Biology and population dynamics of sorghum head bugs (Hemiptera: Miridae)

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ABSTRACT. Four mirid head bugs, *Calocoris angustatus* Leth., *Creontiades pallidus* Ramb., *Eurystylus bellevoyei* Put. and Reut., and *Campylomma* sp., infest sorghum at ICRISAT Centre in India. *C. angustatus* is the predominant species, followed by *Campylomma* sp., *C. pallidus* and *E. bellevoyei*. The incidence of *C. angustatus* is higher in crops grown on Vertisols than on Alfisols, and maximum numbers are recorded in panicles at the milk stage. Females of *C. angustatus* lay eggs inside the glumes before anthesis, whereas the other species insert their eggs in the grain at the milk stage. The life cycle is completed in 15–20, 17–23, 14–16 and 16–17 days by *C. angustatus*, *C. pallidus*, *E. bellevoyei*, and *Campylomma* sp., respectively. The maximum numbers of *C. angustatus*, *C. pallidus* and *E. bellevoyei* were recorded during September–October, whereas *Campylomma* sp. tended to be most active during March–June. Lower minimum temperature (<18°C) and relative humidity (r.h.) (<30%) were associated with a decline in *C. angustatus* density during November–January, while higher temperatures (>32°C) and lower r.h. (<30%) restricted its numbers during March–June. During the rainy season, rainfall, temperature and r.h. were generally positively associated with populations of *C. angustatus*, *C. pallidus* and *E. bellevoyei*. However, there were some exceptions in some years. During the post-rainy season, higher temperatures (>32°C) and moisture deficit had a negative association with numbers of *C. angustatus*, *C. pallidus* and *E. bellevoyei*. However, these factors were positively associated with numbers of *Campylomma*. Weather parameter means for the same week and two preceding weeks showed a greater effect on *C. angustatus* populations.

KEYWORDS: *Calocoris angustatus*; *Creontiades pallidus*; *Eurystylus bellevoyei*; *Campylomma*; biology; population dynamics; *Erythemelus helopeltidis*; parasitoid

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench.) is one of the most important cereal crops after rice and wheat in India, Africa and Latin America, and insect pests are one of the most important factors limiting production on farmers' fields. The mirid head bugs, *Calocoris angustatus* Leth., *Eurystylus bellevoyei* Put. and Reut., *Creontiades pallidus* Ramb., and *Campylomma* spp., are one group of key pests. They feed on the developing sorghum grain from the initiation of ovary development to the hard-dough stage and inflict severe losses in grain yield and quality (Sharma, 1985a). Of these, *C. angustatus* is the predominant species in India, while *Eurystylus* spp. are damaging in both India and West Africa (McFarlane, 1984; Doumbia and Bonzi, 1985; Nwanze, 1985; Sharma 1985b, 1986); *Campylomma angustior* Popp., *C. subflava* Odh., *C. nicolasi* Put. and Reut., *C. pallidus* Ramb., *Lygus* sp., *Paramixia suturalis* Reut., and *Taloriiygus vosseleri* Popp. are the other mirids reported to damage sorghum in Africa (Schmutterer, 1969; McFarlane, 1984; Nwanze, 1985; Seshu Reddy and Omolo, 1985).

Total avoidable losses from insects, including head bugs, feeding on panicles, have been valued at nearly $\$100 \times 10^6$ year^{-1} in India (Leuschner and Sharma, 1983). With the introduction of medium-maturity, high-yielding varieties and hybrids, head bugs have become a key limiting factor in sorghum production. In situations of moderate to heavy infestation, two insecticide sprays are necessary to minimize the quantitative losses from head bugs (Sharma and Leuschner, 1987).

In view of the increasing importance of head bugs and the limited information available on them, the studies reported here were carried out between 1980 and 1986 to collect information on their biology and population fluctuations, as a prelude to host-plant resistance studies and management of these insects.

Materials and methods

Species of mirids infesting sorghum

Seventy-five panicles at the milk stage were sampled at random from the centre of a 0.5 ha plot of sorghum hybrid CSH 1 during the 1980 rainy season at

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ICRISAT Centre. Each panicle was carefully covered with a 45 × 30 cm polyethylene bag containing a small cotton swab soaked with 2 ml ethyl acetate. The panicle was tapped 5–10 times to dislodge the mirids, which were then brought to the laboratory and sorted into species using a 10 × magnifying lens. This procedure was adopted throughout.

Head bug numbers in sorghum grown on different soil types (Alfisols and Vertisols)

Head bug populations were recorded in sorghum grown on the two major soil types at ICRISAT Centre: Alfisols (light-red-sandy loam soils) and Vertisols (deep-black-clay soils) in rain-fed and irrigated fields. Twenty-five randomly selected panicles were sampled at each location.

Head bug incidence in relation to stage of panicle development

Sorghum panicles (commercial hybrid CSH 1) were randomly sampled in a 0.5 ha plot at pre-anthesis, 50% anthesis, complete-anthesis, milk, and dough stages, and at physiological maturity. Ten panicles were sampled, as described earlier, at each stage of development.

