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Incidence of Winter and Summer Diapause in *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in Andhra Pradesh, India

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Abstract: The incidence of winter and summer diapause was studied by large-scale field samplings of larvae and pupae of the cotton bollworm, *Helicoverpa armigera* (Hüb) conducted over a period of 13-years during winter and summer seasons in Andhra Pradesh, India. Induction of winter diapause was associated with cooler prevailing temperatures and shorter day lengths of <12 h in November-January. On the other hand, summer diapause was observed at temperatures >32°C during March-April resulting in greater adult emergence with the onset of the monsoon season during mid-June to early July. In summer, few alternate hosts are available for larvae to sustain by allowing local populations colonizing newly germinated host crops with the onset of the rainy season. In addition, the incidence of winter and summer diapause was higher in male pupae than females in the ratio of 4:1 and 3:1 (♂:♀), respectively. Diapause populations of *H. armigera* were most common in the cyclonic weather prevailed for several weeks during 1977-78 (15.11%) and 1995-96 (17.64%). Under these conditions, an average of <4% and <6% of pupae entered winter and summer diapause, respectively and was associated with severe outbreaks of *H. armigera* in subsequent seasons. Higher populations of *H. armigera* on pigeonpea and chickpea entered winter diapause on pigeonpea and chickpea and summer diapause on irrigated maize, pigeonpea, chickpea and a common weed host, *Datura metel*.

Keywords: *Heliothis armigera*, monsoon, population dynamics, summer diapause, temperature, winter diapause

INTRODUCTION

The cotton bollworm, *Helicoverpa armigera* (Hübner) is widely distributed across different continents throughout Africa, southern Europe, the Middle East, India, south-east Asia, Australia, eastern and northern New Zealand and many Pacific Islands (Fitt, 1989), including the USA (Borchert *et al*., 2003). In Peninsular India, *H. armigera* is a polyphagous pest infesting leguminous, fiber, cereal and horticultural crops (Reed and Pawar, 1982). The annual losses due to cotton and pulses alone by *H. armigera* have been estimated as US $500 billion (Shanower *et al*., 1999). Since the first major outbreak of *H. armigera* reported in 1977-78 on chickpea (ICRISAT, 1978) and pigeonpea (Rao *et al*., 1990) in Andhra Pradesh, India, it has gained importance as a pest in cotton and food crop agroecosystems. Moreover, its pest status in southern India has been exacerbated by the extension of growing season due to increasing irrigation facilities and use of new cultivars allowing for protracted host availability compared to the traditional agricultural practices where fallow periods were common. In addition, resistance to most of the commonly available insecticide classes (Daly and Murray, 1988; Armes *et al*., 1996), the ability for long-range migration (Farrow and Daly, 1987) has made control measures in fructuous. Other factors contributing to increased pest status include: ability to survive over a wide diversity of host plants (Zalucki *et al*., 1986, 1994; Fitt, 1989; Murray, 1991; Hamamura, 1998; Casimero *et al*., 2000), high fecundity (Reed, 1965) and ability to escape adverse seasons *via* diapause (Roome, 1979; Wilson *et al*., 1979; Eger *et al*., 1982).

It completes 7-8 generations annually and adults emerge in two weeks depending on the soil temperature. In Southern India, the rainfall is a key climatic factor that influences the regional population dynamics in any season. Higher rainfall early in the season greatly influences the population buildup. Several reports are available on the ability of *H. armigera* to enter pupal diapause (Reed, 1965; Hardwick, 1965; Wilson *et al*., 1979; Roome, 1979; Hackett and Gatehouse, 1982; Fitt, 1989; Nibouche, 1998; Qureshi *et al*., 1999, 2000; Shimuzi and Fujisaki, 2002; Shimuzi *et al*., 2006; Kurban *et al*., 2007), whose intensity is governed by latitude (Danilevski, 1965; Beck, 1968, 1980; Wu and Guo, 1997b). The influence

