

Original Research Article

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Response of Indian Brown Planthopper, *Nilaparvata lugens* (Stål) Populations to Crowding

Sunil Vailla¹, Jhansi Lakshmi Vattikuti^{1*}, Chiranjeevi Konijeti¹,
Sampathkumar Muthuswamy², Rohini Alavala³, Jagadish S. Bentur⁴,
Chitra Shanker¹ and G.R. Katti¹

¹Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana, India

²National Bureau of Agricultural Insect Resources, Bengaluru, Karnataka, India

³Acharya N.G. Ranga Agricultural University, Bapatla, Andhra Pradesh, India

⁴Agri Biotech Foundation, Rajendranagar, Hyderabad, Telangana, India

*Corresponding author

ABSTRACT

Brown planthopper, *Nilaparvata lugens* (Stål) is a serious pest of rice across the Asian countries. This species exhibits significant wing dimorphism whereby fully developed adults (macropterous forms) are capable of flight. In planthopper species the wing form is determined by a developmental switch that is triggered by environmental factors including crowding, host plant quality, temperature and photoperiod. This study examined the influence of insect density (crowding) on *N. lugens* nymphal survival, nymphal duration, sex ratio, wing dimorphism, adult longevity and fecundity. Response of three BPH populations collected from Nalgonda district of Telangana, West Godavari districts of Andhra Pradesh and Ludhiana of Punjab was observed at four different insect densities i.e., 1, 20, 40 and 60 nymphs/45 days old susceptible variety TN1 plant. High nymphal density/crowding has adversely affected the nymphal survival on 5th and 10th day, nymphal duration, % adult emergence, sex ratio, adult longevity and fecundity. Nymphal density /crowding has differential influence on sex where more number of winged females and wingless males were observed at high nymphal densities but total brachypterous forms were more at increased nymphal density. Nalgonda population exhibited extreme macropterous forms, whereas West Godavari and Ludhiana populations showed more brachypterous forms over the broad ranges of nymphal density. Populations responded similarly regarding lower nymphal survival, prolonged nymphal duration, with increasing nymphal density. Among the populations, West Godavari showed lower nymphal survival rate, shorter nymphal duration in males, lower adult longevity but higher fecundity compared to Ludhiana and Nalgonda populations.

Keywords

Crowding,
Fecundity,
Nilaparvata lugens,
Nymphal density,
Nymphal duration,
Populations, Wing
dimorphism.

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Introduction

Wing dimorphism is a commonly observed phenomenon in insects (Harrison, 1980). The Brown Planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) is one of the most serious insect pests of rice in tropical and

temperate paddy fields in Asian countries. Adults show wing dimorphism, i.e., long winged macropterous and short winged brachypterous males and females. In planthopper species, the wing form is

determined by a developmental switch that is triggered by environmental factors including crowding, host plant quality, temperature, and photoperiod (Denno *et al.*, 1985). Macroptery is usually a density-dependent phenomenon but it often increases when host quality declines (Cook and Perfect, 1985). The production of macropters is influenced mostly by nymphal population density (Kisimoto, 1956). From an adaptive viewpoint, it is an advantage to migrate and colonize new habitats when the population density is high and migration requires macroptery. When the population density is low, in contrast, brachyptery is favourable because of their earlier reproduction than macropters (Kisimoto 1956; Denno *et al.*, 1985).

For other delphacid planthopper species, a genetic basis for wing-form determination has been reported for the small brown planthopper, *Laodelphax striatellus* (Fallen) (Mahmud, 1980) and *Prokelisia marginata* (Roderick, 1987). However, genetics of wing form determination is more complex and yet to be resolved. When the population density is low, it is favourable for development of brachypterous forms. This study was undertaken to know if higher nymphal density favours wing development and if all three populations respond to the same extent.

Materials and Methods

The three populations of *Nilaparvata lugens* were collected from across the country viz., West Godavari district and Nalgonda districts of Andhra Pradesh state and Ludhiana of Punjab state. The populations were separately reared on young rice seedlings (cv TN1) by Japanese method in flexi cages (Heong *et al.*, 2011) to avoid mating and intermixing of the three populations in the green house at the Indian Institute of Rice Research, Hyderabad, India. 30 gravid females were released in a

flexi glass cage for oviposition and were removed after 3 days. The seedlings were allowed for egg hatching for 8-10 days. Newly hatched I instar nymphs were used for this experiment. Four treatments were imposed i.e., 1 nymph/plant, 20 nymphs/plant, 40 nymphs/plant and 60 nymphs/plant. Desired numbers of nymphs were released on 45 day old susceptible TN1 plants (one plant per test tube) placed in a glass test tube (25x200 cm dia) with Hoagland's nutrition media filled upto 5cm level. 5 cm length was marked in the test tube with a marker.