Biology

Studies on the biology of *Calocoris angustatus*, *Creontiades pallidus*, *Eurystylus bellevoyei* and *Campylomma* sp. were carried out under laboratory conditions. Fresh panicles of commercial hybrid CSH 1 at pre-anthesis, but free of head bug infestation, were used to study the oviposition by *C. angustatus*, since the females lay eggs inside the glumes before anthesis. Five primary branches were detached from the panicle at pre-anthesis and placed in a glass vial containing water. The vial was placed inside a 1 l plastic jar with a modified lid that had a 10 cm diameter wire mesh. One pair of newly emerged adult bugs was released in each jar. Sorghum branches provided for oviposition were changed every day. Florets were dissected under a 10 × microscope, and the number of eggs counted. All the eggs were kept for hatching on 3% agar-agar containing 1% formalin, in a Petri dish. For *C. pallidus*, *E. bellevoyei* and *Campylomma* sp., primary branches at the milk stage were similarly provided for oviposition. These bugs lay eggs inside the grain at the milk stage. Sorghum grain with eggs were placed on agar-agar in a Petri dish. Nymphs of all species were reared on milk grain in a 25 ml glass vial, covered with a cotton plug. The vials were placed in an incubator at 25 ± 2°C temperature and 65 ± 5% r.h. Food was changed on alternate days. Nymphs were observed every day, and data recorded on the duration of development of different instars. There were 20 insects under observation for *C. angustatus*, 30 for *C. pallidus* and 41 each for *Campylomma* sp. and *E. bellevoyei*.

Population monitoring

Populations of the four mirid species were monitored at fortnightly intervals at the ICRISAT farm for 5 years (1982–1986). Irrigated and rain-fed fields in Alfisols and Vertisols, and in pesticide-free and sprayed areas, were selected for population monitoring. Head bug samples were collected from three spots diagonally across a field. Ten randomly selected panicles were sampled at each spot. Sampling was carried out in a crop at the milk stage.

The cropping pattern at ICRISAT ensures the continuous availability of sorghum panicles throughout the year, except during May–June. This is ideal for studying insect population dynamics and for evaluating the role of environmental factors in the population fluctuation of an insect.

The mean number of bugs recorded was plotted on a graph. The population density of *C. angustatus* was also plotted in relation to weather data. Analysis of the data on head bug populations in relation to weather on a yearly basis did not show any trend and the correlation coefficients were very low. The correlation and regression coefficients of weather parameters with bug populations were therefore computed separately for the rainy and the post-rainy seasons.

Results

Species of mirids infesting sorghum

C. angustatus, *Campylomma* sp., *C. pallidus* and *E. bellevoyei* constituted 96.0, 3.9, 0.1 and 0.01%, respectively, of the total head bugs collected from 75 panicles of sorghum at the milk stage during the 1981 rainy season.

Head bug incidence in sorghum grown on different soil types

Numbers of *C. angustatus* and *Campylomma* sp. were greater in a crop grown on Vertisols than on Alfisols, while those of *C. pallidus* and *E. bellevoyei* were low on both soils (*Table 1*).

Head bug incidence in relation to stage of panicle development

C. angustatus and *Campylomma* sp. activity was observed in panicles from 25% anthesis to hard-dough stage, with a peak activity at the milk stage and physiological maturity, respectively (*Table 1*). *C. pallidus* was recorded in panicles from 50% anthesis to the hard-dough stage, while *E. bellevoyei* was recorded in panicles from the milk stage to physiological maturity.

Biology

Females of *C. angustatus* laid eggs inside the glumes before anthesis. An average of 182 ± 21 ($\bar{x}$ ± s.e.) eggs during the rainy season, after a pre-oviposition period of 2–4 days, and 113 ± 12 eggs during the post-rainy

TABLE 1. Relative numbers of four head bug species in relation to sorghum panicle development and soil type at ICRISAT Centre, 1980

	No. of bugs per 10 panicles			
	Calocoris angustatus	*Creontiades pallidus*	*Campylomma* sp.	*Eurystylus bellevoyei*
Soil type				
Alfisols	3	1	47	1
Vertisols	186	1	82	1
Growth stage of panicle				
Pre-anthesis	23	0	2	0
25% anthesis	55	0	1	0
50% anthesis	63	1	5	0
Full-anthesis	45	1	4	0
Post-anthesis	39	0	6	0
Milk	87	0	87	4
Hard-dough	46	1	40	15
Physiological maturity	8	0	104	4

TABLE 2. Life cycle studies of *C. angustatus*, *C. pallidus*, *E. bellevoyei* and *Campylomma* sp. under laboratory conditions (25 ± 2°C and 65 ± 5% r.h.)

Head bug species	Egg incubation period (days)	Duration of development (days)					Total nymphal period	Sex ratio (M:F)
		Instar I	Instar II	Instar III	Instar IV	Instar V		
C. angustatus	7–8	2.0 ± 0.00	1.3 ± 0.14	1.7 ± 0.14	2.1 ± 0.13	2.3 ± 0.16	9.3 ± 0.16	1:2.0
C. pallidus	6–8	2.1 ± 0.10	2.1 ± 0.10	2.4 ± 0.15	2.7 ± 0.15	3.2 ± 0.16	12.8 ± 0.20	1:1.7
E. bellevoyei	7	2.1 ± 0.09	1.2 ± 0.09	1.4 ± 0.09	1.8 ± 0.10	1.8 ± 0.07	7.3 ± 0.07	1:1.4
Campylomma sp.	5	2.6 ± 0.13	1.7 ± 0.15	1.8 ± 0.15	1.9 ± 0.13	2.2 ± 0.14	11.1 ± 1.15	1:1.2

season, after a pre-oviposition period of 5–8 days were recorded. Eggs hatched in 7–8 days. Egg hatching was higher in the rainy (93 ± 2%) than in the post-rainy (73 ± 11%) season. There are five nymphal instars and the development was completed in 8–12 days (*Table 2*). Ballard (1916) and Cherian, Kylasam and Krishnamurti (1941) reported that this insect took 15–17 days to complete its life cycle. Females survived for 14–23 days during the rainy season and 12–23 days during the post-rainy season.