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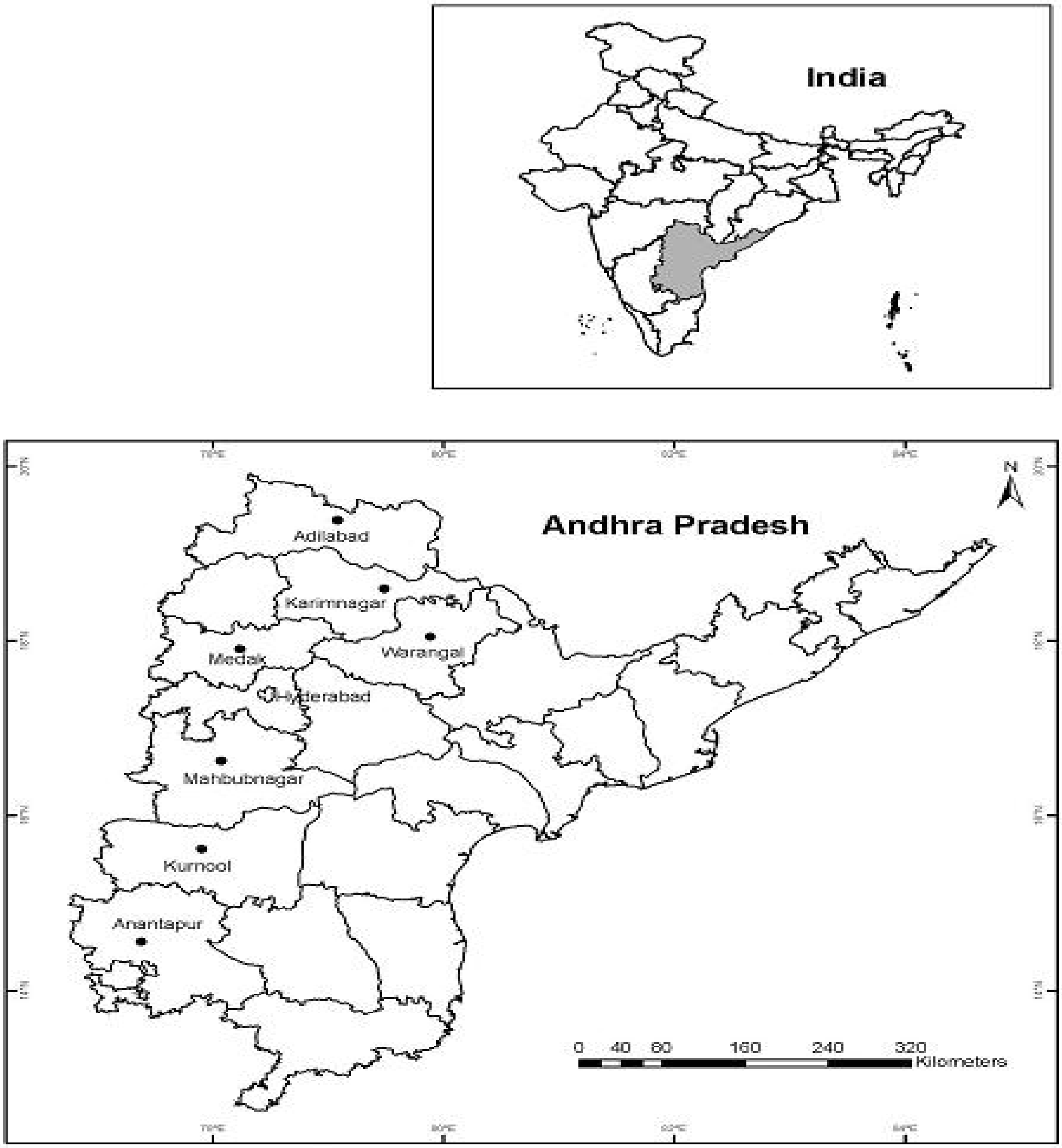


Fig. 1: Sampling of *H. armigera* larval populations conducted in various districts of Andhra Pradesh, India (• Marked denote the districts surveyed)

of temperature and photoperiod on the induction, maintenance and termination of winter diapause in *H. armigera* has been reported from Russia (Kuznetsova, 1972), India (Bhatnagar and Davies, 1978), Botswana (Roome, 1979), Australia (Wilson *et al*., 1979; Kay, 1982), China (Wu and Guo, 1997a; Ge *et al*., 2005), Japan (Qureshi *et al*., 1999), Israel (Zhou *et al*., 2000), the USA (Borchert *et al*., 2003) and Greece (Mironidis *et al*., 2010). Similarly, the induction of diapause resulting from long photoperiods and high temperatures during summer has been reported (Masaki, 1980; Butler *et al*., 1985; Denlinger, 1986, 2002; Danks, 1987, 2005; DeSouza *et al*., 1995; Nibouche, 1998). In Andhra Pradesh, winter diapause has been reported as a mechanism allowing the survival of populations when few alternate crops are available for the off-season survival of larvae in summer (Bhatnagar and Davies, 1978). King (1994) reported the occurrence of a low proportion of diapause pupae of <2 and 1% in winter and summer seasons, respectively. Martinat (1987) reported that severe cyclones are associated with the occurrence of heavy to incessant rains during November-December, especially in coastal districts of Andhra Pradesh. Normally, the cyclonic rains continue for 4-10 days with cool and overcast cloudy conditions, which can have a significant impact on the larvae of *H. armigera*. Very few studies have been conducted on the ecological performance of diapause in *H. armigera* (Hackett and Gatehouse, 1982; Nibouche, 1998; Masaki, 2002) and *H. virescens* (Potter and Watson, 1980; Butler *et al*., 1985). Very few studies are available on the seasonal incidence of diapause in *H. armigera*. These studies are based on long term field work and investigate to relate the agroclimatic factors influencing the incidence of diapause of *H. armigera* in tropical agroecosystems.

MATERIALS AND METHODS

Over a 13 year period from 1974-96 large-scale periodic field samplings of *H. armigera* larvae were made on crops such as pigeon pea (*Cajanus cajan* (L.) Millsp.), chickpea (*Cicer arietinum* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum americanum* (L.) Leeke), tomato (*Lycopersicon esculentum* Mill.), cowpea (*Vigna unguiculata* (L.) Walp), black gram (*Vigna mungo* (L.) Hepper.), green gram (*Vigna radiata* (L.) Wilczek), cotton (*Gossypium* spp.), safflower (*Carthamus tinctorius* L.), linseed (*Linum usitatissimum* L.), sunflower (*Helianthus annuus* L.), soyabean (*Glycine max* (L.) Merrill), marigold (*Tagetes erecta* L.), groundnut (*Arachis hypogaea* L.), peas (*Pisum sativum* L.), okra (*Abelmoschus esculentus* L.), coriander (*Coriandrum sativum* L.), chilli (*Capsicum annuum* L.), onion (*Allium cepa* L.k), green mulch crop (*Sesbania bispinosa* (Jacq.) W.F. Wight) and weeds (*Lagascea mollis* Cavanilles; Hindu datura (*Datura metel* L.) in eight districts of Andhra Pradesh (Adilabad, Anantapur, Karimnagar, Kurnool, Mahbubnagar, Medak, Warangal and Hyderabad), India (Fig. 1 and 2).