The nymphs were confined within 5cm marked area of the test tube by keeping cloth below and above the mark. The nymphs were under crowding condition within 5 cm gap. When plants showed yellowing symptom due to feeding by nymphs, they were replaced by Plants of the same age. Hoagland solution in the test tube was maintained at the desired level. Observations were recorded on nymphal survival on 5th day and 10th day after release, nymphal duration and no of adults emerged, number of males and females, winged and wingless adults and adult longevity. Fecundity was observed in the surviving adults by releasing them separately.

Data analysis

Nymphal survival, nymphal duration, percent adult emergence and wing dimorphism were analysed by split plot design to know the interaction between populations and crowding. Longevity and fecundity was analyzed by a General Linear Model (GLM) SYSTAT 12 (Systat software Inc. Chicago IL) with population and crowding included as factors. Datasets were transformed wherever necessary to satisfy assumptions of normality and homogeneity of variances. Where a significant interaction between the two factors occurred in the GLM analysis, a *post hoc* comparison of means was carried out. The

Games and Howell method was used to compare means SYSTAT 12 (SYSTAT software Inc. Chicago IL).

Results and Discussion

Nymphal survival rate on 5th day and 10th day of release

Across the treatments in West Godavari and Nalgonda populations, 100 percent nymphal survival rate was observed @ 1 nymph/plant density on 5th day and 10th day after release whereas in Ludhiana it was 100 percent on 5th day and 77 percent on 10th day. Population density significantly affected the nymphal survival of West Godavari and Nalgonda BPH where lower nymphal survival was observed at higher nymphal density (60 nymphs/plant) on both 5th and 10th day after release whereas Ludhiana BPH had not shown significant reduction on 5th day but it was decreased on 10th day.

Across the treatments, nymphal survival rate decreased with increasing nymphal density on both 5th and 10th day after release (Table 1). Among the populations, lowest nymphal survival rate was observed in West Godavari population on 10th day after release compared to Ludhiana and populations. However, there was no significant difference on 5th day after release (Table 1).

Nymphal developmental duration

West Godavari population showed shorter nymphal duration male and brachypterous male (12.0 days) at lowest nymphal density (1 nymph/plant) compared to other nymphal densities whereas, nymphal density had not shown significant difference in nymphal duration of female, brachypterous female, macropterous female and males. Nymphal density had not influence the nymphal duration of Ludhiana BPH. Nymphal density significantly affected the nymphal duration in

females (irrespective of wing forms) in Nalgonda population where prolonged nymphal duration was observed at higher nymphal density (60 nymphs/plant) than at lower nymphal densities (20 and 40 nymphs/plant) Whereas in males (irrespective of wing forms) reduced nymphal duration was observed at lower nymphal densities than at other higher nymphal densities (Table 1).

Across the different nymphal densities, population density affected the nymphal duration of BPH where prolonged nymphal developmental duration was observed at higher nymphal density than at lower nymphal densities.

Among the populations, Ludhiana population showed significantly prolonged nymphal duration i.e. 22.3, 18.5, 22.5, 18.2, 18.7, 18.0 days in females, males, brachypterous females and males, macropterous females and males respectively compared to West Godavari and Nalgonda populations.

Nymphal to adult emergence rate

West Godavari and Nalgonda populations showed 100 percent nymphal to adult emergence at lower nymphal density (1 nymph/plant) compared to Punjab population (44%). However, adult emergence reduced significantly with increased nymphal densities in all populations.

Across the nymphal densities, highest adult emergence (81.4%) was observed at lower nymphal density (1 nymph/plant) and lowest emergence (22.8) was observed at highest nymphal density (60 nymphs/plant). Adult emergence was negatively correlated with nymphal density. Among the populations, it was the lowest in Ludhiana population (20.0 %) compared to Nalgonda (33.8 %) and West Godavari (25.9%) populations.