The host range of *C. angustatus* is not restricted to sorghum and it has been observed to feed on pearl millet (*Pennisetum glaucum* (L.) R. Br.) and maize (*Zea mays* L.) foliage and inflorescence, both during the rainy and post-rainy seasons. However, no nymphs have been recorded on the vegetative stage of these crops. Egg laying and breeding seem to be restricted to the reproductive phase of the crop. This has also been reported by Ballard (1916) and Cherian *et al.* (1941). During the summer season (April to June), this insect has been recorded on summer sorghum in farmers' fields. No insects have been recorded in sorghum stalks or in grasses growing in and along water channels at ICRISAT.

Females of *C. pallidus* lay eggs in grain at the milk stage. Eggs are inserted inside the grain and the tip or operculum of the egg can be seen from outside. The grain pericarp develops a red-brown or black ring around the egg. The pre-oviposition period lasted 2–5 days and eggs hatched in 6–8 days. Females were observed to lay 45–251 eggs. Five nymphal instars were recorded and the development was completed in 11–15 days. Adult longevity was 11 days for males, and 13 days for females. *Erythemelus helopeltidis* Gahan was recorded as an egg parasite on this species. *C. pallidus* has also been observed to feed on pearl millet and pigeonpea at ICRISAT.

Females of *E. bellevoyei* also laid their eggs in the milk grain and the egg tip projected outside the pericarp. Eggs hatched in 7 days and nymphal development was completed in 7–8 days: the entire life cycle took 14–16 days. Not much is known about natural enemies, alternate hosts and off-season carry-over of this species.

Campylomma sp. laid its eggs inside the milk grain. Eggs hatched in 5 days. Five nymphal instars were recorded and the development was completed in 11 days. Species belonging to this genus are known to feed on many crops (Schmutterer, 1969).

In the absence of food, all the mirid head bugs are cannibalistic and are also predacious on members of the other species. They are also predatory on the sorghum midge, *Contarinia sorghicola* Coq. The anthocorid, *Orius maxidentex* Ghauri, is a common predator of all head bug species.

Population monitoring

C. angustatus was the predominant head bug species infesting sorghum at ICRISAT (*Figure 1*), followed by *Campylomma* sp., *C. pallidus* and *E. bellevoyei*. The peak in *C. angustatus* numbers occurred between 10 September

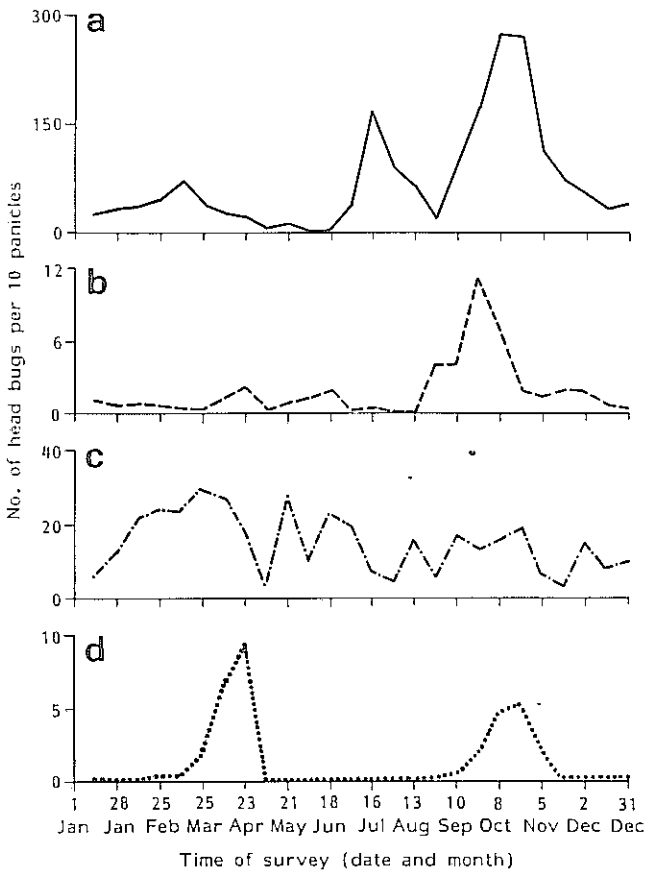

FIGURE 1. Population fluctuations of a, *C. angustatus*, b, *C. pallidus*, c, *Campylomma* sp., and d, *E. bellevoyei* (means of 5 years 1982–1986) at ICRISAT Centre

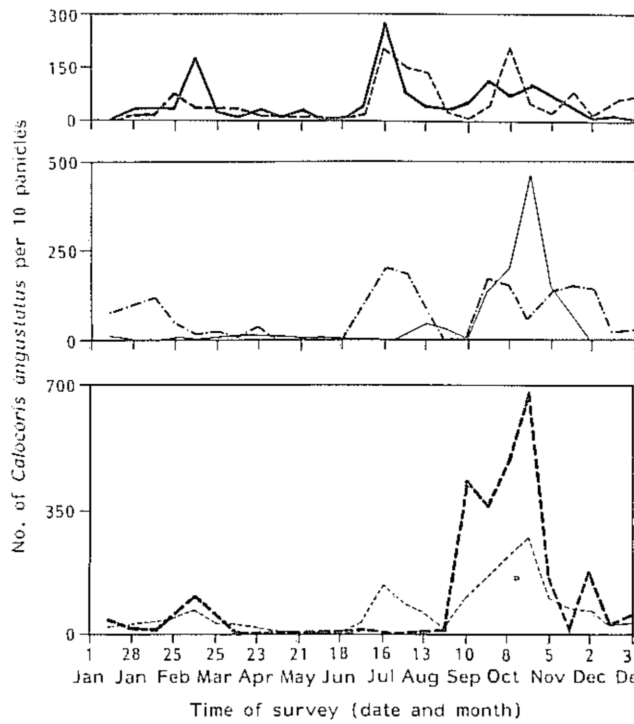

FIGURE 2. Population fluctuations of *C. angustatus* between 1982 and 1986 at ICRISAT Centre, a, ——, 1985; ---, 1986; b, -·-, 1983; —, 1984; c, ---, 1982; ---, 5-year mean

and 10 October. Its population declined sharply from November onwards, even though there was a continuous availability of sorghum panicles until the next April. A smaller peak was recorded in February–March. There was a third peak during July on limited sorghum planted during summer. The head bug numbers increased on this crop nearly one month after the onset of monsoon rains.