Sampling sites were chosen based on crops' flowering because adults of *H. armigera* prefer oviposition on flowers and flowering buds where the resulting larvae feed on the flowers and fruiting structures (Zalucki *et al*., 1986; Jallow and Zalucki, 1997). Collection of larval samples were individually confined in glass tubes (80×20 mm) supplemented with tender pods and fruiting parts of the same host plants where from they were collected till pupation. Data was recorded on the duration of pupal period, sex and the date of adult emergence. The average critical day length at the sampling sites of the districts is shown in Fig. 3. Light traps were placed in ICRISAT fields to monitor the adult moths with an objective of determining the seasonal population dynamics as well as immigration

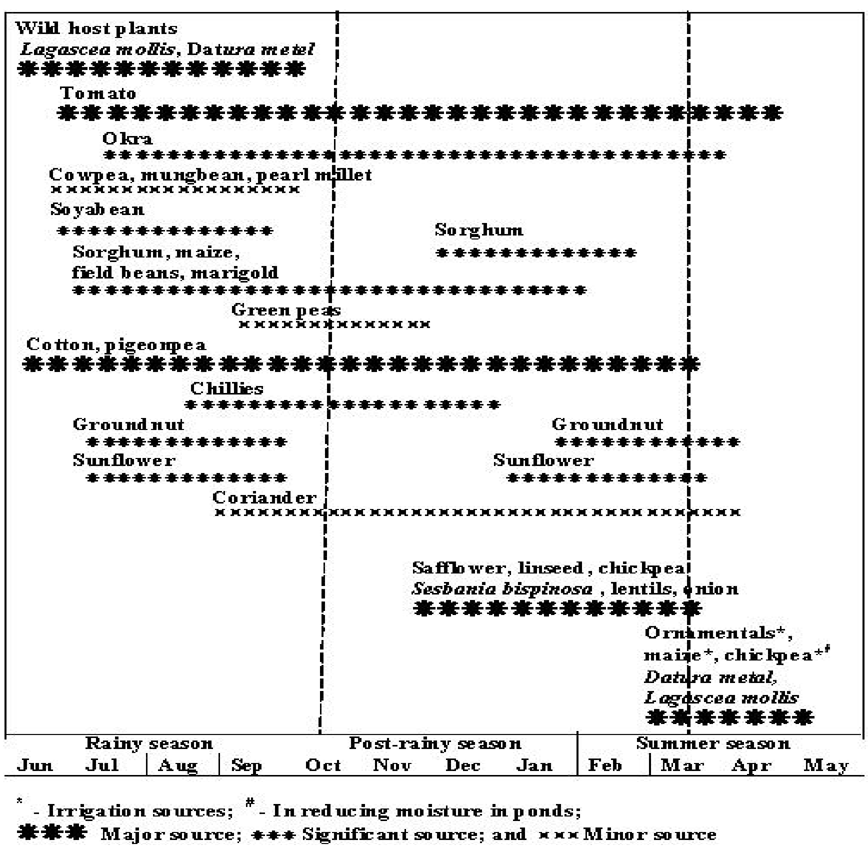


Fig. 2: Seasonal abundance of *H. armigrera* sampled from different host crops and weeds grown during rainy, winter and summer seasons of Andhra Pradesh, India

Table 1: Mean meteorological parameters recorded in Andhra Pradesh, India (1974-96)

				Temperature (ºC)	
Month	Rainy days (no)	Rainfall (mm)	Relative humidity (%)	Min.	Max.
June	10	132.0	79.7	23.6	33.6
July	15	200.1	87.6	22.5	30.2
August	15	196.2	89.1	22.1	29.1
September	12	134.1	89.8	21.1	30.0
October	8	115.0	88.1	19.7	30.1
November	3	13.7	87.8	16.3	28.5
December	1	1.0	87.5	13.1	27.7
January	1	10.8	85.6	14.2	28.6
February	4	5.7	73.6	16.9	31.9
March	2	11.9	64.3	20.0	35.7
April	4	30.2	57.9	23.2	38.0
May	4	26.2	56.2	25.4	39.1

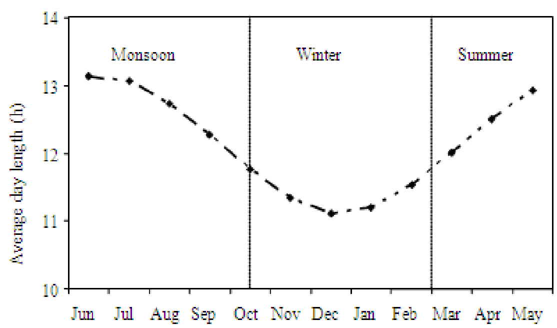


Fig. 3: Average critical day lengths recorded during June-May in Andhra Pradesh, India

influx. In addition, observations were recorded at weekly intervals on the agrometerological data with monthly averages of maximum and minimum temperatures, humidity, rainfall and rainy days (Table 1). The retention of pigmented eyespots in the pupal stage was considered as a diagnostic feature of diapause (Shumakov and Yakhimovich, 1955; Phillips and Newsom, 1966), which usually coincided at >35 days prior to adult emergence.

