to develop management programme based on the prediction of the pest activities expressed by different growth models.

MATERIALS AND METHOD

Two crop seasons, both pre-kharif (February to May) and post-kharif (September to December) of consecutive two years 2018 and 2019 were considered for experiments. The experimental site was located in the Instructional Farm, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India. It is situated between 26°19′86″N latitude and 89°23′53″E longitude at an elevation of 43.0 m above mean sea level. The plot size for the experiment was 30mx 20m. The sowing of black gram variety Saroda was made with the help of 11 tynemulti crop planter on 7^{th} and 39^{th} SMW (standard meteorological week) in pre-kharif and post-kharif season respectively.

Seed biopriming was carried out with bioinoculant consortium of *Rhizobium* (URH), *Trichoderma viride* (UBT-18) and phosphate solubilising bacteria (UBPS-9) @5g/kg of seed for 30 minutes under shade and sown immediately after drying. The bioinoculants were collected from the Department of Plant Pathology of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar. Standard agronomic packages were followed, while raising the crop.

Pest populations were recorded at seven days intervals during morning hours. Thirty crop plants were randomly selected and tagged for weekly observations. The observations on pest population were taken from 21 days of crop age in both the seasons and continued upto physiological maturity of the crop.

The incidence of aphids *A. craccivora* was recorded from 10 cm twig per plant. The populations of jassid *E. Kerri* were recorded from three fully formed leaves of upper, middle and lower canopy of each plant and presented as number per trifoliate per plant. The data on pest populations were transformed before analysis.

Daily weather parameters like temperature (maximum and minimum), relative humidity (morning and evening), rainfall and bright sunshine hour were collected from the Meteorological Observatory of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar. The growing degree day was computed by using the formula proposed by (Nuttonson, 1955) with base temperature as 10^0C for black gram crop (Singh *et al*, 2013). Accumulated growing degree day (AGDD) was calculated by simple accumulation of GDD upto different crop phenological stages from the sowing date as base fix.

Statistical significance of Pearson's correlation coefficients and stepwise regression analysis were made between pest population and weather parameters of 1-lag week (preceding week). The population dynamics of *A. craccivora* and *E. kerri* were subjected to analysis for evaluating different models to predict activities of the pests in relation to accumulated degree day at different stages of crop phenology. All the statistical analysis were done by using statistical software SAS ver. 9.2

RESULTS AND DISCUSSION

The population build-up of important sucking pest aphid and jassid were recorded on black gram variety Saroda in both crop seasons. The pooled mean data of two years study are represented in Table 1.

In post kharif season the aphid and jassid population started infesting the crop at 4 weeks after sowing in last week of October (43^{rd} SMW) at branch initiation stage. The initial mean aphid and jassid populations were observed 0.73/10 cm twig/plant and 1.72 N&A/trifoliate/plant. The peak population of aphid of 15.32 N&A/plant was observed at peak flowering stage on 49 days old crop on 46^{th} SMW in2nd week of November. The peak jassid population was noticed in 45^{th} SMW (6.70 N&A/trifoliate/plant) at 7 weeks after sowing during 1^{st} week of November.

Table 1: Infestation level of major insect-pests of black gram in pre-kharif and post –kharif crop seasons (Pooled mean of 2018-2019).

Pre-kharif season			Post-kharif season		
SMW	Aphid/10cm twig/plant	Jassid/trifoliate/ plant	SMW	Aphid/10cm twig/plant	Jassid/trifoliate/ plant
10	0.00(0.71)	0.20(0.84)	42	0.00(0.71)	0.00(0.71)
11	0.00(0.71)	1.10(1.26)	43	0.73(1.11)	1.72(1.49)
12	1.57(1.44)	2.60(1.76)	44	2.17(1.63)	3.35(1.96)
13	10.25(3.28)	4.33(2.20)	45	4.32(2.19)	6.70(2.68)
14	49.42(7.07)	2.03(1.59)	46	15.32(3.98)	5.37(2.42)
15	7.03(2.74)	2.67(1.78)	47	14.97(3.93)	4.38(2.21)
16	3.47(1.99)	1.52(1.42)	48	12.73(3.64)	1.65(1.47)
17	0.52(1.01)	0.27(0.88)	49	5.60(2.47)	0.38(0.94)
18	0.00(0.71)	0.00(0.71)	50	0.90(1.18)	0.00 (0.71)