The maximum density of *C. pallidus* was recorded during September and October (*Figure 1*), with low densities for the rest of the year. *Campylomma* sp. populations showed a great deal of fluctuation over the year. However, its numbers tended to be higher during the post-rainy and summer seasons (February–June) than in the rainy season (June–October) (*Figure 1*). *E. bellevoyei* had two distinct peaks during March and October (*Figure 1*). Its numbers remained low during the cooler and hot dry periods of the year.

Population dynamics of C. angustatus

The population density of *C. angustatus* was greater in 1982, followed by 1984, and low during 1983, 1985, and 1986 (*Figure 2.*). However, the average population was much higher in 1983 than in 1984 and 1985. Three peaks were recorded in 1982, and four in 1983. The peak in July was not recorded in 1982 and 1984. The first peak during February–March was recorded earlier in January in 1983, and very low numbers were recorded in 1984. Maximum numbers during September–October were observed across years, although there was some shift in peaks over the years. The bug population remained quite low during the drought years of 1985 and 1986.

The relationships between head bug numbers and the environmental factors of rainfall, maximum and minimum temperature and relative humidity are given in *Figure 3.* Head bug numbers declined sharply in April when maximum and minimum temperature rose above 32 and 20°C, respectively and r.h. fell below 70 and 30%, respectively (*Figure 3*). During 1984 and 1985, intermittent rains increased the relative humidity and lowered the temperature during the post-rainy season, and, as a result, there was a corresponding increase in head bug numbers soon after rainfall during these years.

During the first part of the rainy season (July–October), temperatures (28–32°C) and r.h. (>80%) were moderate and steady and favoured a steady increase in insect numbers during this period (*Figure 3*). However, during the second half of the rainy season (November–December) head bug density declined sharply with a fall in minimum r.h. (<40%) and temperature (<18°C). The decline in head bug numbers began 30–40 days after the rains ceased (except in 1983). Generally, an increase in head bug numbers was associated with the onset of rainfall in November–December (see 1982, 1983, 1985 and 1986). Temperatures >32°C or <18°C and r.h. <30% appear to affect head bug populations adversely.