Statistical analysis: The replicated data was pooled together and means and standard errors were calculated. All data were analyzed by Analysis of Variance (ANOVA) to compare the significance using SPSS (Version 11.5).

RESULTS

The critical day length triggering higher than normal percentage of pupae at 13 h in June-July, 11.5 h in December and >12 h in March-May (Fig. 3). A smaller proportion of *H. armigera* pupae entered diapause in winter during late November to early-December. Significantly higher moth emergence was observed in 7th and 8th week followed by 6th and 11th week. However, no significant differences were observed in adult moth emergence between 6th and 8th week. No emergence of adult moth was recorded from 19th week. A continuous trend of increase in pupal period was recorded throughout the experimental period. However, significantly greater pupal period was observed in 23rd and 24th week onwards (Fig. 4). There was a greater significance in adult emergence in 23rd and 24th week followed by 27th, 26th and 28th week. Higher pupal period was observed in 26th week; however, there was no significant difference in pupal period in 24th, 25th and 27th week. Pupal period was lowest in 20th week (Fig. 5). In Andhra Pradesh, tomato is cultivated throughout the year; cotton and pigeon pea in June-March; okra in July-March; cowpea, mungbean, pearl millet, soybean, groundnut and sunflower crops in both June-July and Dec/Jan-March; coriander in August-April; sorghum in June-February; and chillies in August-December; safflower and chickpea in winter; and with supplemental irrigation in summer and *D. metel* and *L. mollis* Cav. Grow both in rainy and summer (March-May) seasons (Fig. 2).

Significantly greater no. of adult moths was caught between 45th to 52nd weeks, followed by 34th-39th week. Moth catches were observed throughout the experimental period. The larval population of *H. armigera* appeared in two peaks each moderately at 26th and 29th week in the rainy season and larger peaks at 46th and 48th week in winter season and a single smaller peak at week 21-in the summer season (Fig. 6). During cyclonic years in 1977-78 and 1995-96, a higher proportion of pupae of 15.11 and 17.64% entered diapause, respectively (Table 2). Among the diapause population, the total adult emergence was appeared in the ratio of 3:2 (648♂:419♀) during January to early-June. The staggered pattern of adult emergence occurred mostly between mid-February and March, very few in April, but only two adults each in May and June, respectively. During summer (March-April), a smaller proportion of pupae (2.00-10.43%) entered pupal diapause followed by an adult emergence ratio of 3:1 (35♂:11♀) between June and mid-July (Table 3).

Pupal recovery and diapausing pupae during winter diapause were significantly higher on pigeonpea than on chickpea (Fig. 7A and B). Significantly higher number

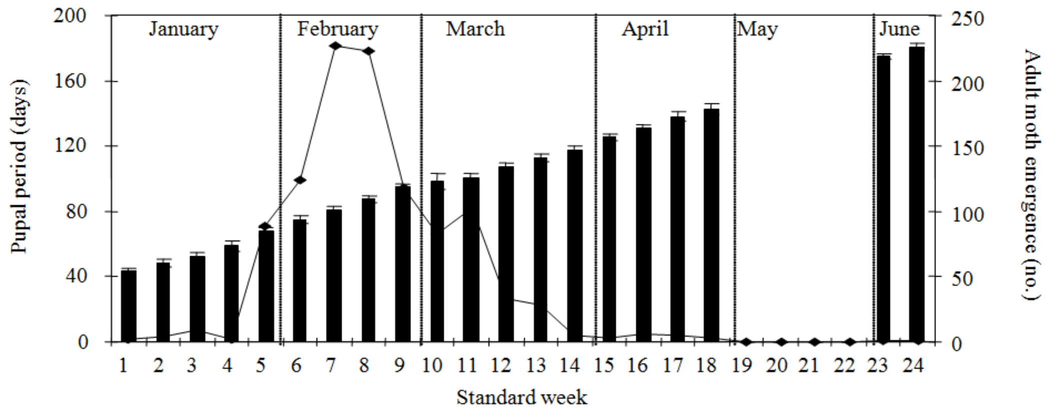


Fig. 4: Pupal period and adult moth emergence from winter diapausing pupae of *H. armigera* in Andhra Pradesh, India (1974-96)

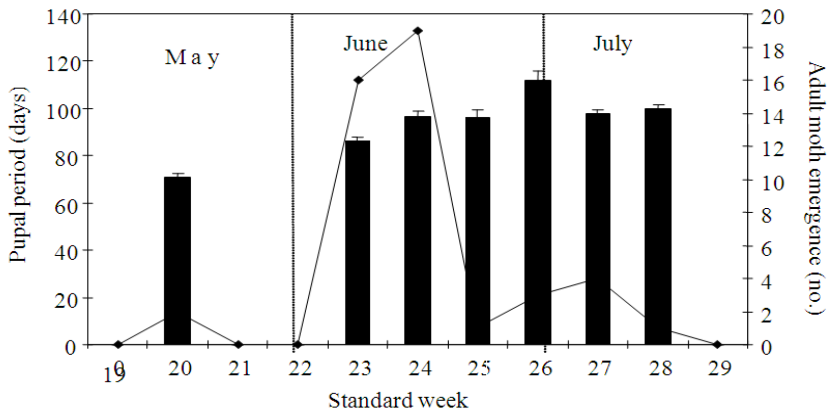


Fig. 5: Pupal period and adult moth emergence from summer diapausing pupae of *H. armigera* in Andhra Pradesh, India (1974-96)