Table.1 Effect of nymphal density on nymphal survival, nymphal duration and % adult emergence of brown planthopper

Main treatment (population)	Sub treatment (Nymphal density)	Nymphal survival (%)		Nymph to Adult Developmental Duration(days)						%Adult Emergence
		5 DAR	10 DAR	♀	♂	B♀	B♂	M♀	M♂	
WG	T1	100.00	100.00	13.00	12.00	13.00	12.00	-	12.00	100.00
	T2	88.89	50.56	13.39	13.43	13.47	13.41	13.00	13.10	26.11
	T3	90.28	45.00	13.46	13.29	13.46	13.35	-	13.40	21.40
	T4	81.67	38.15	13.26	13.43	13.26	13.49	13.00	13.28	27.59
LDH	T1	100.00	77.78	21.00	14.00	21.00	14.00	-	20.00	44.44
	T2	95.00	88.89	21.43	18.25	21.60	17.48	14.00	18.71	42.22
	T3	76.11	49.44	23.71	18.90	23.86	18.53	18.00	24.00	11.4
	T4	79.63	64.63	22.10	19.02	22.40	19.17	20.83	18.67	17.96
NLG	T1	100.00	100.00	12.80	13.50	12.50	-	13.00	13.50	100.00
	T2	89.40	80.00	13.52	13.47	13.85	14.33	13.42	13.43	58.33
	T3	81.10	71.94	13.46	14.76	14.82	14.79	15.37	14.97	36.67
	T4	76.30	60.93	15.64	14.66	15.83	14.25	15.62	14.87	22.80
LSD(P=0.05)	Population vs nymphal density	NS	15.00	NS	1.35	NS	1.35	NS	1.49	17.32
	Nymphal density vs Population	NS	14.22	NS	1.25	NS	1.25	NS	1.47	16.44
LSD(P=0.01)	Population vs nymphal density	NS	20.16	NS	1.82	NS	1.82	NS	2.00	23.26
	Nymphal density vs Population	NS	18.87	NS	1.66	NS	1.66	NS	1.96	21.83
Populations	WG	85.86	42.98	13.3	13.0	13.34	13.29	13.00	12.98	25.90
	LDH	81.18	63.73	22.3	18.5	22.51	18.20	18.75	18.02	20.00
	NLG	80.26	68.04	14.4	14.2	14.66	14.45	14.60	14.26	33.88
LSD(P=0.05)	Population	NS	8.58	0.68	NS	0.59	NS	0.67	0.77	9.86
LSD(P=0.01)	Population	NS	11.83	0.94	NS	0.81	NS	0.92	1.07	13.59
Treatments	T1	100	92.59	14.67	12.67	15.51	12.67	13.00	13.40	81.48
	T2	91.1	73.15	14.63	13.56	16.79	15.73	13.39	14.37	42.22
	T3	81	54.45	18.26	15.52	18.21	15.65	15.89	15.05	23.15
	T4	79.2	54.57	17.20	15.88	17.37	15.98	15.78	15.74	22.78
LSD(P=0.05)	Nymphal density	5.06	8.21	0.74	0.72	0.75	0.72	0.78	0.85	9.49
LSD(P=0.01)	Nymphal density	6.72	10.9	0.98	0.96	0.99	0.96	1.04	1.13	12.60

*T1- One Nymph/plant; T2- Twenty Nymphs/plant; T3- Forty Nymphs/plant; T4- Sixty Nymphs/plant
 *WG- West Godavari; LDH-Ludhiana; NLG-Nalgonda; DAR-Days after release; ♀- Female; ♂- Male; B♀- Brachypterous female;
 B♂- Brachypterous male; M♀- Macropterous female; M♂- Macropterous male