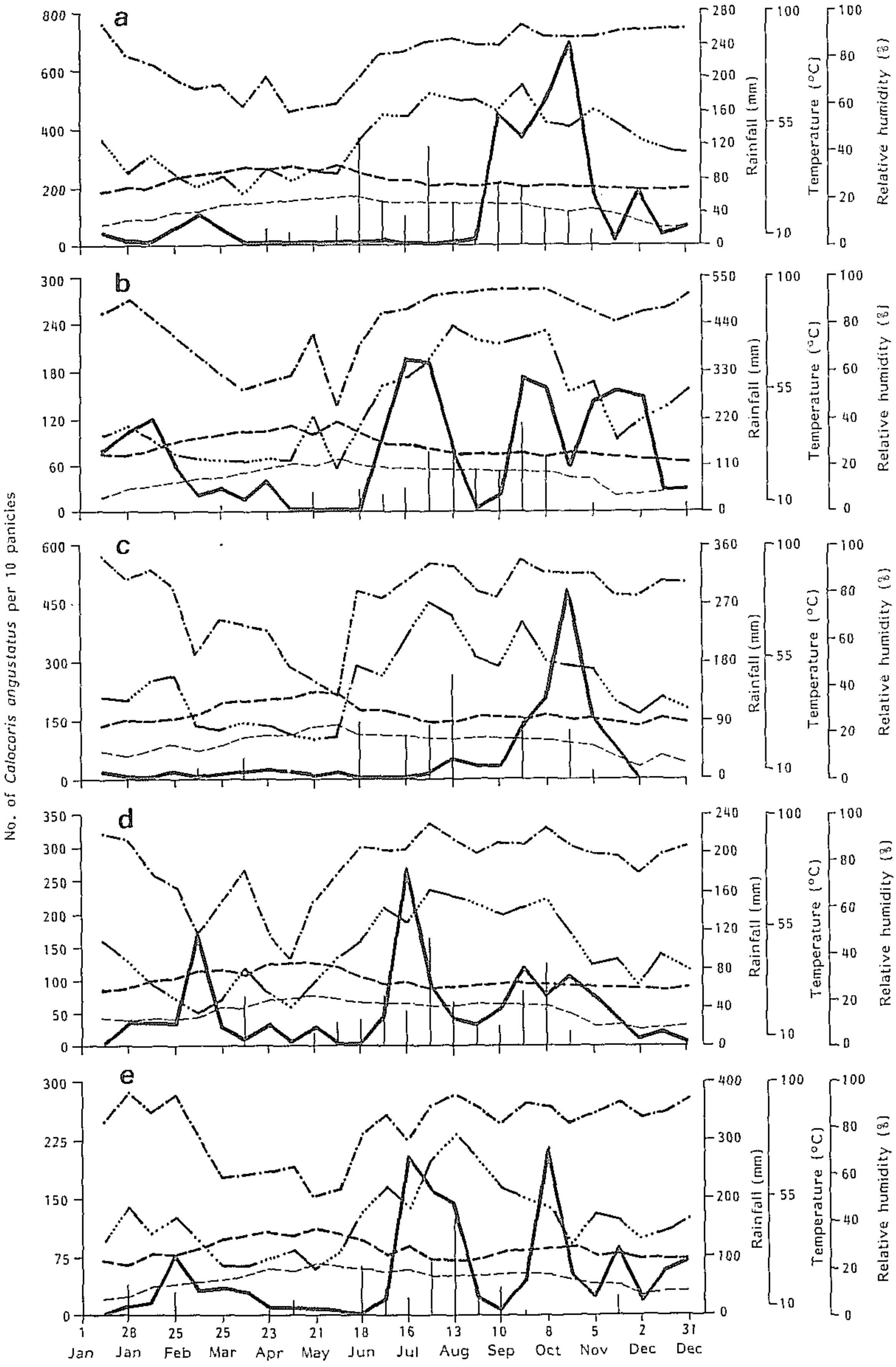

FIGURE 3. Populations of *C. angustatus* in relation to maximum and minimum temperatures and relative humidity (1982–1986). —, No. of *C. angustatus*; ....., rainfall; ----, maximum temperature; – – –, minimum temperature; ·–·–, maximum r.h.; ...., minimum r.h. a, 1982; b, 1983; c, 1984; d, 1985; e, 1986

Association of weather parameters with head bug numbers

Rainy season. Rainfall (except in 1986) and temperature (except in 1983) showed a positive association with fortnightly means for the population density of *C. angustatus* (*Table 3*). Relative humidity was positively correlated with head bug numbers during 1984 and 1985. Moisture deficit and wind velocity showed a negative effect on head bug numbers, though the correlation coefficients were low and non-significant. The weather parameters explained 80.2 and 85.7% of the variance (R^2) in 1983 and 1984, respectively.

The association of weather parameters with head bug numbers was also analysed for weekly means between 1981 and 1983 (*Table 4*). Rainfall was positively correlated with *C. angustatus* numbers during

Table 3. Correlation and regression analysis of fortnightly means for weather parameters and head bug numbers during the rainy season at ICRISAT

Parameter	Correlation coefficient (r)				
	1982 ($Y1$)	1983 ($Y2$)	1984 ($Y3$)	1985 ($Y4$)	1986 ($Y5$)
Calocoris angustatus					
Rainfall ($X1$)	0.76**[a]	0.20	0.64*	0.53[a]	−0.35[a]
Pan evaporation ($X2$)	0.09	−0.16	−0.34	−0.19	0.09
Maximum temperature ($X3$)	0.73*	0.002	0.24	0.50	0.36
Minimum temperature ($X4$)	0.43	−0.11	0.39	0.54	0.17
Maximum r.h. ($X5$)	−0.20	−0.32	0.52	0.53	0.38
Minimum r.h. ($X6$)	0.26	−0.12	0.41	0.56	−0.10
Wind velocity ($X7$)	−0.33	−0.20	−0.33	−0.19	−0.25
Sunshine ($X8$)	−0.02	0.006	−0.16	−0.46	−0.07
Campylomma sp.					
Rainfall ($X1$)	0.25	−0.27[a]	0.68	0.49[a]	−0.46[a]
Pan evaporation ($X2$)	0.40	0.18	−0.35	−0.15	0.19
Maximum temperature ($X3$)	0.13	−0.22	0.05	0.42	0.34
Minimum temperature ($X4$)	−0.04	−0.37	0.25	0.37	0.22
Maximum r.h. ($X5$)	−0.33	−0.46	0.44	0.29	0.22
Minimum r.h. ($X6$)	−0.17	−0.33	0.31	0.36	−0.03
Wind velocity ($X7$)	−0.17	−0.27	−0.31	0.32	−0.23
Sunshine ($X8$)	−0.11	0.18	−0.24	−0.45	−0.15
Creontiades pallidus					
Rainfall ($X1$)	0.66*	0.28[a]	0.05[a]	0.56[a]	−0.23
Pan evaporation ($X2$)	−0.16	−0.11	−0.21	0.06	0.18
Maximum temperature ($X3$)	0.22	0.40	0.24	0.67*	0.46
Minimum temperature ($X4$)	0.30	0.33	0.14	0.60	0.51
Maximum r.h. ($X5$)	0.16	0.25	0.31	0.57	0.32
Minimum r.h. ($X6$)	0.37	0.21	0.13	0.57	0.19
Wind velocity ($X7$)	−0.21	−0.13	−0.29	0.30	−0.49
Sunshine ($X8$)	−0.30	−0.28	0.17	−0.53	−0.37
Eurystylus bellevoyei					
Rainfall ($X1$)	0.52	0.40[a]	0.85**	0.69**[a]	−0.28[a]
Pan evaporation ($X2$)	−0.36	−0.80**	−0.55	0.01	0.23
Maximum temperature ($X3$)	0.09	−0.11	0.14	0.71*	0.40
Minimum temperature ($X4$)	0.35	0.35	0.38	0.68*	0.33
Maximum r.h. ($X5$)	0.47	0.34	0.71*	0.67	0.18
Minimum r.h. ($X6$)	0.60	0.47	0.54	0.67*	0.07
Wind velocity ($X7$)	−0.18	0.49	−0.45	0.42	−0.21
Sunshine ($X8$)	−0.35	−0.44	−0.30	−0.56	−0.18

Regression equations

C. angustatus

$Y2 = 3564 + 3.2X1 - 1.8X2 + 0.7X3 + 1.1X4 - 2.7X5 - 1.2X6 + 0.1X7 + 0.7X8$ ($R^2 = 80.2\%$)

$Y3 = 1614 + 3.4X1 - 6.0X2 - 154.5X3 + 174X4 + 29X5 - 53.1X6 + 8.2X7 + 20.3X8$ ($R^2 = 85.7\%$)

Campylomma sp.