*Figure in parenthesis indicates square root transformed value

The aphid population became maximum when maximum weekly temperature, minimum weekly temperature, weekly morning relative humidity, weekly evening relative humidity and weekly bright sunshine hours of 1 lag week were recorded 30.04°C, 17.68°C, 78.14%, 60.71% and 5.71 hours respectively; where the parameters were 31.36°C, 18.51°C, 70.21%, 53.36% and 8.00 hours respectively at peak jassid population level in field. A steady population of both the pests was observed up to 48th SMW, when the crop was at full pod formation stage.

In pre-kharif season, the aphid population started to infest the black gram crop at 5 weeks after sowing in 3rd week of March with a population of 1.57 N&A/plant, while the jassid population (0.20 N&A/trifoliate/plant) was first noticed at 3 weeks after sowing on 1st week of March (10th SMW). The peak population of jassid of 4.33 N&A/trifoliate/plant was observed on 13th SMW at 6 weeks after sowing during 4th week of March. The peak aphid population (49.42 N&A/plant) was observed at 7 weeks after sowing in 1st week of April (14th SMW), when the crop was at flowering stage. The maximum weekly temperature and minimum weekly temperature, weekly morning relative humidity, weekly evening relative humidity and weekly bright sunshine hours of 1 lag week of peak aphid population were recorded 29.23°C, 17.08°C, 71.21%, 54.14% and 5.95 hours respectively. It was 31.41°C, 17.39°C, 67.21%, 46.29% and 6.45 hours respectively when the jassid populations were highest.

Therefore, the populations of both the pests were found to infest the crop from early vegetative stage of the crop to its pod formation stage with peak in flowering stage of the crop in both the seasons. Low population of pest was found in pod formation of stage in pre-kharif season as compared to post kharif season. This was might be due to light to heavy rainfall received during pod formation stage in pre-kharif seasons in both the years, but the same stage of the crop was free from rainfall in post-kharif seasons. The overall infestation of aphid was higher in pre-kharif crop as compared to post-kharif crop but the reverse trend was observed in jassid infestation.

The outcome of present investigation is in conformity of earlier works. In lower Gangetic plains of West Bengal, aphid population were recorded on kharif black gram crop from 5 weeks after sowing and continued up to 10 weeks after sowing with a peak on 7 weeks after sowing, while in summer crop it was observed from 5 weeks after sowing with maximum infestation level at 6 weeks after sowing in other varieties. The dominance of aphid infestation in pre-kharif season also corroborates with the finding of the present investigation (Biswas and Banerjee 2019). In cowpea crop, high black aphid population was noticed in flowering to pod formation stage during 1st week of December in Pantnagar (Yadav *et al*, 2015). The jassid population was found from 2to 3weeks after sowing and peak population was reached between 7to 13weeks after sowing depending upon the sowing period of crop. At peak period the population level varied from 4.36 to 16.50/plant (Radhika *et al.*, 2018; Sharma and Singh, 2015; Yadav *et al.*, 2015; Justin *et al.*, 2015; Vikrant *et al.*, 2013; Kore, 2011) supports the present result. However, the pest was noticed in cowpea crop from 1st week after sowing, while the peak population was observed 8th to 9th week after sowing (Yadav *et al.*, 2015b; Anandamurthy *et al.*, 2018).

This variation of temperature regime along with relative humidity and rainfall during the period of study might be the reason of comparatively higher aphid population on flowering stages of the crop in pre-kharif season, but moderate to high level of population was not sustained for longer period of time in the later stages of the crop like post kharif season.

In earlier research findings, it was found that temperature range of 22.0°C to 28.0°C is most favourable for growth and development of black aphid *A. craccivora*. The intrinsic rate of increase of black aphid gradually declines above 30.0°C and became almost zero at 35.0°C (Filho *et al.*, 2019; Cho *et al.*, 2018; Singh *et al.*, 2017; Berberet *et al.*, 2009; Berg, 1984 and Campbell *et al.*, 1974). Moreover, higher night temperature during hot days is also unfavourable for aphid survival (Zhao *et al.*, 2014).