Table.2 Effect of nymphal density on sex ratio and wing dimorphism

Main treatment (Population)	Sub treatment (Nymphal density)	Sex Ratio (Male to Female)	Wing Dimorphism							
			♀	♂	Brachypterous	Macropterous	B♀	M♀	B♂	M♂
WG	T1	1:0.8	44.44	55.56	22.22	77.78	50.00	50.00	0.00	100.00
	T2	1:0.6	38.30	61.70	72.34	27.66	88.89	11.11	62.07	37.93
	T3	1:0.5	35.06	64.94	83.12	16.88	100.00	0.00	74.00	26.00
	T4	1:0.8	44.97	55.03	88.64	11.36	92.54	7.46	80.49	19.51
LDH	T1	1:1	50.00	50.00	75.00	25.00	100.00	0.00	50.00	50.00
	T2	1:1.11	52.63	47.37	82.89	17.11	97.50	2.50	66.67	33.33
	T3	1:1.28	56.10	43.90	82.93	17.07	86.96	13.04	77.78	22.22
	T4	1:1.06	51.55	48.45	74.23	25.77	88.00	12.00	59.57	40.43
NLG	T1	1:1.25	55.56	44.44	22.22	77.78	40.00	60.00	0.00	100.00
	T2	1:0.69	40.95	59.05	23.81	76.19	46.51	53.49	8.06	91.94
	T3	1:1.64	62.12	37.88	21.21	78.79	23.17	76.83	18.00	82.00
	T4	1:1.67	62.60	37.40	37.40	62.60	36.36	63.64	39.13	60.87
LSD(P=0.05)	Population vs nymphal density	-	NS	NS	NS	21.93	NS	25.40	20.47	27.50
	Nymphal density vs population	-	NS	NS	NS	20.26	NS	22.72	19.69	27.16
