Host preference of Xanthopimpla stemmator (Hymenoptera: Ichneumonidae) and its reproductive performance on selected African lepidopteran stem borers

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Host preference of *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae) and its reproductive performance on selected African lepidopteran stem borers

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Abstract

The Asian pupal parasitoid, *Xanthopimpla stemmator* Thunberg, was imported into East Africa as a classical biological agent of lepidopteran cereal stem borers. Preference of *X. stemmator* females for four common borers of maize and sorghum; the crambid *Chilo partellus* (Swinhoe), the pyralid, *Eldana saccharina* Walker, and the noctuids, *Busseola fusca* Fuller and *Sesamia calamistis* Hampson, was investigated. Pre-adult experience of *X. stemmator* females did not influence choice of host. In dual choice tests, more *B. fusca* were attacked than *E. saccharina*, while *E. saccharina* were attacked more than *Ch. partellus*. Life table studies on three of the hosts revealed that the intrinsic rate of increase was highest when *X. stemmator* was reared on *S. calamistis*. Net reproductive rates, mean generation times and doubling times were not different between hosts. Results suggest that *X. stemmator* can be successfully reared on the three stem borer species and released in areas where any combination of the three hosts occurs.

Introduction

The Asian stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), has become one of the most damaging pests of maize and sorghum in low and medium elevation areas of East and southern Africa (Kfir et al. 2002). Yield losses to maize attributed to *Ch. partellus* in East Africa are estimated to be as high as 73% (Seshu Reddy & Walker 1990). In addition to the exotic borer, there are several native borers that attack maize and sorghum. *Busseola fusca* Fuller (Lepidoptera: Noctuidae) is damaging at medium and high elevation areas (>600 m) (Kfir et al. 2002). *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) is widely distributed in tropical Africa

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and is one of the most damaging borers in West Africa (Bosque-Perez & Schulthess 1998), although in East Africa, densities are typically low (Cardwell et al. 2004). *Eldana saccharina* Walker (Lepidoptera: Pyralidae) is a serious pest of sugarcane in South Africa (Atkinson 1980) and of maize in West Africa (Bosque-Perez & Schulthess 1998), but in East Africa this borer is considered to be of minor importance (Overholt et al. 2001).

As part of a biological control program against stem borers in sub-Saharan Africa, an old association parasitoid of *Ch. partellus*, *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae), was introduced into the coastal area of Kenya from Pakistan in 1993 (Overholt 1998). Surveys conducted in the area of release indicate that this parasitoid has established and reduced the *Ch. partellus* population by an estimated 53% and the total borer population by 37% (Zhou et al. 2001). Although *Co. flavipes* can successfully parasitize *Ch. partellus*, *Chilo orichalcociliellus* (Strand) (Lepidoptera: Crambidae) and *S. calamistis*, it does not complete development in *B. fusca* or *E. saccharina* (Ngi-Song et al. 1995; Overholt et al. 1997).

In an effort to further suppress the population density of *Ch. partellus*, and to increase natural mortality of *B. fusca*, the International Centre of Insect Physiology and Ecology (ICIPE) imported the solitary pupal endoparasitoid, *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae), from South Africa in 2001. The South African colony was initiated with field material collected from Mauritius, which in turn originated from insects introduced from Sri Lanka in 1939 for biological control of *Chilo sacchariphagus* Bojer (Lepidoptera: Crambidae) in sugarcane (Greathead 1971). *Xanthopimpla stemmator* is an idiobiont parasitoid with a host range that is taxonomically broad, but ecologically restricted to gramineous lepidopteran stemborers. It has been reported to parasitize *Ch. partellus* in India (Vinson 1942), *Chilo infuscatellus* Snellen, *Eucosoma scistaceana* (Snellen) (Tortricidae), *Ostrinia furnicalis* (Guenee) (Pyralidae), *Scirpophaga nivella* (F.) (Pyralidae), and *Sesamia inferens* (Walker) (Noctuidae) in Taiwan (Sonan 1929; Cartwright 1933; Takano 1934) and *O. furnacalis* in west Malaysia (Yunus & Hua 1969) and the Philippines (Camarao 1979). In Africa, host range tests revealed that *Ch. partellus*, *B. fusca* and *S. calamistis* were equally suitable for development of *X. stemmator*, while *E. saccharina* was an inferior host (Gitau et al. 2005).