In pre-kharif season correlation and regression studies between aphid and jassid populations and weather parameters of 1-lag week presented in Table 2 revealed significant negative association of morning relative humidity (r= 0.332, 0.487), evening relative humidity (r= 0.135, 0.440) and weekly rainfall (r=0.254, 0.218), while bright sunshine hour showed significant positive effect (r=0.157, 0.222) on pest population. The maximum temperature (r=0.253) showed positive influence on jassid population. The stepwise multiple regression (Table 3) analysis revealed that all the weather parameters posed significant influence on aphid population fluctuation and the multiple correlation co-efficient (R^2) was found 0.4905, explaining 49.05% variation of aphid population by the weather factors. The multiple correlation coefficient (R^2) was found 0.2946 for jassid population, which depicts 29.46% contribution on variation of jassid population by morning relative humidity, rainfall and bright sunshine hour.

Table 2: Correlation studies between important sucking pests of black gram and weather parameters in pre-kharif during 2018-2019 (pooled) (n=270).

Sr. No.	Pest	Max. Temp.	Min. Temp.	Mor RH	Eve RH	Rainfall	BSH
1.	Aphid	0.036 (0.5544)	-0.042 (0.4895)	-0.332 (<.0001)	-0.135 (0.0268)	-0.254 (<.0001)	0.157 (0.0099)
2.	Jassid	0.253 (<.0001)	-0.117 (0.0540)	-0.487 (<.0001)	-0.440 (<.0001)	-0.218 (0.0003)	0.222 (0.0002)

*Value inside the parenthesis indicates the exact significance level,
n= Number of Observations, Max Temp= Maximum Temperature, Min Temp= Minimum Temperature, Mor RH= Morning Relative Humidity, Eve RH= Evening Relative Humidity, BSH= Bright Sunshine Hours

Table 3: Stepwise multiple regression between pest population and weather parameters of pre-kharif season during 2018-2019(Pooled).

Variable	Regression Coefficients	Standard error	t-value	p- value	
A. Aphid					
Intercept	174.732	13.090	13.35	<.0001	R^2 value = 0.4905, Adjusted R^2 = 0.4789, F value = 42.19, p= <.0001, DF = 269, Mean Square Error = 2.230
Maximum Temperature	-4.417	0.405	-10.90	<.0001	
Minimum Temperature	3.030	0.341	8.88	<.0001	
B. Jassid					
Intercept	10.985	1.211	9.07	<.0001	R^2 value = 0.2946, Adjusted R^2 = 0.2866, F value = 37.03, p= <.0001, DF = 269, Mean Square Error = 0.337
Morning Relative Humidity	-0.107	0.012	-9.20	<.0001	
Rainfall	0.032	0.011	2.92	0.0038	
Bright Sunshine Hours	-0.334	0.083	-4.03	<.0001	

In post-kharif crop season, maximum temperature (r=0.142), minimum temperature (r=0.212), evening relative humidity (r=0.266) and weekly rainfall (r=0.358) had a significant negative association with aphid population, while strong positive relation with morning relative humidity (r=0.178) and bright sunshine hour (r=0.200) was observed. The maximum and minimum temperature as well as bright sunshine hours showed strong positive influence on jassid population build up having correlation coefficient (r) 0.412, 0.241 and 0.422 respectively. In-contrary, morning relative humidity (r=0.123) and rainfall (r=0.322) had a negative impact of the jassid population (Table 4).

Table 4: Correlation studies between important sucking pests of black gram and weather parameters in post-kharif during 2018-2019 (pooled) (n=270).