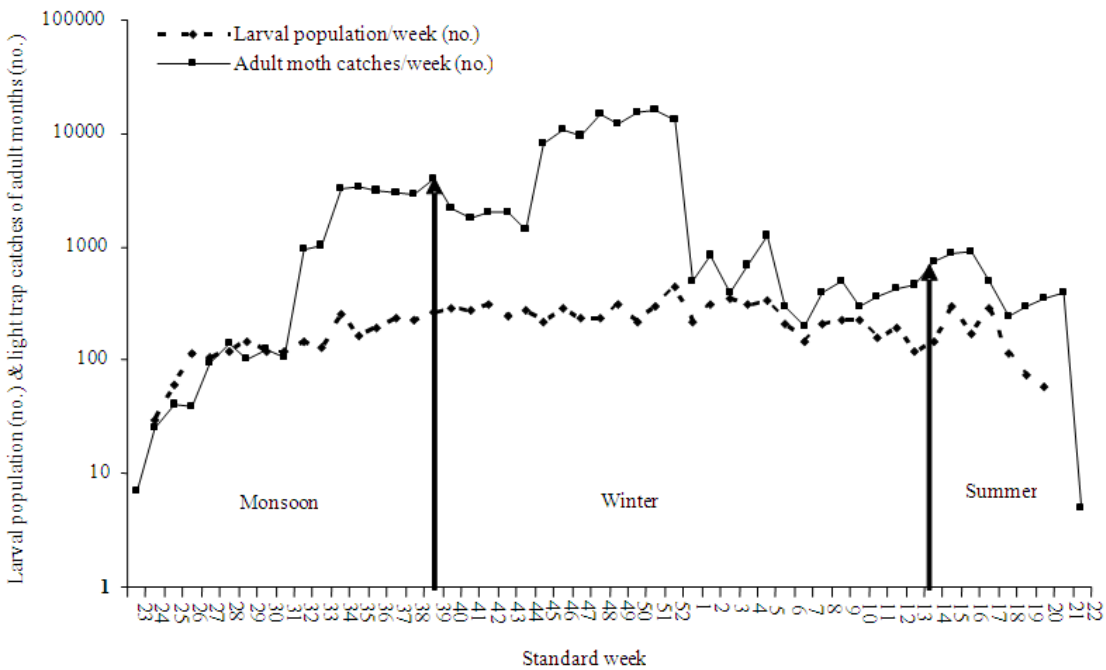


Fig. 6: Mean recovery of larvae and light trap catches of adult moths of *H. armigera* in Andhra Pradesh, India (1974-96)

Table 2: Incidence of winter diapause in the field samplings of *H. armigera* on leguminous crops grown in Andhra Pradesh, India (1974-96)

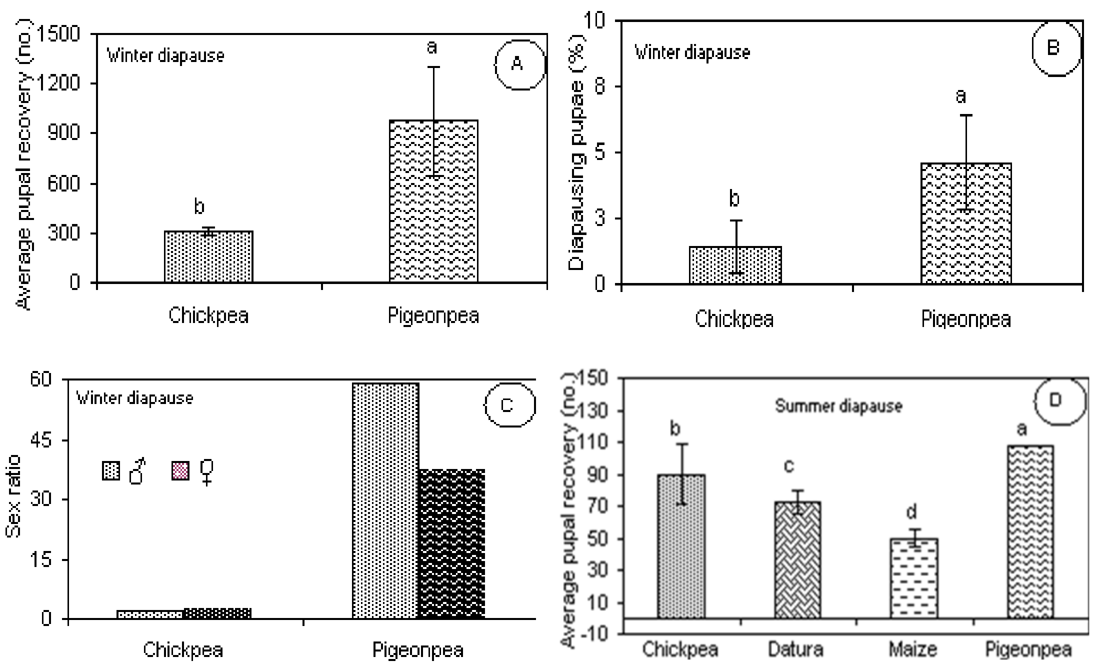
				Diapause pupae		Adult emergence (no.)		
Year	Period of sampling	Crop	Pupal recovery (no) ±S.E.	No.	(%)	♂	♀	Ratio
1974-75	Nov 15-Dec 3	Chickpea	335 ± 2.51^{f}	5^{c}	1.49	1^{c}	4^{c}	1:4
1975-76	Dec 1-5	Pigeonpea	934 ± 2.40^{cd}	14^{c}	1.49	10^{c}	4^{c}	5:2
1976-77	Nov 29-Dec 6	Pigeonpea	1330 ± 1.53^{c}	2^{c}	0.21	1^{c}	1^{c}	1:1
1977-78*	Dec 1-12	Pigeonpea	3500 ± 7.50^{a}	529^{a}	15.11	319^{a}	210^{a}	3:2
1978-79	Dec 1-10	Pigeonpea	518 ± 3.60^{de}	10^{c}	1.93	6^{c}	4^{c}	3:2
1980-81	Dec 3-13	Pigeonpea	435 ± 1.73^{de}	6^{c}	1.38	4^{c}	2^{c}	2:1
1981-82	Dec 10-16	Pigeonpea	216 ± 4.04^{f}	4^{c}	1.85	2^{c}	2^{c}	1:1
1982-83	Nov 25-Dec 7	Pigeonpea	400 ± 1.73^{de}	10^{c}	2.50	6^{c}	4^{c}	3:2
1984-85	Dec 20-Jan 4	Chickpea	284 ± 1.15^{f}	4^{c}	1.41	3^{c}	1^{c}	3:1
1990-91	Dec 2-13	Pigeonpea	300 ± 1.52^{f}	9^{c}	3.00	6^{c}	3^{c}	2:1
1991-92	Nov 24-Dec 3	Pigeonpea	205 ± 0.57^{f}	7^{c}	3.41	5^{c}	2^{c}	5:2
1992-93	Dec 4-12	Pigeonpea	274 ± 3.05^{f}	6^{c}	2.19	4^{c}	2^{c}	2:1
1995-96*	Dec 24-Jan 7	Pigeonpea	2729 ± 3.46^{b}	461^{b}	17.64	286^{b}	175^{b}	3:2