LSD(P=0.01)	Population vs nymphal density	-	NS	NS	NS	29.49	NS	34.21	27.48	36.86
	Nymphal density vs population	-	NS	NS	NS	26.89	NS	30.16	26.13	36.06
Populations	WG	1:0.70	41.03	58.97	80.85	19.15	93.57	6.25	75.16	24.84
	LDH	1:0.94	52.75	47.25	91.30	8.70	65.05	34.95	78.90	21.1
	NLG	1:1.28	56.10	43.90	27.27	72.63	33.33	65.22	21.60	80.25
LSD(P=0.05)	Population	-	NS	NS	11.19	13.16	13.84	16.08	11.35	14.26
LSD(P=0.01)	Population	-	NS	NS	15.42	18.14	19.07	22.16	15.64	19.66
Treatments	T1	1:1	36.36	63.64	45.45	54.55	75.00	25.00	28.57	71.43
	T2	1:0.80	44.30	55.70	53.51	46.49	74.26	25.74	37.01	62.99
	T3	1:0.87	52.80	47.20	50.40	49.60	74.26	25.74	37.01	62.99
	T4	1:0.72	52.57	47.43	66.67	33.33	69.07	30.93	64.00	36.00
LSD(P=0.05)	Nymphal density	-	NS	NS	15.05	11.69	16.42	13.11	11.36	NS
LSD(P=0.01)	Nymphal density	-	NS	NS	19.97	15.52	21.79	17.41	15.08	NS

*T1- One Nymph/plant; T2- Twenty Nymphs/plant; T3- Forty Nymphs/plant; T4- Sixty Nymphs/plant.

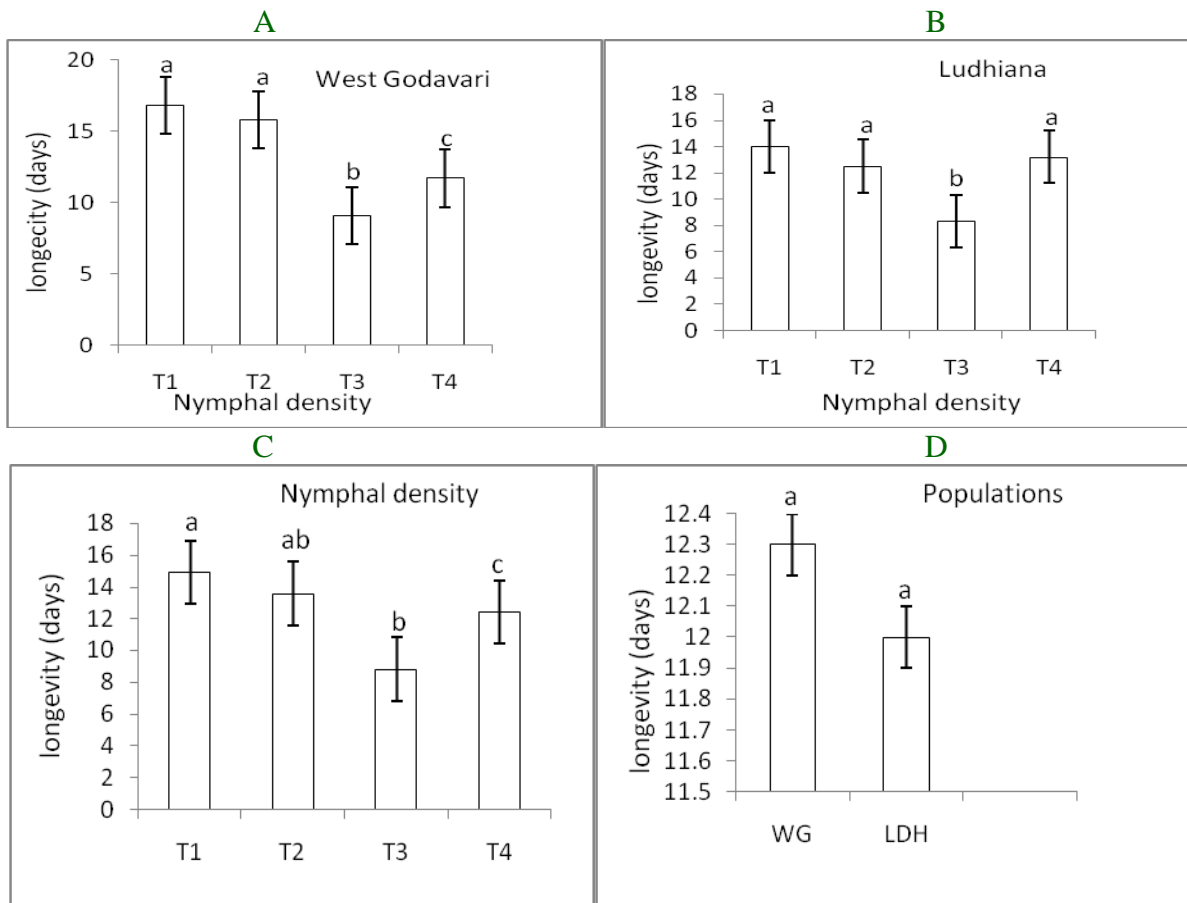
*WG- West Godavari; LDH-Ludhiana; NLG-Nalgonda; DAR-Days after release; ♀- Female; ♂- Male; B♀- Brachypterous female;