Although several species of pupal parasitioids of stem borers have been reported in sub-Saharan Africa, parasitism is typically low (Oloo 1989; Ogol et al. 1998; Zhou et al. 2003). *Xanthopimpla stemmator* uses a drill and sting foraging strategy (Smith et al. 1993), which is not shared by common native pupal parasitoids of stemborers in eastern and southern Africa, and thus may fill a vacant niche. Interspecific competition between *X. stemmator* and the native pupal parasitoid *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae), which uses an ingress and sting foraging strategy (Smith et al. 1993), suggests that these two parasitoids may be able to co-exist because they partly exploit different ecological niches; *D. busseolae* searches for hosts in maize stems and ears, while parasitism by *X. stemmator* is restricted to the stem. Based on these finding, Muli et al. (2006) hypothesized that maize ears would provide competition-free space for the native parasitoid.

Xanthopimpla stemmator was first released in Africa against *E. saccharina* in sugarcane in South Africa, but did not establish (Conlong 1997). More recently it was released against maize and sorghum stemborers in Mozambique, and in the same country against *C. sacchariphagus*, a recently introduced exotic borer in sugarcane.

Evidence indicates that the parasitoid is now established (Conlong & Goebel 2002; Cugala, unpublished data). Additional releases are currently being made in Malawi, Tanzania, Zimbabwe, Ethiopia, Eritrea and Kenya (Omwega, pers. comm).

The success of biological control agents depends on their ability to search for and locate target pests (Lewis et al. 1990; Jervis & Kidd 1996). Some immature parasitoids gain experience through developing inside hosts, which may in turn influence their selection of hosts (Vinson et al. 1977; Drost et al. 1988; Sheehan & Shelton 1989). Whether pre-adult experience influences host preference of *X. stemmator* is not known, but knowledge of this may be useful for planning field releases since the parasitoid can be successfully reared on several different hosts. Moreover, studies have shown that graminaceous plants are often infested by a complex of stem borer species (Girling 1978; Hughes et al. 1982; Kaufmann 1983; Seshu Reddy 1983; Ofomata et al. 1999). It would therefore be useful to determine whether *X. stemmator* discriminates between stem borer species in order to better predict its behavior in the field. In this study, the effect of pre-adult experience on the choice of hosts attacked by *X. stemmator* and host preference for *B. fusca*, *Ch. partellus*, *E. saccharina* and *S. calamistis* pupae were examined.

Additionally, population growth parameters were estimated through the construction of life-fertility tables for *X. stemmator* females reared on pupae of the three most common maize/sorghum stem borers in East Africa; *B. fusca*, *Ch. partellus* and *S. calamistis*. *Eldana saccharina* was not included in the study because it was inconsistently available from the insectary and previous work had shown that it was an inferior host (Gitau et al. 2005). Information on population growth rates of *X. stemmator* on the different borers will be useful in the selection of release sites, and to provide insight into the establishment and eventual performance of *X. stemmator*. Additionally, this information will be useful for selecting an optimal host for mass rearing.

Materials and methods

Insects

The four stem borers used for these studies were reared in the laboratory at ICIPE. *Chilo partellus* and *S. calamistis* colonies were initiated with insects collected from maize fields in the coastal area of Kenya. Colonies of *B. fusca* and *E. saccharina* were initiated with material collected from western Kenya. *Chilo partellus* and *E. saccharina* were reared on a diet described by Ochieng et al. (1985), while *S. calamistis* and *B. fusca* were reared using the method developed by Onyango and Ochieng-Odero (1994).