Values (Mean±SEM) carrying same alphabet (s) within a column are not significantly different by Duncan's multiple range test, ($p\leq0.05$); *: Cyclonic years

Table 3: Incidence of summer diapause in the field sampling of *H. armigera* on different crops and weeds grown in Andhra Pradesh, India (1974-96)

				Diapause pupae		Adult emergence (no.)		
Year	Period of sampling	Crop/weed	Pupal recovery (no) ±S.E.	No.	(%)	♂	♀	Ratio
1974-75	April 15-18	Maize	30 ± 2.51^{d}	1^{bc}	3.33	1^{c}	0^{a}	1:0
1974-75	Feb 18-20	Chickpea	70 ± 1.73^{c}	2^{bc}	2.86	1^{c}	1^{a}	1:1
1977-78	April 10-13	Maize	45 ± 1.52^{d}	1^{bc}	2.22	0^{c}	1^{a}	0:1
1978-79	April 4-7	Datura	65 ± 1.53^{c}	5^{b}	7.69	4^{b}	1^{a}	4:1
1981-82	April 15-19	Chickpea	40 ± 1.00^{d}	4^{b}	10.00	3^{b}	1^{a}	3:1
1984-85	April 4-9	Datura	80 ± 1.53^{c}	7^{ab}	8.75	5^{ab}	2^{a}	5:2
1990-91	March 17-21	Chickpea	150 ± 2.88^{a}	3^{b}	2.00	2	1^{a}	2:1
1990-91	March 12-16	Pigeonpea	108 ± 0.99^{b}	3^{b}	2.78	3^{b}	0^{a}	3:0
1991-92	March 10-15	Chickpea	115 ± 1.00^{b}	12^{a}	10.43	9^{a}	3^{a}	3:1
1992-93	April 13-17	Maize	50 ± 2.51^{d}	3^{b}	6.00	3^{b}	0^{a}	3:0
1995-96	March 15-19	Chickpea	75 ± 2.64^{cde}	5^{b}	6.67	4^{b}	1^{a}	4:1

Values (Mean±SEM) carrying same alphabet (s) within a column are not significantly different by Duncan's multiple range test, ($p\leq0.05$)



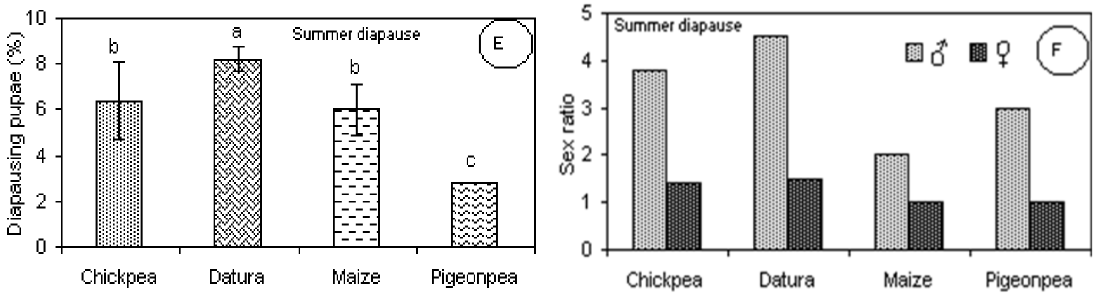


Fig. 7: Pupal recovery and incidence of winter and summer diapause and sex ratio of adult emergence in *H. armigera* on different crops and weed in Andhra Pradesh, India (1974-96)