B♂- Brachypterous male; M♀- Macropterous female; M♂- Macropterous male

Table.3 Longevity and fecundity of different brown planthopper populations at different nymphal densities

Measurements	Treatments	F-value/ (d.f.)	P-value
Adult longevity			
Brachypterous female	West Godavari	20.704(3)	0.000
	Ludhiana	4.198(3)	0.01
	Nymphal density	16.256(3)	0.000
	Population	0.09(1)	0.76
Macropterous Male	West Godavari	6.63(3)	0.02
	Ludhiana	1.53(3)	0.267
	Nalgonda	5.370(3)	0.002
	Nymphal density	3.751(3)	0.01
	Populations	6.39(2)	0.002
Fecundity (no of eggs/female)			
	West Godavari	8.516(3)	0.000
	Ludhiana	4.787(3)	0.01
	Nalgonda	3.320(3)	0.02
	Nymphal density	9.86(3)	0.000
	Populations	6.750(2)	0.002

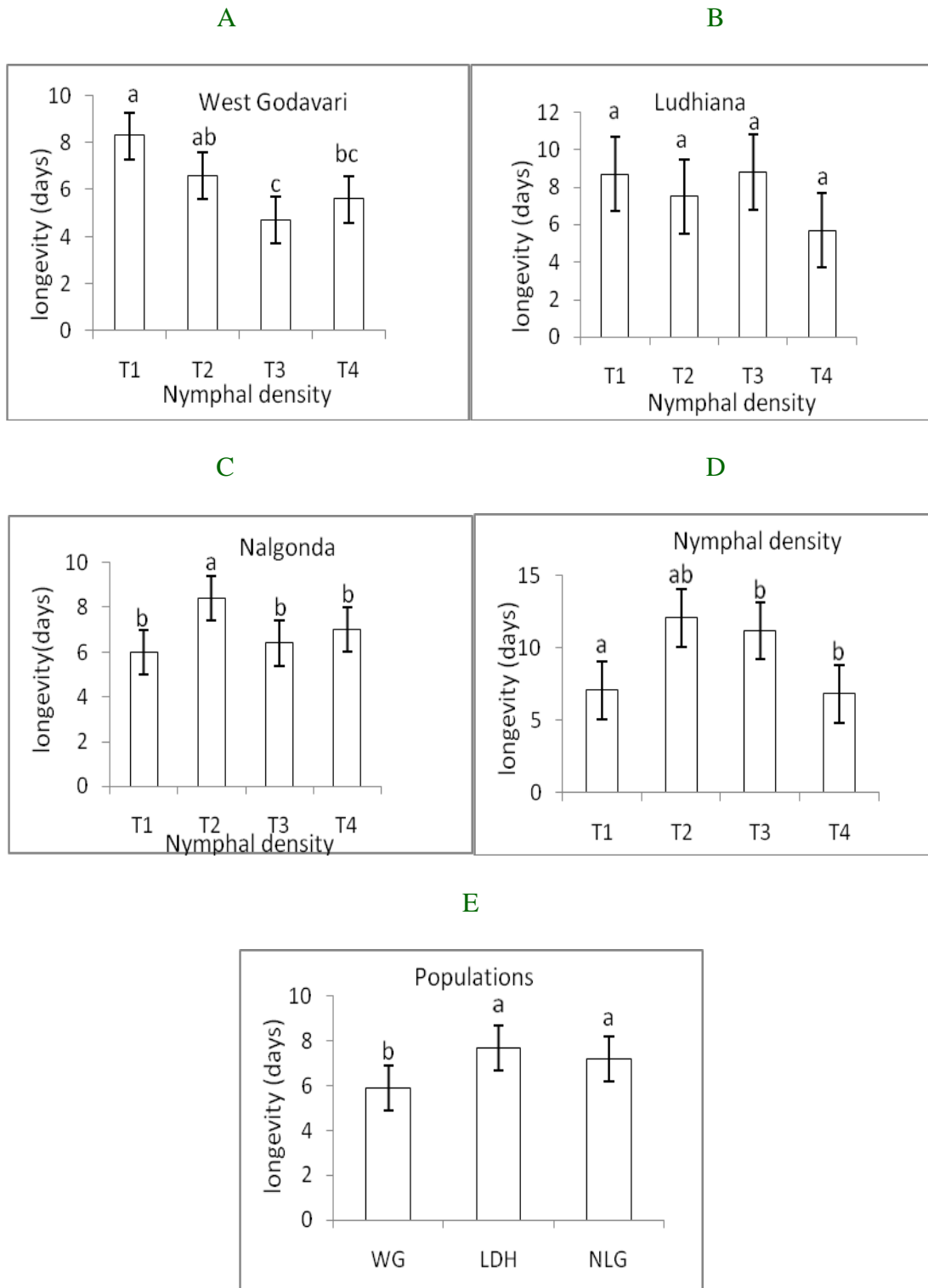
Fig.1 Longevity of brachypterous females of BPH populations at different nymphal densities



*T1- One nymph/plant; T2- Twenty nymphs/plant; T3- Forty nymphs/plant; T4- Sixty nymphs/plant. WG= West Godavari; LDH= Ludhiana.

Different letters on the bars in a panel denotes significant difference (LSD test, p=0.05).

Fig.2 Longevity of macropterous males of BPH populations at different nymphal densities