Two- to 3-day-old pupae of *B. fusca*, *Ch. partellus*, *E. saccharina* and *S. calamistis* were exposed to *X. stemmator* females. Previous host suitability studies showed that these pupal ages were optimal for parasitoid development (Gitau et al. 2005). Since *X. stemmator* does not attack naked pupae (Smith et al. 1993), pupae were enclosed in paper straws, which were smeared with frass. The frass was produced by introducing fourth instar larvae of *B. fusca*, *Ch. partellus*, *E. saccharina*, and *S. calamistis* into plastic jars with fresh maize-stalk sections for 24 h. Pupae were exposed for 1 h to mated *X. stemmator* females in acrylic cages measuring $15 \times 15 \times 15$ cm at a ratio of 100 host pupae to 20 female parasitoids. At the end of the exposure period, the pupae

were removed from the straws and kept in Petri dishes (8 cm in diameter) until adult parasitoid emergence.

Host preference of X. stemmator

Dual choice test. A 5- or 6-day-old, mated, naïve *X. stemmator* female that emerged from a pupa of one of the four stem borer species was released into a plastic jar (9.5 × 16.5 cm). Pupae of each of the four stem borer species were presented to the female in dual choice tests. A pupa of one species was inserted into the lower half of an 8-cm long paper straw, which was secured upright in the jar with a piece of clay at the base. A piece of cotton wool was tightly inserted halfway down the straw to prevent movement of odors inside the straw. A second pupa of a different stem borer species was placed in the upper half of the straw. Frass of the corresponding stem borer species was smeared at each end of the straw. The straw containing both pupae was placed at the center of the plastic jar containing the *X. stemmator* female. Females were observed as they searched for and attacked hosts. Observations continued for 1 h, or until the female had oviposited. Females that did not make a choice within 1 h were removed and replaced with a fresh female. After one oviposition or 1 h, pupae were removed from the straw and recorded as attacked when inspection under a dissecting microscope revealed probe wounds. The experiments were repeated 30 times for each of the six dual choices; *B. fusca* vs. *Ch. partellus*, *B. fusca* vs. *E. saccharina*, *B. fusca* vs. *S. calamistis*, *Ch. partellus* vs. *E. saccharina*, *Ch. partellus* vs. *S. calamistis* and *E. saccharina* vs. *S. calamistis*, and with females reared from each host species in the dual choice. The position of the two hosts was interchanged in 15 of the 30 observations in order to avoid any positional bias.

Four choice tests. A pupa of each of the four stem borer species was placed individually in a 5-cm paper straw. The straws were smeared and sealed with frass from the corresponding species. The four straws were placed 5 cm from the corners of a clear Perspex cage and secured to the base of the cage with clay. A 5- or 6-day-old mated *X. stemmator* female that had emerged from one of the four borers was released into the cage. The female was observed for 1 h and the first choice was recorded. This was repeated for *X. stemmator* females that had emerged from each of the other three stem borer species. A total of 90 observations were made for females emerging from each of the four stem borer species. The positions of the straws containing the different stem borer species were rotated regularly within the cage to avoid any bias.

Life table parameters of X. stemmator *reared on three stem borers.* Reproductive performance was assessed by construction of life tables for *X. stemmator* females reared on *B. fusca*, *Ch. partellus* and *S. calamistis* at 27 ± 2°C, 49–61% RH and 12:12 (L:D) h photoperiod. Six mated *X. stemmator* females that had emerged from *B. fusca* were randomly selected within 24 h of emergence and placed singly in clean acrylic cylinders (5 × 9 cm). Ten *B. fusca* pupae were inserted into two erect paper straws (0.5 × 7 cm) smeared with frass from *B. fusca*. Each female was then provided diet consisting of a small piece of cotton wool soaked in a 10% honey–water solution. Pupae and diet were replenished daily until the female died. Six mated *X. stemmator* females reared from *Ch. partellus* and *S. calamistis* were exposed to the respective stem

borer pupae in the same way. This procedure was repeated six times for *B. fusca* and *Ch. partellus* and five times for *S. calamistis* so that a total of 36 *X. stemmator* females emerging from *B. fusca* and *Ch. partellus* and 30 emerging from *S. calamistis* were used. Parasitized pupae were kept in Petri dishes (4 cm diameter) and monitored until emergence of parasitoids. Daily emergence of moths and *X. stemmator* adults, sex of progeny and number of female survivors were recorded. Mortality of parasitized pupae was also recorded.