Sr. No.	Pest	Max Temp	Min Temp	Mor RH	Eve RH	Rainfall	BSH
1.	Aphid	-0.142 (0.0197)	-0.212 (0.0005)	0.178 (0.0033)	-0.266 (<.0001)	-0.358 (<.0001)	0.200 (0.0010)
2.	Jassid	0.412 (<.0001)	0.241 (<.0001)	-0.123 (0.0434)	-0.019 (0.7527)	-0.322 (<.0001)	0.422 (<.0001)

*Value inside the parenthesis indicates the exact significance level, n= Number of Observations, Max Temp= Maximum Temperature, Min Temp= Minimum Temperature, Mor RH= Morning Relative Humidity, Eve RH= Evening Relative Humidity, BSH= Bright Sunshine Hours.

The multiple correlation coefficient(R^2) obtained from stepwise multiple regression analysis was 0.5225, explaining 52.25% variation of aphid population by maximum temperature, minimum temperature, morning relative humidity and rainfall. Whereas, in jassid population fluctuation maximum temperature, evening relative humidity and rainfall played significant role with corresponding multiple correlation coefficient (R^2) 0.3850, contributing 37.81% variations in jassid populations (Table 5).

Similar trends were observed in the earlier works of many researchers, where maximum temperature, minimum temperature, relative humidity and rainfall had a significant negative influence on black aphid population build-up in different host crops (Chakraborty and Das 2021; Manjunatha *et al.*, 2019; Kishor *et al.*, 2019; Gocher and Ahmad, 2019; Rakshan *et al.*, 2018; Jat *et al.* 2017; Kumar and Singh, 2016 and Yadav *et al*. 2015), while positive correlation was found with bright sunshine hours (Biswas and Bannerjee, 2019; Kumar *et al.*, 2019). In contrast to present findings, many workers observed positive correlation of temperature and humidity with aphid population infesting different hosts crop grown in different crop seasons under different climatic conditions (Kataria and Kumar, 2017; Pathan and Rahaman, 2019; Kumar *et al.*, 2019; Ramesh *et al.*, 2019). However, the long-term research experiments of continuous seven years revealed that maximum temperature, minimum temperature, morning relative humidity and evening relative humidity showed negative correlation with the black legume aphid *A. craccivora* population (Prasad *et al.*, 2008). The findings of earlier works on impact of weather parameters for population dynamics of jassids in different host crops including black gram (Kumar *et al.*, 2019; Rechappa *et al.*, 2016; Anandamurthy *et al.*, 2018; Sahoo, 2016; Khanpara and Acharya, 2012; Yadav and Singh, 2006) are in line with the present result.

As temperature was found to have profound effect on population dynamics of both the sucking pest aphid and jassid, the emphasis was given to corroborate its infestation with crop phenology based on growing degree day. The accumulated degree-day in each day of observations when correlated with pest data, it was revealed that the pests showed a positive correlation with accumulated degree-day. The correlation coefficient (r) was found as 0.366 and 0.227 for aphid and jassids respectively (Table 6).

Table 5: Stepwise multiple regression between pest population and weather parameters in post-kharif season during 2018-2019 (Pooled).

Variable	Regression Coefficients	Standard error	t-value	p-value	
A. Aphid					
Intercept	-35.640	3.737	-9.54	<.0001	R^2 value= 0.5225, Adjusted R^2= 0.5153, F value= 72.49, p= <.0001, DF= 269, Mean Square Error = 0.948
Maximum Temperature	0.852	0.124	6.84	<.0001	
Minimum Temperature	-0.467	0.057	-8.19	<.0001	
Morning Relative Humidity	0.273	0.019	14.71	<.0001	
A. Post-Kharif Season (Pooled)					
Intercept	1.444	0.456	3.17	0.0017	R^2 value=0.3850, Adjusted R^2=0.3781, F value=55.52, p= <.0001, DF=269, Mean Square Error = 0.442
Minimum Temperature	0.284	0.030	9.44	<.0001	
Evening Relative Humidity	-0.081	0.015	-5.48	<.0001	
Rainfall	-0.259	0.052	-4.97	<.0001	

Table 6: Correlation studies between important pests and accumulated degree days of black gram crop growth period during 2018-2019 (Pooled).