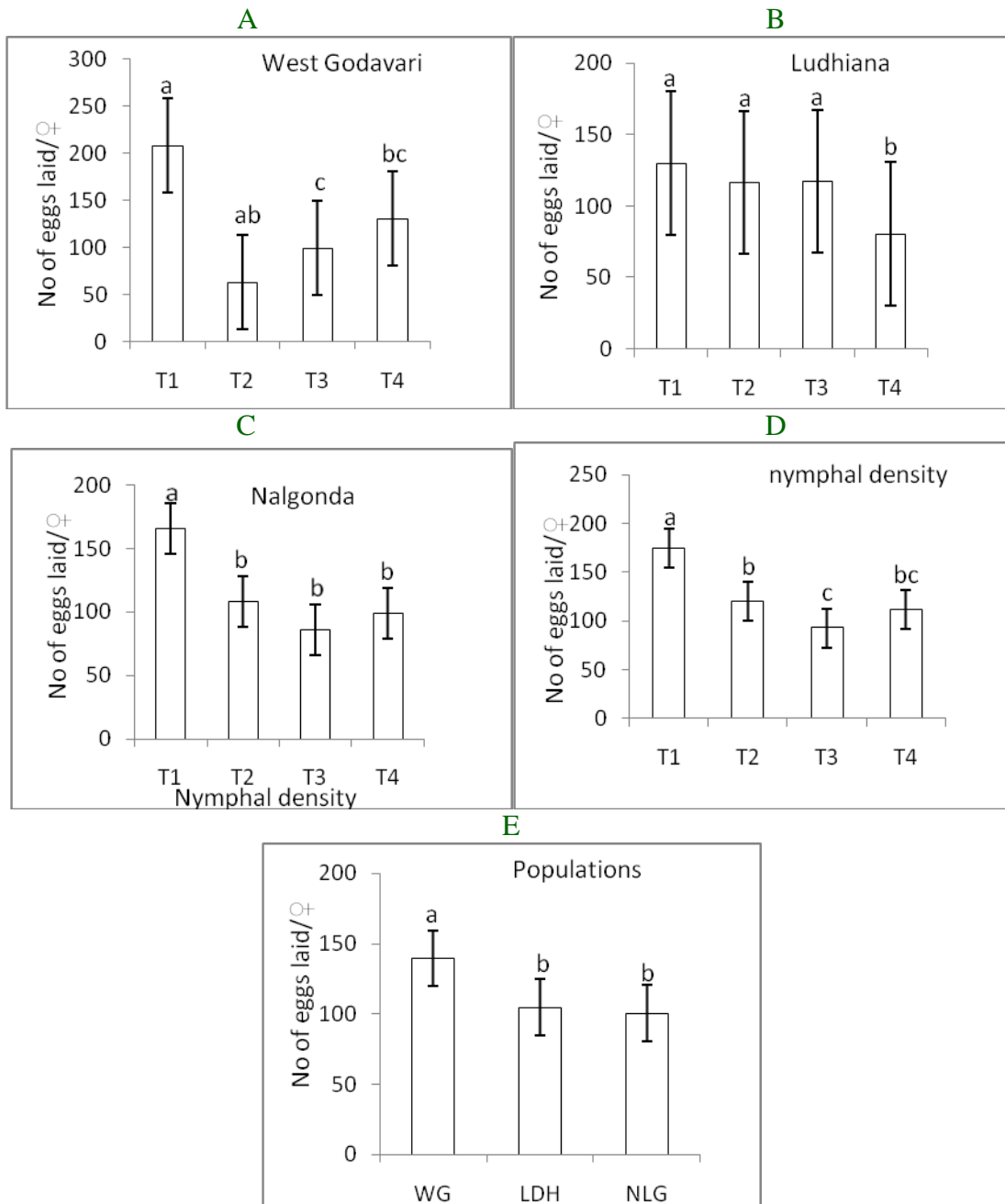


*T1- one nymph/plant; T2-twenty nymphs/plant; T3-forty nymphs/plant; T4-sixty nymphs/plant.

*WG= West Godavari; LDH= Ludhiana; NLG= Nalgonda.

Different letters on the bars in a panel denotes significant difference (LSD test, p=0.05).

Fig.3 Fecundity of three BPH populations at different nymphal densities



*T1- one nymph/plant; T2-twenty nymphs/plant; T3-forty nymphs/plant; T4-sixty nymphs/plant.

*WG= West Godavari; LDH= Ludhiana; NLG= Nalgonda.

Different letters on the bars in a panel denotes significant difference (LSD test, p=0.05).

Sex ratio

West Godavari population showed more no. of males than females across all the densities whereas it was vice versa in Ludhiana and

Nalgonda where more no of females emerged. Across the treatments, more no of males emerged than females at all nymphal densities. Among the populations, Nalgonda showed higher no of females than that of

West Godavari and Ludhiana populations (Table 2).

Wing dimorphism

The percent macropterous adults significantly differed among the populations. The macropterous forms emerged in high proportion at all nymphal densities in Nalgonda population. Among the populations, high percentage of macropterous forms were observed in Nalgonda population (72.63) compared to West Godavari (19.15) and Punjab populations (8.70).

In West Godavari and Ludhiana populations, higher percent of brachypterous forms were noticed at all nymphal densities (Table 2). Across the nymphal densities, the percent macroptery was high at lower nymphal densities compared to higher nymphal densities.

Adult longevity

Brachypterous female

Lower adult longevity was observed with increasing nymphal density in West Godavari, Ludhiana populations and across the treatments. However, there was no significant difference among the populations. Very few brachypterous females were observed in Nalgonda population (Table 3 and Fig. 1).

Macropterous male

Adult longevity was highest at lower nymphal density (1 nymph/plant) whereas it was lowest at 40 nymphs/plant in West Godavari population and no significant difference was observed in Ludhiana population. In Nalgonda population, highest adult longevity was observed at 20 nymphs/plant than other nymphal densities. Among the populations, lowest longevity was observed in West

Godavari population compared to Ludhiana and Nalgonda populations (Fig. 2).