It was not possible to dissect the host pupae to determine the presence of parasitoid eggs, as this would have killed the hosts. Pre-imaginal survivorship (percentage of offspring females alive until adulthood) was therefore calculated by exposing 100 pupae of each stem borer species for 2 h to *X. stemmator* females that had emerged from the same host. Pupae were exposed in groups of 10 (two straws with five pupae each) to two mated, naïve, female parasitoids. Previous work had shown that exposure of hosts in a 5:1 ratio with female *X. stemmator* for 2 h resulted in high parasitism and minimal superparasitism (Gitau 2002). The parasitized pupae were placed in Petri dishes in groups of 10. Pupae in five randomly selected groups were dissected 24 h post exposure to check for the presence of parasitoid eggs. The rest of the pupae were allowed to develop until adult *X. stemmator* emerged. Numbers of pupae containing eggs were recorded. Mean numbers of eggs per group were computed. Upon emergence, mean number of adult *X. stemmator* (both males and females) and *X. stemmator* females emerging were counted and recorded. It was assumed that survival of male and female eggs to adult emergence was equal. Pre-imaginal survivorship was then computed as the mean number of female offspring that emerged divided by the product of number of pupae with an egg out of 10 that were dissected and the proportion of females that emerged.

Data analysis

Host preference by X. stemmator *females*. Data from the dual choice tests were analyzed using a *G*-test of independence (Sokal & Rohlf 1981). A log–linear model was used to test if the hosts from which the females were reared had an effect on host choice, and if the choices made were different in the dual choices. Analysis for the choice of four hosts was conducted using a one-way ANOVA.

Parasitization potential for *X. stemmator* was assessed by comparing fertility (both cumulative and daily), progeny production and adult longevity of female parasitoids reared on the three stem borer species. For each host species, the intrinsic rate of natural increase (r_m) was calculated by analyzing the fecundity of ovipositing females based on emergence of their offspring. The span between two consecutive time periods was represented by its midpoint (female age $+ 0.5$) called the pivotal age (x). The number of female eggs laid at the pivotal age (x) was calculated as described above. Population parameter estimates for *X. stemmator* females emerging from and exposed to pupae of the three stem borer species were compared using the method by Maia et al. (2000). Confidence limits (95%) for life table parameters were computed using jackknife estimates of variance and means. Means for eggs laid by each group of females, proportion of females (sex ratio) and the number of parasitoid progeny were compared with ANOVA. Proportional data was arcsine transformed before ANOVA and means were separated using Student's Newman Keul's test (SAS Institute 2000).

Results

Preference of X. stemmator *females for four stem borer species*

The parasitoids always attempted to oviposit on the first host that they encountered. The mean time females took to make a choice was 2.6 ± 0.5 min (range $<1-10$ min). Choice of host pupae did not depend on the host species from which the female was reared ($\chi^2 = 2.11$; df $= 9$; $P > 0.05$). Analysis for choice of host by *X. stemmator* females was therefore conducted without consideration to the rearing history of the *X. stemmator* females.

In the dual choice tests, *B. fusca* pupae were more often attacked than *E. saccharina* pupae ($G = 26.16$; $P < 0.0001$) and conversely *E. saccharina* pupae were more attached than *Ch. partellus* ($G = 13.23$; $P < 0.01$). There were no significant differences in preference between the other four host combinations (*B. fusca* vs. *Ch. partellus* ($G = 1.44$; $P > 0.05$); *B. fusca* vs. *S. calamistis* ($G = 0.36$; $P > 0.05$), *Ch. partellus* vs. *S. calamistis* ($G = 1.00$; $P > 0.05$) and *E. saccharina* vs. *S. calamistis* ($G = 1.00$; $P > 0.05$)) (Figure 1).