	N	Aphid	Jassids
AGDD	44	0.366(0.015)	0.227(0.138)

Five non-linear growth models viz. logarithmic, power, exponential, logistic and gompartz along with linear growth model were tested for predicting pest population against the accumulated growing degree-days of crop phenological stages of black gram crop. It was noticed that power model explained best prediction of aphid activity and Jassid population was well fitted with logistic model having highest R^2 (coefficient of determination) value of 0.318and 0.256 respectively (Table 7). Therefore, power model explained 31.8% population variation of aphid, while logistic model expressed 25.6% variation of jassid population. The test of significance of coefficient of determination was revealed that it was significant at 5% level in all models when aphid pest was considered. However, in case of jassids, R^2 was found significant at 5% level in logarithmic, power, logistic and gompartz models.

Table 7: Model Expression of aphid population based on growing degree day.

Sr. No.	Name of the Model	Estimated Model Equation	Goodness of Fit (n=44)		Test of Significance (R^2)
			R^2	MSE	F value
1	Linear	Y=0.893+0.002x	0.134	2.300	6.50*
2	Logarithmic	Y=-3.431+0.880 ln(x)	0.185	2.165	9.53*
3	Power	ln(y)=ln(0.057)+0.531 ln(x)	0.318	0.381	19.58*
4	Exponential	ln(y)=ln(0.757)+0.001 x	0.251	0.419	14.07*
5	Logistic	Y=2.669/(1+168.3 exp(-0.014x)	0.274	1.975	15.85*
6	Gompertz	Y=2.667 exp(-595.8 exp(-0.018 x))	0.259	2.016	14.68*

*Significant at 5% level

Table 8: Model Expression of jassid population based on growing degree day.

Sr. No.	Name of the Model	Estimated Model Equation	Goodness of Fit (n=44)		Test of Significance (R^2)
			R^2	MSE	F value
1	Linear	Y=1.082+0.000x	0.052	0.416	2.30 (NS)
2	Logarithmic	Y=-0.614+0.321ln(x)	0.148	0.373	7.30*
3	Power	ln(y)=ln(0.256)+0.252ln(x)	0.164	0.206	8.24*
4	Exponential	ln(y)=ln(0.977)+0.000 x	0.055	0.233	2.44 (NS)
5	Logistic	Y=1.581/(1+4.565 exp(-0.009x))	0.256	0.334	14.45*
6	Gompertz	Y=1.575 exp(-2.053 exp(-0.007 x))	0.243	0.340	13.48*

*Significant at 5% level

Aphid population started infesting the crop at flower bud stage (475.78 AGDD) and continued up to pod formation stage (Fig. 1). It required 197.20 accumulated degree days from its appearance in the field to reach its peak population at flowering stage (672.98 AGDD).

Jassid population found infesting crop throughout the crop growth period from vegetative (377.48 AGDD) to pod formation stage. However, moderate level of infestation was noticed in flower bud initiation stage (475.78 AGDD), peak flowering (672.98 AGDD) and early pod formation stage (770.56 AGDD). Highest population was observed at early flowering stage at 578.44 AGDD (Fig. 2). It required 200.96 accumulated degree days from its appearance to reach at highest infestation level. Many workers attributed on the studies of the thermal requirement (degree-days) of different pests based on laboratory as well as field population data. The thermal units (degree days) required for total development of insect species, varies from crop to crop and the conditions under which the crop is being grown. Black legume aphid, *A. craccivora* required 72±4 mean degree days for its appearance in lucerne and the peak population was attained when the accumulated degree day was found as 199 (Singh *et al.*, 2017). Rao *et al.* (2018) observed that mean degree days 247.07±64.77 required for total development of *A. craccivora* on cow pea crop at *a*CO_2 level. It was also noticed that the number of generations in a year was increased due to increase in accumulated degree days (Hassan *et al.*, 2015). The findings of the present investigation are almost in conformity of the earlier works.