Fecundity

In West Godavari, Nalgonda populations and across the nymphal densities, females emerged at lower nymphal density (1 nymph/plant) laid higher number of eggs compared to those emerged at higher nymphal densities. In Ludhiana population, there was no significant difference among the different nymphal densities. Among the populations, higher fecundity was noticed in West Godavari population compared to Ludhiana and Nalgonda populations (Fig. 3).

Our study demonstrated that nymphal density significantly influenced the biology of brown planthopper.

All the populations responded similarly, where increased nymphal density significantly reduced nymphal survival, number of adults emerged, adult longevity and fecundity and prolonged nymphal duration, at high population densities, intraspecific competition can be intense and adversely affects many components of fitness. When species live under crowded conditions rates of survival are reduced (Denno and Roderick, 1990; Heong, 1988). Kisimoto, (1965) suggested that under crowded conditions individuals develop more slowly and Kenmore, (1980) reported that fecundity is lower because of competition for oviposition sites. Thus high density populations result in decreased reproductive rate (R_0) and population growth (Kuno, 1979).

In planthoppers, wing form is heritable and under polygenic control, but it can be modified substantially by environmental factors (Cook and Perfect, 1985; Iwanaga *et al.*, 1985; Mahmud, 1980; and Mochida,

1973). Depending on the conditions it experiences as a nymph, an individual can molt into either a macropter or a brachypter. Various environmental cues such as crowding, host plant condition, temperature, and photoperiod act on a hormonal messenger that triggers a developmental switch to determine wing form. The presence of genetically determined brachypterous *N. lugens* populations and whitebacked planthopper, *Sogatella furcifera* populations was first determined by Nagata and Masuda (1980) in the populations collected in Philippines and Thailand. Recent studies have shown that Indonesian populations showed extremely high proportion of brachyptery under crowding conditions (Nagata, unpublished; Iwanga and Tojo, unpublished)

In our results, high frequency of long winged macropterous forms was observed in Nalgonda population whereas, in West Godavari and Ludhiana, higher percent of brachyptery forms were noticed over the broad range of densities. Within a single species, geographic variation in wing form composition also occurs and results from genetically controlled differences among populations in their response to density (Iwanaga *et al.*, 1985; Iwanaga *et al.*, 1987; and Kisimoto, 1981). Within bush crickets, where populations were under crowding conditions more individuals developed into long winged forms in *Metrioptera roeselii*, *M.brachyptera* compared to *M. roeselii* (Fitzgerald and Tipping, 2013). Chu *et al.*, (1982) observed that under crowding conditions, 19 BPH populations showed highly brachypterous and six populations developed into winged forms in a density dependent manner.

Denno and Roderick (1990) reported that atlantic and pacific coast populations of *Prokelisia marginata* are largely macropterous, whereas Gulf Coast

populations are predominantly brachypterous. Differences in host plant persistence, nutritional heterogeneity, and isolation explain the discrepancy in wing form composition among North American populations. Iwanga *et al.*, (1987) reported that some tropical populations of *N. lugens* are predominantly brachypterous; wing form responds weakly to changes in nymphal density and is more influenced by host plant physiology. By contrast, wing form in temperate populations tends to be much more sensitive to density and also observed various responses in the wing form (Macropterous and brachypterous) ratio among the immigrant populations of *N. lugens*. Matsumura, 2002 (unpublished data), investigated the annual variation of density and wing form relationship in the immigrant populations and showed a high ratio of brachypterous females in the 2005 bph population. Under experimental conditions the proportion of the macropterous females can vary from 0 to 100%. Poorer living conditions (e.g. dense populations) during the nymphal stage resulted in more macropterous females. For the male, however, there is apparently an optimum density range that stimulates the appearance of the brachypterous form; the male becomes a macropterous adult at both low and high densities.

In the present study, high nymphal density (crowding) has significantly affected various biological parameters, such as reduced nymphal survival, prolonged nymphal duration, wing dimorphism, reduced longevity and fecundity. Geographical variations were observed in the populations of *N. lugens* collected from Ludhiana, West Godavari and Nalgonda. Among the populations, Ludhiana population was significantly different from other two populations, where prolonged nymphal duration, lower nymphal survival and higher

brachypterous forms were observed. However, West Godavari population showed reduced adult longevity and higher fecundity whereas in Nalgonda population more number of macropterous forms was observed irrespective of nymphal density. The presence of brachypterous population is to maintain and increase their progenies and macropterous populations to adopt for a migratory life as they predominately produce macropterous forms even at low nymphal density.

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