In the four choice tests, host pupae from which females had emerged did not influence choice ($F = 0.48$; df $= 3$; $P = 0.70$). *Xanthopimpla stemmator* females did not discriminate between the four host species provided ($F = 1.28$; df $= 3, 12$; $P = 0.33$). Out of the 90 *X. stemmator* females observed, 24, 32, 26 and 18% attacked *B. fusca*, *Ch. partellus*, *E. saccharina* and *S. calamistis,* respectively.

Life table parameters of X. stemmator

Life table statistics of *X. stemmator* reared on the three stem borer species are presented in Table I. The jackknife estimate for intrinsic rate of natural increase (r_m) was higher for *X. stemmator* females reared on *S. calamistis* compared to those
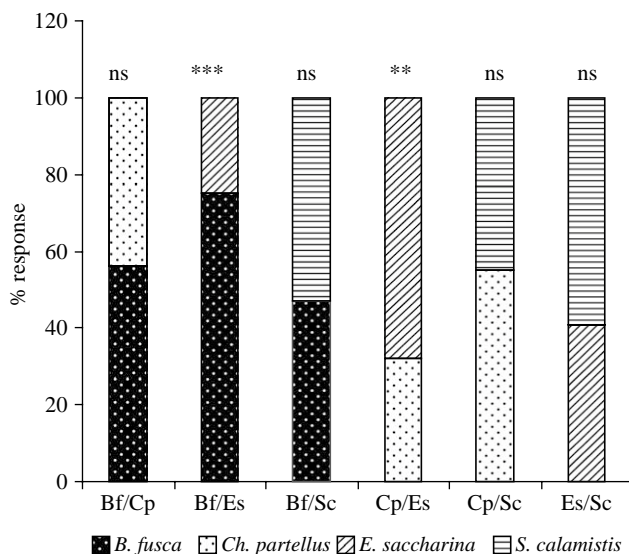

Figure 1. Response of naïve *X. stemmator* females to pupae of four stem borer species in dual choice tests ($n = 60$ for each dual test). Bf, *B. fusca;* Cp, *Ch. partellus;* Es, *E. saccharina;* and Sc, *S. calamistis*. **$P < 0.0001$; *$P < 0.01$; ns, $P > 0.05$.

Table I. Jackknife estimates of life table parameters of *X. stemmator* reared on three stem borer species.

Life table parameter	Host species		
	B. fusca	*Ch. partellus*	*S. calamistis*
Intrinsic rate of increase	0.103a (0.099−0.108)	0.096a (0.088−0.103)	0.110b (0.102−0.117)
Net reproductive rate	25.36 (20.29−30.44)a	18.12a (13.86−22.37)	21.75a (17.10−26.41)
Mean generation time	31.44a (29.91−32.98)	30.32a (27.60−33.03)	28.19a (26.24−30.14)
Doubling time	6.72a (6.40−7.06)	7.23a (6.68−7.79)	6.33a (5.91−6.75)

Means in the same row followed by the same letters are not significantly different ($P > 0.05$). Upper and lower 95% confidence limits are between parentheses.

reared on *B. fusca* and *Ch. partellus*. The net reproductive rates (R_o), mean generation times (T) and the population doubling times (t_D) did not differ among the three hosts (Table I).

Longevity of *X. stemmator* females was lower when reared on *S. calamistis* than on *B. fusca* or *Ch. partellus* ($F = 4.12$; df $= 2,202$; $P = 0.02$) (Figure 2). Age specific fecundity was higher on *Ch. partellus* compared to *B. fusca* and *S. calamistis* ($F = 14.37$; df $= 2,202$; $P = 0.0001$) (Figure 3). Maximum mean female progeny production per day (m_x) was 1.59 on the 13th day for *X. stemmator* females reared on *B. fusca* and *S. calamistis*. The m_x was 1.04 on the 11th day and 1.66 on the 78th day for *Ch. partellus*. The latter mean value of m_x was due to an atypical female that lived for 83 days and laid eggs towards the end of her life.