$Y1 = 1061 + 1.4X1 + 0.1X2 - 45.4X3 + 23.0X4 + 3.3X5 - 9.6X6 + 4.4X7 - 2.3X8$ ($R^2 = 76.7\%$)

$Y3 = -37 + 0.8X1 - 1.2X2 - 13.9X3 + 20.5X4 + 5.7X5 - 8.6X6 + 8.6X7 + 0.5X8$ ($R^2 = 68.3\%$)

C. pallidus

$Y1 = 107.3 + 0.2X1 + 0.04X2 - 6.4X3 + 3.1X4 + 0.9X5 - 1.2X6 - 0.01X7 - 1.2X8$ ($R^2 = 96.4\%$)

$Y5 = 598 - 8.2X1 - 1.8X2 - 4.1X3 + 4X4 - 1.2X5 - 2.8X6 - 7.9X7 + 4X8$ ($R^2 = 96.4\%$)

E. bellevoyei

$Y1 = -52.9 + 0.03X1 + 0.04X2 + 0.1X3 - 0.5X4 + 0.5X5 + 0.2X6 - 0.1X7 - 0.3X8$ ($R^2 = 100\%$)

$Y3 = 14.5 + 0.02X1 - 0.03X2 + 0.9X3 + 0.8X4 + 0.1X5 - 0.2X6 - 0.1X7 + 0.1X8$ ($R^2 = 91.8\%$)

*, ** Significant at $p < 0.05$ and 0.01, respectively; [a] residual is greater than the variance for regression analysis

TABLE 4. Correlation and regression coefficients between *C. angustatus* numbers and environmental parameters during the rainy season (Vertisols)

Environmental parameter	1981 ($Y1$)			1982 ($Y2$)			1983 ($Y3$)		
	SW	*W1*	*W2*	*SW*	*W1*	*W2*	*SW*	*W1*	*W2*
Rainfall ($X1$)	0.53	0.33[a]	0.18	0.22	−0.03[a]	−0.01	−0.41	−0.48	−0.42[a]
Maximum temperature ($X2$)	−0.11	0.21	0.43	0.50	0.39	−0.26	0.08	0.35	0.57
Minimum temperature ($X3$)	0.31	0.59	0.33	−0.02	−0.03	0.18	−0.24	−0.13	0.08
Maximum r.h. ($X4$)	0.67*	0.36	0.26	0.20	0.02	0.31	−0.51	−0.32	−0.07
Minimum r.h. ($X5$)	0.44	−0.01	−0.43	−0.23	−0.20	0.33	−0.39	−0.32	−0.16

Regression equations

$Y1\,(SW) = -1010 + 0.1X1 + 30.4X2 - 46.5X3 + 8.0X4 + 6.8X5\ (R^2 = 41.2\%)$
$Y1\,(W2) = 220 + 0.6X1 + 44.3X2 - 113.1X3 + 15.6X4 - 5.7X5\ (R^2 = 86.1\%)$

$Y2\,(SW) = -5419 - 1.6X1 + 83.8X2 + 45.9X3 + 27.5X4 - 6.7X5\ (R^2 = 92.2\%)$
$Y2\,(W2) = -2116 - 1.1X1 - 77.4X2 + 142.0X3 + 36.1X4 - 29.4X5\ (R^2 = 54.0\%)$

$Y3\,(SW) = 1526 + 0.01X1 - 37.0X2 + 33.8X3 - 9.2X4 - 4.8X5\ (R^2 = 88.9\%)$
$Y3\,(W1) = 428 - 0.1X1 - 3.0X2 + 18.5X3 - 5.9X4 - 2.5X5\ (R^2 = 96.9\%)$

SW, means for weather parameters for the same week; *W1*, means for weather parameters one week before, and *W2*, means for weather parameters 2 weeks before head bug counts. * significant at $p < 0.05$; [a] residual greater than the variance for regression analysis

1981 but negatively during the 1983 rainy season. This variation may be due to different rainfall distribution patterns (*Figure 3*) and crop growth during these years. Maximum temperature showed a positive association with head bug density, as temperatures were low to moderate (25–32°C) during the rainy season. Relative humidity was positively associated with head bug density (except in 1983). Weather parameters accounted for 41.2, 92.2 and 88.9% of the variance for the same week and 86.1, 54.0 and 8.4% 2 weeks before head bug counts during 1981, 1982 and 1983, respectively. Thus, head bug numbers seem to be strongly influenced by weather conditions during the same week and the preceding 2 weeks. This also fits well with its life cycle, which is completed in nearly 2 weeks.

Campylomma did not show a consistent pattern in its association with weather parameters (*Table 3*). However, its population density was higher during hot dry months and such relationships were apparent during the post-rainy season. Weather parameters explained 76.7 and 68.3% of the variance during 1982 and 1984, respectively.

Rainfall (except in 1986), temperature and relative humidity were positively associated with populations of *C. pallidus* during the rainy season (*Table 3*). Wind velocity (except in 1985) and sunshine hours (except in 1984) showed negative association. However, the correlation coefficients were not significant. Weather factors explained 96.4% of the variance during 1982 and 1986.

E. bellevoyei populations were positively correlated with rainfall (except in 1986), temperature (except in 1983), and r.h. during the rainy season (*Table 3*). Moisture deficit was significantly and negatively associated with its numbers during 1983. Weather parameters accounted for 100.0 and 91.8% of the variance during 1982 and 1984, respectively.