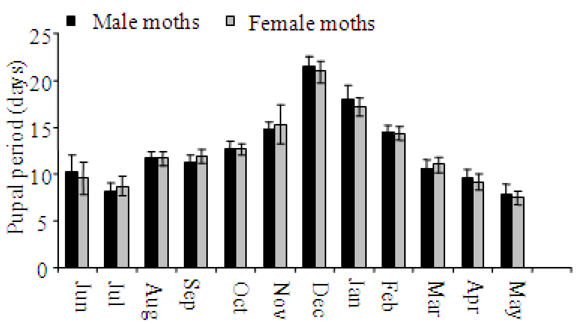


Fig. 8: Non diapausing pupal period of *H. armigera* collected from various host crops and weeds in Andhra Pradesh, India (1974-96)

of males than females was recorded on pigeonpea, while no significant difference was observed between number of males and females on chickpea (Fig. 7C). Among different crops in summer diapause, significantly higher pupal recovery was observed on chickpea and pigeonpea than on *Datura* and maize (Fig. 7D). *Datura* showed significantly higher pupal diapause during summer than pigeonpea and maize. However, no significant difference was recorded in pupal diapause between chickpea and maize (Fig. 7E). Pigeonpea showed the lowest pupal diapause. Significantly greater difference in sex ratio during summer daipause was observed in *Datura*, followed by chickpea and pigeonpea (Fig. 7F). There was no significant difference in pupal period between non diapausing males and females across the year. However, pupal period was significantly higher in December followed by January as compared to the rest of the months. The nondiapausing adult moth emergence was observed throughout the 12 months (Fig. 8).

DISCUSSION

The incidence of diapause in *H. armigera* during winter and summer is governed by agroclimatic factors. The multi-year data on the patterns of winter and summer diapause development and emergence correlated with the field activity of adult moth emergence is important in better understanding the role of local population dynamics in the ecology and genetics of *H. armigera*. Present investigation revealed that shorter day length and cooler temperatures in November-December and higher temperatures in March-April are influencing the pupae to enter diapause. The summer diapause can significantly impact the rainy season crops by early emergence of adult populations resulting in considerable yield losses, while the winter diapause doesn't impact the crop damage to same degree because there is already a resident population multiplying at that time. However, there is a possibility of increased population explosion in winter crops if the timing of the cyclonic weather events in Andhra Pradesh coincides with the fruiting and podding stages in legume and oilseed crops and boll formation in cotton. The continuous emergence of moths from winter diapause pupae is a mechanism to ensure increasing their population by breeding with the emerging local population during late-January to April. Further, drought conditions associated with low local populations in the region have greater significance with diapause populations for the overall population dynamics. It was also observed by field sampling of larvae and pupae as well as monitoring of adult catches in light traps indicated that a majority of the pupae of *H. armigera* did not enter winter diapause.

In general, the incidence of diapause in winter and summer was significantly higher not only in male than female pupae but also in the sex ratio for adult emergence. The pupal period of non-diapause populations remain active throughout the year and migrate to crops that are planted in the neighboring areas, which are favorable for their suitability for population buildup. This was supported by the light trap catches of adult moths during September, December and March. Induction and termination of diapause was influenced in both winter and summer by decreased day length and daily temperatures (Mansingh, 1971; Tauber and Tauber, 1976; Masaki, 1980; Tauber *et al*., 1986; Danks, 2005). However, at extreme temperatures (>35ºC) exceeded by more than 2 months in Australia (Dillon, 1998) and China (Wu and Gu, 1997c). Larval rearing of *H. armigera* induced diapause at 18°C and 27°C with a range in pupal duration of 76-103 and 123-

49 days, respectively in the winter and summer seasons (Nel, 1961; Roome, 1979). In general, the winter diapause was induced in <7.7% population of pupae sampled on maize, pigeonpea, cotton, tobacco and field bean (*Dolichos lablab*), which continued over a period of 30-171 days at 20°C in Ukiriguru (Tanzania) (Reed, 1965). In contrast, no diapause has been reported in *H. armigera* populations in Namulonge (Uganda), with an exception of two pupae collected on sunflower entered diapause over a period of 53 and 84 days (Coaker, 1959) and from tropical and sub-tropical regions at room temperatures during winter day lengths (Hardwick, 1965). In contrast, under similar conditions, the pupal diapause was 8% in Rehovot (Israel; 32°N), 19% in Rotorua (New Zealand; 38ºS) and 82% at Nelson (New Zealand; 41ºS). Similarly, no diapause has been reported in the larvae of *H. zea* reared at 27°C with a day length of 10 h in Louisiana (USA) (30°N) (Phillips and Newsom, 1966), but 8% of *H. armigera* pupae entered diapause when reared at 25.6°C and 10 h day length in Azerbaidzhan SSR (40°N) and Ukrainian SSR (47°C) (Komarova, 1959). Adult emergence of *H. armigera* took shorter period of 35 days at 30°C but increased its duration by 4 days at 25°C and 111 days at 20°C in Stavropol (45°N) (Kuznetsova, 1972). On the other hand, the pupae took 152 days at 20°C; 80 days at 25°C; 73 days at 30°C in Tadzhikistan (40°N) (Kuznetsova, 1972); and 70 days at 35 and 20°C, respectively in Japan (34°N) (Qureshi *et al*., 1999).

The critical day length for induction of diapause ranged between 12L: 12D and 14L: 10D during the larval stage in *H. armigera*, but the termination took a longer period without any latitudinal variation at 20°C (Qureshi *et al*., 2000). In contrast, the diapause in *H. zea* was associated with the latitude from tropical regions and summer diapause at 37°C in Burkina Faso (Nibouche, 1998). While the developmental period of *H. armigera* pupae was prolonged with increased latitude but shortened at low temperatures in central and northern China (Wu and Guo, 1997 b, c, d).