Females lived for an average of 34, 33 and 26 days during which time they laid an average of 103, 96 and 71 eggs in *B. fusca*, *Ch. partellus* and *S. calamistis*, respectively (Table II). Mean numbers of females and males produced during the entire lifetime of *X. stemmator* females emerging from the three stem borer species was not different. However, the sex ratio of progeny was more male biased for females emerging from and ovipositing in *S. calamistis* ($F = 2.47$; df $= 2,97$; $P = 0.04$). Proportion of days spent ovipositing did not differ between the three stem borer species (Table II).
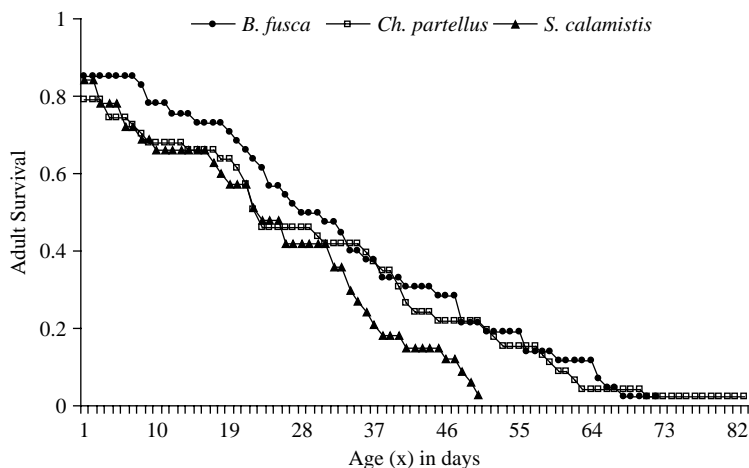

Figure 2. Survival at $27 \pm 2°C$, 49−61% RH and 12:12 (L:D) h photoperiod of adult females in the reproductive period of female *X. stemmator* parasitoids emerging from and exposed to pupae of *B. fusca*, *Ch. partellus* and *S. calamistis*.
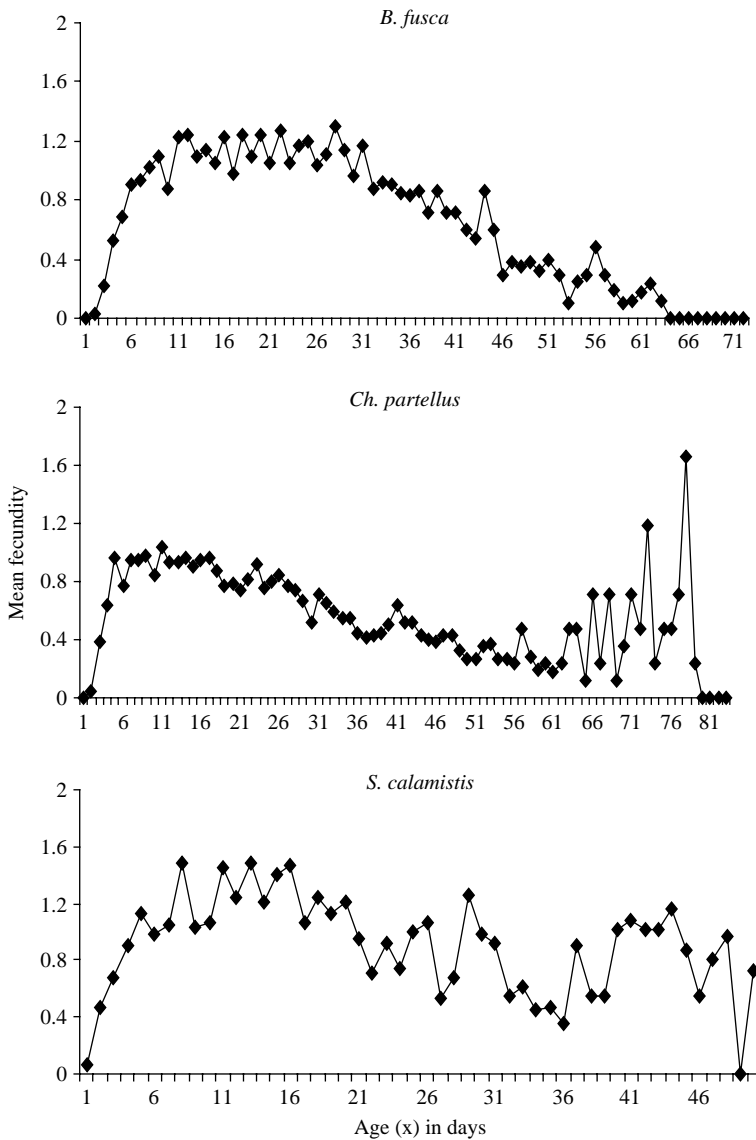
Figure 3. Age specific fecundity (m_x) of *X. stemmator* females emerging from and exposed to pupae of *B. fusca*, *Ch. partellus* and *S. calamistis*.