Post-rainy season. Moisture deficit and maximum temperature showed significant and negative effects on *C. angustatus* numbers in 1983 (*Table 5*). Relative humidity was positively associated with head bug density. However, the pattern of correlation coefficients was not consistent across years. Weather parameters explained 68.9 and 70.4% of the variance during 1984 and 1986, respectively.

The role of weather parameters in *C. angustatus* population fluctuations was also studied on a weekly mean basis during the 1982 post-rainy season (*Table 6*). Temperature showed a negative and r.h. a positive association with *C. angustatus* populations.

Temperature showed a positive (except in 1983 and 1986) and r.h. a negative (except in 1983) association with numbers of *Campylomma* sp. (*Table 5*). Weather parameters explained 75.0, 71.7 and 84.2% of the variance during 1982, 1984 and 1986, respectively. Based on weekly population means, temperature showed a positive and r.h. a negative association with *Campylomma* populations. This is the reverse of the pattern observed in the case of *C. angustatus*.

C. pallidus numbers were significantly and negatively associated with moisture deficit and temperature, and positively associated with r.h. and wind velocity during 1984. Temperature was positively associated with *E. bellevoyei* populations. However, the correlation coefficients were not significant.

Discussion

C. angustatus is the predominant head bug species infesting sorghum in India and it is also reported as a pest of sorghum in East Africa. *Eurystylus* spp., which are the most important head bugs infesting sorghum in West Africa, tend to remain at lower population densities in India. This may be due to interspecific

TABLE 5. Correlation and regression coefficients between fortnightly means for weather parameters and head bug numbers during the post-rainy season at ICRISAT Centre

Parameter	Correlation coefficient (r)				
	1982 ($Y1$)	1983 ($Y2$)	1984 ($Y3$)	1985 ($Y4$)	1986 ($Y5$)
Calocoris angustatus					
Rainfall ($X1$)	−0.48^a	−0.29^a	0.16	−0.27^a	0.24
Pan evaporation ($X2$)	0.07	−0.79**	0.48	0.25	0.12
Maximum temperature ($X3$)	0.09	−0.88**	0.48	0.33	0.11
Minimum temperature ($X4$)	0.03	−0.72*	0.76**	−0.19	0.27
Maximum r.h. ($X5$)	−0.11	0.88**	0.28	−0.57	0.01
Minimum r.h. ($X6$)	−0.21	0.91**	−0.11	−0.49	0.10
Wind velocity ($X7$)	−0.34	−0.19	0.25	−0.56	0.36
Sunshine ($X8$)	0.32	−0.63	0.08	0.54	0.46
Campylomma sp.					
Rainfall ($X1$)	0.29	−0.01^a	0.85**	0.28^a	0.20
Pan evaporation ($X2$)	0.78**	−0.17	0.45	0.65*	0.06
Maximum temperature ($X3$)	0.75**	−0.24	0.43	0.64*	0.04
Minimum temperature ($X4$)	0.81**	−0.02	0.35	0.20	0.30
Maximum r.h. ($X5$)	−0.62	0.26	−0.49	−0.48	0.40
Minimum r.h. ($X6$)	−0.51	0.31	−0.40	−0.70*	0.25
Wind velocity ($X7$)	0.32	0.36	−0.40	−0.58	0.68
Sunshine ($X8$)	0.29	−0.25	−0.02	0.30	0.26
Creontiades pallidus					
Rainfall ($X1$)	0.62	−0.20	−0.44^a	0.57^a	0.02
Pan evaporation ($X2$)	0.54	0.36	−0.80**	−0.24	0.49
Maximum temperature ($X3$)	0.54	0.23	−0.72*	−0.24	0.43
Minimum temperature ($X4$)	0.50	0.35	−0.62	−0.31	0.53
Maximum r.h. ($X5$)	−0.59	−0.23	0.81**	0.24	−0.02
Minimum r.h. ($X6$)	−0.41	0.07	0.66*	0.78**	−0.20
Wind velocity ($X7$)	0.17	0.35	0.41	0.75*	0.11
Sunshine ($X8$)	0.60	0.46	−0.21	−0.74*	0.53
Eurystylus bellevoyei					
Rainfall ($X1$)		−0.15		−0.08^a	
Pan evaporation ($X2$)		0.58		0.43	
Maximum temperature ($X3$)		0.47		0.43	
Minimum temperature ($X4$)		0.58		0.37	
Maximum r.h. ($X5$)		0.45		−0.37	
Minimum r.h. ($X6$)		−0.32		−0.45	
Wind velocity ($X7$)		0.51		0.06	
Sunshine ($X8$)		0.55		−0.30	

Regression equations

C. angustatus

$Y3 = 641 - 3.4X2 - 16.1X3 + 31.5X4 - 3.9X5 - 4.0X6 + 7.9X8$ ($R^2 = 68.9\%$)

$Y5 = 576 - 41.6X3 + 39.6X4 - 1.4X5 - 1.9X6 - 13.3X7 + 37.8X8$ ($R^2 = 70.4\%$)

Campylomma sp.