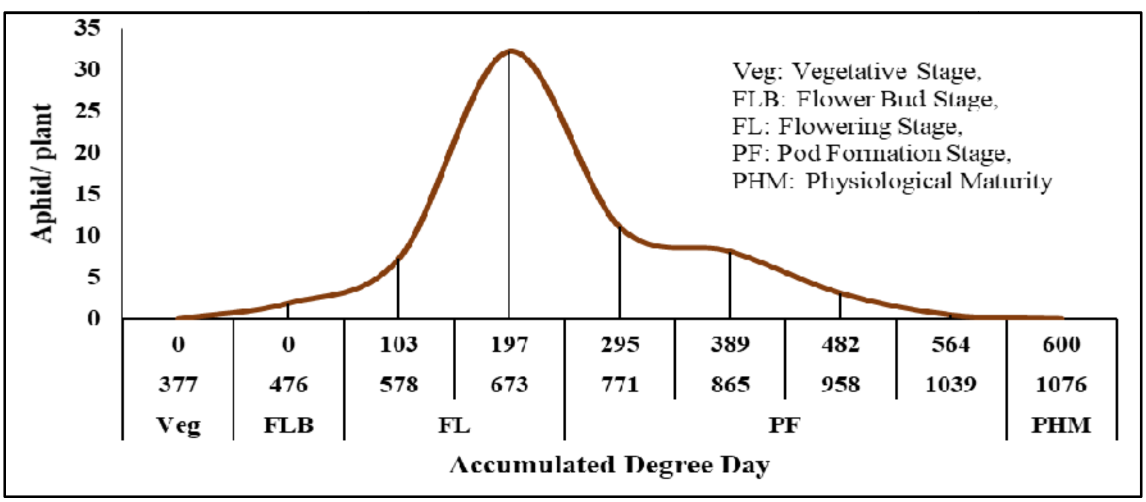

Fig. 1. Aphid population dynamics and its relation with degree-days of phenological events of black gram crop.

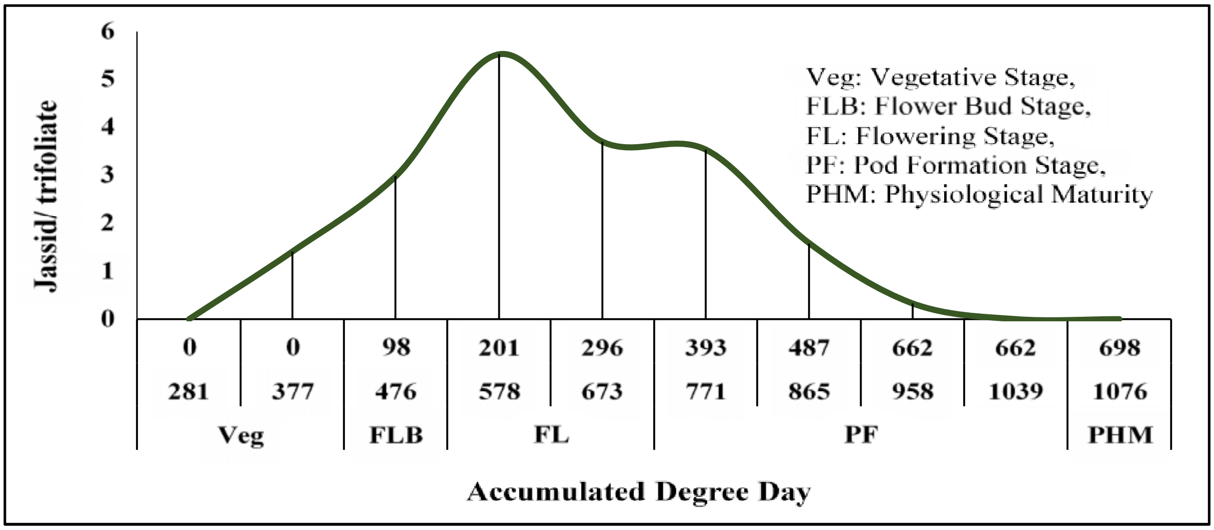

Fig. 2. Jassid population dynamics and its relation with degree-days of phenological events of black gram crop.

CONCLUSION

Aphid and jassids, two important sucking pests of black gram crop infested the crop in high level at flowering stage. Their population build-up was highly influenced by weather parameters. They required 197.20 and 200.96 degree days to reach their peak population level respectively. Power model and logistic model was found the best models to predict the aphid and jassid population infestation level respectively at different crop growth stages.

Hence, integrated control strategies may be adopted on time based on the prediction of the pest activities expressed by two best fitted models.

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