Discussion

Female *X. stemmator* did not discriminate between pupae based on the rearing history of the searching female. Stimuli perceived during development or upon emergence apparently did not condition *X. stemmator* females to respond to odors associated with the host from which they emerged. Idiobioint parasitoids such as *X. stemmator* are typically less specialized than koinobionts. The latter must co-exist with developing hosts (Waage 1979; Askew & Shaw 1986; Gauld et al. 1992), while idiobionts are dependent upon the host resources present at oviposition.

Table II. Mean adult longevity $\pm$ (SE) of *X. stemmator* females that were offered hosts until their natural death and the percentage of female progeny that emerged from *B. fusca*, *Ch. partellus* and *S. calamistis*.

Stem borer species	Mean adult longevity in days	Proportion of days spent for egg laying	Parasitoid progeny		Sex ratio (proportion ♀)	Mean number of eggs laid
			Female	Male		
B. fusca	34.6±3.1	28.7±2.49	27±4.24	75±9.16	0.29±0.04b	103.3±10
Ch. partellus	33.3±3.0	28.0±2.79	24±4.25	72±9.96	0.26±0.04b	96.4±11
S. calamistis	26.3±2.0	20.7±2.31	26±3.70	45±6.80	0.41±0.05a	71.3±8

Means in the same column followed by the same letter are not statistically different (SNK $P < 0.05$).

Xanthopimpla stemmator females in our study did not discriminate between the three major borers found in maize and sorghum in eastern and southern Africa; *B. fusca*, *Ch. partellus* and *S. calamistis,* which suggests that this parasitoid may not discriminate between these stem borer pupae in nature. However, *E. saccharina* was attacked significantly less when presented with *B. fusca*, while it was preferred when presented with *Ch. partellus*. *Chilo partellus* is an old association host of *X. stemmator* while *B. fusca* and *E. saccharina* are new associations. The preference for the new association host, *E. saccharina*, over the old association host, *Ch. partellus*, is difficult to explain, although the *X. stemmator* colony originated from a colony in South Africa which was maintained on *E. saccharina* for many generations. Smith et al. (1993) found that *X. stemmator* accepted a variety of stem borer pupae enclosed in grass stems. The host range of *X. stemmator* in nature will likely depend on the diversity of hosts in the grass habitats that the parasitoid searches. In Kenya, the host range will probably include the maize/sorghum borers *Ch. partellus*, *B. fusca*, *S. calamistis*, *B. fusca* and *C. orichalcociliellus* and possibly other stem borers typically found only in wild grasses, such as the noctuids *Sesamia penniseti* Tams & Bowden, *Sciomesa piscator* Fletcher, *Sesamia poephaga* Tams & Bowden, and *Busseola phaia* Bowden (Nye 1960; Khan et al. 1997; Le Ru et al. 2006). Field studies will be useful for confirming the host range of *X. stemmator*.