Frequent outbreaks of *H. armigera* have been reported in late-fruiting cultivars, larger fields and extended growing season of cotton, pigeonpea and chickpea crops. Late-flowering/fruiting cultivars usually favored large over-wintering populations of *H. armigera* resulting in predisposed infestation in subsequent crop season. Temperature and photoperiod although considered as key stimuli for the induction and termination of diapause in *H. armigera*, increased latitude also played a significant role. Diapausing pupae have the ability to survive during winter in southern Japan (Qureshi *et al*., 1999, 2000; Izumi *et al*., 2005). In Western Tanganyika, a greater proportion of diapause pupae (45%) have been reported on maize and pigeon pea, followed by cotton (2.5%) and tobacco (2.3%) during April-July which period coincided with a decrease in day length (Reed, 1965). In south-eastern Australia, a significant proportion of *H. armigera* overwinter as pupae during summer and with a high recovery on cotton (Duffield, 2004). In Australia, adult emergence during mid-October-mid-November had two weeks later in the southern region compared to northern parts of New South Wales (Duffield and Dillon, 2005). A smaller proportion of pupae entered in winter diapause in Tanzania (Reed, 1965), Rhodesia (Jones, 1937), South Africa (Parsons, 1939; Nel, 1961), Russia (Komarova, 1959) and Botswana (Roome, 1979). In general, the adult emergence was more rapid from the summer diapausing pupae compared to winter ones. Higher incidence of diapause was induced not only by low temperatures but also by photoperiod in *H. zea* (Pullen *et al*., 1992), *H. punctigera* (Cullen and Browning, 1978), *H. virescens* (Henneberry, 1994) and *H. armigera* (Qureshi *et al*., 1999). Despite variation in photoperiodic conditions the Okayama population of *H. armigera* did not enter diapause at 30°C (Li and Xie, 1983). Present results also indicated that a small proportion of *H. armigera* pupae entered winter diapause representing a bimodal-shape curve that has coincided with the cyclonic years. Similar trend in bimodal emergence influenced by fluctuating environments has been reported in *H. zea* (Waldbauer, 1978). In addition, long-term studies of summer diapause coincided with maximum temperatures ranged between 32° and 35°C by mid-March associated with an adult emergence in 70-115 days in a bimodal fashion. Similar bimodal emergence of adults has been reported for *Chlorideae obsoleta* in USSR (Danilevski, 1965), tobacco budworm (*Protoparce sexta*) (Rabb, 1966) and *H. virescens* in the USA (Butler *et al*., 1985). Long-duration of adult emergence was also recorded in *H. armigera* in Sudan (Hackett and Gatehouse, 1982) and India (Tripathi and Singh, 1993). Geographic variation in photoperiod and temperature sensitivity to *H. armigera* populations for diapause was 40 and 70% in Japan and China respectively at 25°C and 10L: 14D (Li and Xie, 1983; Wu *et al*., 1997). Present investigation also showed a similar tendency of entering diapause by a greater proportion of male pupae than females. Similar observations were made in *H. virescens* (Butler *et al*., 1985) and *H. armigera* (Wu and Guo, 1997a).

Summer diapause in *H. virescens* was associated not only with high temperatures (>32°C) (Butler *et al*., 1985) but in low rainfall years (Schneider, 2003). In Sudan, the duration of diapause extended to more than 2 months at low temperatures with fewer pupae of *H. armigera* still continued to remain in diapause at high temperatures and commenced development only when the temperatures was lowered (Hackett and Gatehouse, 1982). Present studies also indicated that diapause terminates more rapidly at higher temperatures. These results are in consonance with earlier reports (Mangat and Apple, 1966; Roach and Adkisson, 1970; Kuznetsova, 1972). Higher incidence of diapause in winter during October-December and summer diapause in April-May was reflected by the recovery of pupae from the crops such as maize, pigeonpea, chickpea and *Datura*. This situation contributed to increased population buildup that led to severe infestation in the succeeding crops.

Further, the large-scale appearance of *H. armigera* larvae is indicative of greater fitness and faster development. In *H. virescens*, the photoperiod however had a negligible effect on the induction of summer diapause (Butler *et al*., 1985). Early emergence of moths from summer diapausing pupae in June-July was associated with a break in rainfall after a prolonged dry season. The wild and volunteer crop plants also played a significant role early in the season for the population buildup of *H. armigera*. Although the populations are initially low they dispersed widely by maintaining optimal populations until suitable crops become available in the monsoon season where the major agricultural diversity begins. Current studies provide a basis in understanding of *H. armigera* population dynamics for their impact on rainy season crops due to summer diapause in southern India. From these studies, it can be inferred that diapause is an adaptive trait in *H. armigera* in the semi-arid tropics and its occurrence is maintained by natural selection and not by intrusion of genes from elsewhere.

CONCLUSION

The cotton bollworm, *H. armigera* is a major pest of agricultural crops in the semi-arid regions of Indian sub-continent. The long term studies suggest the pupae undergoes facultative diapause and remains concern with the sudden appearance of larvae in the beginning of the monsoon crops. The long-term studies give the pests ability to survive the favorable and adverse weather conditions and be pestiferous. It is also recommended for the farming community to deep plough the soil where summer diapausing pupae are buried, so they could be killed which may result in lesser population build-up and could prevent out-breaks in cyclonic conditions. In untilled land, increased survival of pupae may allow the buildup of early populations.

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