$Y1 = -649 - 0.9X1 - 17.0X3 + 31.5X4 + 4.2X5 - 2.2X6 + 39.4X8$ ($R^2 = 75.0\%$)

$Y3 = -0.7 + 0.03X2 - 0.1X3 - 0.1X4 + 0.1X5 - 0.1X6 - 0.3X8$ ($R^2 = 71.7\%$)

$Y5 = 177 - 13.3X3 + 13.6X4 + 0.2X5 - 1.6X6 - 2.8X7 + 8.7X8$ ($R^2 = 84.2\%$)

C. pallidus

$Y1 = 1.2 + 0.1X1 - 0.1X3 - 0.04X4 + 0.02X5 - 0.03X6$ ($R^2 = 94.3\%$)

$Y3 = -631 + 0.1X2 + 8.2X3 - 1.9X4 + 1.9X5 + 1.3X6 + 21.1X8$ ($R^2 = 88.3\%$)

$Y5 = -46.5 + 0.9X3 - 0.4X4 + 0.1X5 + 0.2X6 - 0.3X7 + 1.9X8$ ($R^2 = 96.6\%$)

E. bellevoyei

$Y2 = -3982 + 0.9X2 + 51.7X3 - 11.8X4 + 12.2X5 + 7.0X6 + 128.5X8$ ($R^2 = 84.8\%$)

*, ** Significant at $p < 0.05$ and 0.01, respectively; ^{a} residual is greater than the variance for regression analysis

competition with *C. angustatus*, which infests and multiplies on sorghum panicles about 10–15 days earlier than *Eurystylus*. This is also supported by our observations in the 1984 rainy season, when numbers of *E. bellevoyei* became quite high in an experiment on insecticide control of *C. angustatus* (Sharma and Leuschner, 1987).

All the four species complete development in 15–20 days and thus they are capable of assuming serious proportions within a single cropping season. Off-season carry-over of *C. angustatus* seems to be as the adult stage on summer sorghum. Long-distance migration may be another possible mode of survival and dispersion. Future studies are needed on the

TABLE 6. *Correlation* and regression coefficients between head bug numbers and environmental parameters during the post-rainy season, 1982 (Vertisols)

	Calocoris angustatus						*Campylomma* sp.					
	Adults (*Y1*)			Nymphs (*Y2*)			Adults (*Y3*)			Nymphs (*Y4*)		
Enviromental parameters	*SW*	*W1*	*W2*	*SW*	*W1*	*W2*	*SW*	*W1*	*W2*	*SW*	*W1*	*W2*
Maximum temperature (*X1*)	−0.52	−0.37	−0.24	−0.62	−0.44	−0.29	0.46	0.48	0.40	0.47	0.72*	0.65*
Minimum temperature (*X2*)	−0.37	−0.44	−0.39	−0.65*	−0.50	−0.37	0.58	0.50	0.41	0.57	0.74*	0.59
Maximum r.h. (*X3*)	0.36	0.73*	0.13	0.48	0.32	0.01	−0.35	−0.04	−0.11	−0.64*	−0.22	−0.30
Minimum r.h. (*X4*)	0.63*	0.19	0.06	0.41	0.07	0.18	0.08	−0.41	−0.19	−0.31	−0.47	−0.49

Regression analysis

$Y1\ (W1) = 84 - 7.1X1 + 4.8X2 + 3.1X3 - 4.1X4\ (R^2 = 43.8\%^a)$
$Y3\ (SW) = -1050 + 323X1 - 9.2X2 - 2.2X3 + 11.8X4\ (R^2 = 80.0\%^a)$
$Y4\ (W1) = -96 - 0.1X1 + 4.1X2 + 0.5X3 - 0.2X4\ (R^2 = 26.5\%^a)$
$Y4\ (W2) = -226 + 12.0X1 - 9.6X2 - 0.6X3 + 2.2X4\ (R^2 = 16.6\%^a)$

SW, *W1*, *W2* as in *Table 4*; * significant at $p < 0.05$; [a] residual is greater than the variance for regression analysis

off-season carry-over and natural enemy complex of all the mirid head bugs in Asia and Africa.

The major peak in *C. angustatus* was observed in September and October. In India, its maximum density has earlier been reported during this period at Hyderabad (Sharma, 1985a), during May–June at Bhavanisagar (Balasubramanian and Balasubramanian, 1979) and during August at Dharwad (Thimmaiah *et al.*, 1972), and it seems to follow the cropping and rainfall pattern at these locations.

Observations on the population dynamics of head bugs are a valuable input in screening and breeding for resistance to head bugs at ICRISAT. Sorghum sown between 15 July and 8 August flowers during the peak population density of head bugs. To a limited extent, these observations can also be used in avoiding head bug damage by adjusting planting dates. The crop flowering between November and April suffers minimum head bug damage. It is probably for this reason that farmers in the vicinity of ICRISAT, and some other areas in India, plant and use the rainy season crop only for fodder, and the post-rainy season crop for grain. Furthermore, the market value of the post-rainy season produce is greater than the rainy-season grain, and head bug damage and grain moulds are to a large extent responsible for this difference. The severity of mould incidence also increases with head bug damage (Sharma, 1985b).

Rainfall, temperature (25–32°C) and r.h. (50–95%) were positively associated with *C. angustatus*, *C. pallidus* and *E. bellevoyei* populations during the rainy season. However, there were distinct exceptions in some years. During the post-rainy season, higher temperatures (>32°C) and moisture deficit exercised a negative effect on *C. angustatus*, *C. pallidus* and *E. bellevoyei* populations. Relative humidity was positively associated with head bug density (with some exceptions). However, higher temperatures and lower r.h. seem to favour *Campylomma* populations, a pattern opposite to that of other head bug species. *Campylomma* tends to multiply during hot and dry periods, when the *C. angustatus* population is low. Thus, different combinations of weather parameters influence head bug density during the rainy and the post-rainy seasons. Weather parameter means for the same week and 2 preceding weeks showed a greater effect on head bug populations. This fits well with the life cycle of head bugs, which is completed in nearly 2 weeks. The influence of weather parameters on head bug density is, therefore, evident in the following generations as well.

These results emphasize the need for a thorough understanding of the interactions between the insect, host-plant and the environment. This information is also vital for the management of insect pests.

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