An important limitation of the present study was the absence of odors from different host plants. Maize frass was the only plant-derived cue utilized. Volatile odors from different plants, or feeding by-products from different plants, may influence the host searching and acceptance behavior of parasitoids (Ngi-Song & Overholt 1997). Additionally, the arenas used for the choice tests were small, and frass odors from different host species may have intermixed. However, this may not have been too unrealistic as more than one species of stem borer often occurs in the same plant (Ofomata et al. 1999). The preference exhibited by *X. stemmator* for some hosts in the dual choice experiments indicates that the parasitoid was able to discriminate at some level. Additional laboratory studies to examine tritrophic effects on searching and acceptance behavior would be useful.

The R_o values for parasitoids emerging from and exposed to pupae of the three stem borer species were substantially higher than unity, implying increasing populations from one generation to another. The intrinsic rates of natural increase quantifies how much a population can increase between successive time periods and plays an important role in evaluating the ability to recover after depletion. Based on r_m, *S. calamistis* appears to be a slightly better host for *X. stemmator* than *Ch. partellus* or *B. fusca*. However, the overall r_m values obtained for *X. stemmator* females that

emerged from *Ch. partellus* in this study were low compared to a previous study conducted in India (Nikam & Basarkar 1981). The reasons for the difference are unknown, although the two studies were conducted under different conditions.

Furthermore, the genetic make up of the females in the two studies was likely to have been different, as the females used in our experiment were derived from an aboriginal population in Sri Lanka, which likely went through several bottlenecks during the transfer from Sri Lanka to Mauritius, then to South Africa and finally to Kenya. This series of bottlenecks may have resulted in a genetically impoverished culture. Although field releases have already been initiated in Kenya and other countries, it may be advisable to import additional *X. stemmator* from the native range to broaden the genetic base of colonies being used for the production of individuals for future releases.

The sex ratio of the progeny produced in this study was highly male biased, which clearly depressed the values of r_m. The male-biased sex ratio may be a reflection of low genetic diversity in the colony, resulting in the production of diploid males due to few alleles at the sex locus. Diploid males are produced in species in which sex is determined by the single locus complementary sex determination mechanism, whereby females are heterozygous at the sex locus and males are hemizygous or homozygous (Whiting 1943). In small cultures, alleles may be lost through genetic drift, which increases the probability of homozygosity at the sex locus. The production of diploid males through inbreeding has been demonstrated in a number of Hymenoptera species (Stouthamer et al. 1992). *Xanthopimpla stemmator* females tended to produce a greater proportion of males as they grew older. When supplied with an unlimited number of hosts in the laboratory, the sex ratio of parasitoids often becomes increasingly male biased with time due to sperm depletion (van den Assem 1986; King 1987). In the field, it is unlikely that *X. stemmator* females will find hosts in large numbers on a daily basis, and thus the increased prevalence of male progeny as females age may not occur. Maximum female production was from females 11–13 days old. Mean longevity of parasitoids emerging from *Ch. partellus* in this study was higher than that recorded by Nikam and Basarkar (1981) in India. It is difficult to explain this difference as they were working at a cooler temperature, which would be expected to increase longevity. As suggested previously, genetic differences between populations may have been involved.

The present study provides information that may be useful in planning releases of *X. stemmator*. Additional comparative studies on the growth rates of both *X. stemmator* and its stem borer hosts at different temperatures and diet would be useful to further refine laboratory rearing procedures. Clearly, releases can be made in areas dominated by any of the three hosts included in the life table study, which covers much of the maize growing region of eastern and southern Africa. However, some of these areas have bimodal rainfall patterns where hosts are available throughout much of the year, whereas other locations have only one rainy season. In areas with unimodal rainfall, both *Ch. partellus* and *B. fusca* diapause in senescent maize stems during the dry seasons (Overholt et al. 2001; Kfir et al. 2002). There is no information on the ability of *X. stemmator* to diapause. Further investigation is required in order to determine whether this parasitoid has any mechanism that would allow it to survive during extended periods when stem borer larvae are not actively feeding.

Acknowledgements

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