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Host Suitability of *Bracon hebetor S*ay on Different Lepidopterous Host Larvae

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Abstract: Performance of *Bracon hebetor* on various host species is necessary to enhance the biological control program for the management of different insect pests. The study was undertaken to determine the suitability of different lepidopteran host species for development, oviposition and reproductive performance of a parasitoid, *Bracon hebetor.* Nine potential lepidopteran host species on behalf of four families were evaluated for their effect on the development and reproduction of *B. hebetor*. The hosts were *Leucinodes orbonalis, Galleria mellonella, Corcyra cephalonica, Spodoptera litura*, *Plutella xylostela, Helicoverpa armigera*, *Maruca vitrata, Eucrysops cnejus* and *Earias vittella.* Studies were conducted in Petri-dishes (100 x15 mm) as experimental arenas. *Bracon hebetor* females were released singly in side petridishes containing five full-grown larvae of each host for five consecutive days. Parasitization of the host larvae and oviposition by *B. hebetor* females were varied with host species. The cumulative fecundity in the five-day period was the highest on *Galleria mellonella* (26.3±1.4) and the lowest on *E. cnejus* (2.5±0.3). The egg-to-adult survivorship and progeny sex ratio were also varied with host species. The highest percentage of parasitoid survival at adult stage was found on *G. mellonella* (84.85±2.87) and the lowest on *S. litura* (21.39±2.8). Duration of egg to adult development was the shortest on *E. vittella* (8.55±0.25 days) and longest on *S. litura* (11.4±0.22 days). Results of the present studies suggested that *B. hebetor* females may apply as a wide range of lepidopteran hosts for parasitism and ovipositing but *G. mellonella* was the most preferred host.

Key words: Lepidoptera · Host suitability · Field insects · Parasitoid · Biological control

INTRODUCTION

Bracon hebetor Say (Hymenoptera: Braconidae) is a cosmopolitan, gregarious, ecto-endo-parasitoid that attacks the larval stage of several Lepidopterous species . It is considered as one of the best potential biological control agents for stored-product insects under the family Pyralidae [1]. Its females first paralyze their hosts, which are typically last larval stage by stinging them, injecting paralytic venom and ovipositing variable numbers of eggs on or near the surface of paralyzed host larvae [2].

As little as one part of venom in 200 million part of host blood was sufficient to cause permanent paralysis in the host larvae , *Galleria mellonella*; during her lifetime a tiny («0.5 mg) female Bracon could theoretically paralyze over 25 kg of larvae and in number i.e. 500-1000. *Galleria mellonella* L. (Lepidoptera: Pyralidae) called greater wax moth, a destructive pest of bee hive [3, 4]. The venom is, however, strongly paralytic only to lepidopterous larvae (except *Ostrinia nubilalis*) and not to members of other orders [5, 6]. The paralyzed larvae cannot survive. The paralyzed host larvae are then used as food sources for developing wasp and also for the adult females. These paralyzed larvae are not commonly recovered again although still alive for a long time (about 15 days) [7, 8].

Bracon hebetor is primarily known as a parasitoid of pyralid moths in the subfamily Phycitinae including Indian meal moth (*Plodia interpunctella* (Hubner) [9], Mediterranean flour moth *Ephestia kuehniella* (Zeller) [10], tobacco moth (*E. elutella* (Hubner), dried fruit moth, (*Vitula edmansae* (Packard), *Moodna* sp. and almond moth (*E. cautella* (Walker) [11, 1]. *Bracon hebetor* also attacks several other non phycitine pyralid moths, such as the rice moth (*Corcyra cephalonica* (Stainton) (subfamily:

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Galleriinae), the greater wax moth (*Galleria mellonella* L. (subfamily: Galleriinae), grass moth (*Laetilia coccidivora* (Comstock) (subfamily: Crambidae) and some species outside Pyralidae such as potato tuber worm (*Phthorimaea operculella* (Zeller) (family: Gelechiidae) and Angoumois grain moth (*Sitotroga cerealella* (Olivier) (Gelechiidae).*Bracon hebetor* females can use a wide range of lepidopteran hosts for paralysis and oviposition including tobacco budworm (*Heliothis virescens* (Fabricus), corn earworm *Helicoverpa zea* (Boddie), beet armyworm (*Spodoptera exigua* (Hubner) (Noctuidae) [12, 13].

Host records from Asian countries indicate that *B. hebetor* attacks a number of nonpyralid lepidoptera species that occur in both grain storage and field habitats [14, 15, 16]. However, *B. hebetor* can successfully attack larvae in Noctuidae family in the field [17].

The suitability of 12 lepidopteran host species on *B. hebetor* associated with stored product pests in the laboratory was studied [13]. Paralysis and oviposition of the host larvae *B. hebetor*, cumulative fecundity, egg-to-adult survivorship and progeny sex ratio were significantly affected by host species. Egg to adult development was shortest on *E. cautella* (9.75± 0.25 days) and longest on *G. mellonella* (12.63± 0.28 days). They suggested that by *B. hebetor* females can use a wide range of lepidopteran hosts for paralysis and oviposition. Comparative biology of *B. hebetor* on seven lepidopteran pest (using five different field and stored product pest) *Maruca testulalis* Geyer, *Galleria mellonella* L., *S. cerealella* Oliver, *C. cephalonica*, *S. litura* Fab, *H. armigera* (Hubner) Hardwick and *Earias vittella*, showed that *C. cephalonica* and *S. cerealella* are the best hosts for this parasitoid in terms of percentage egg hatch, developmental parameter, fecundity and, low male production [18]. The biological parameters and digestive enzymes of this parasitoid in five different lepidopteran hosts w ere investigated [19]. The parasitoid performed better on stored product pests, such as *E. kuehniella* and *P. interpunctella*, than field crop pests, such as *H. armigera* and *M. disstria* in terms of percentage of egg hatch, developmental rate, sex ratio and adult dry mass. The biology of two lepidopteran hosts on *B. hebetor* was studied and reported that *C. cephalonica* was found to be better host than *M. testulalis* in respect to number of eggs laid, percentage of egg hatch, growth index and percentage of adult emergence [20] and also revealed that *C. cephalonica* was better host than *Opisina arenosella* Walker when reared on *B. hebetor* [21].

A good understanding of host-parasitoid relationship is the key to the success of biological control programs. A host's value to the reproductive fitness of a parasitoid mainly depends on number and quality of the progeny from that host. Thus, physiological suitability of host is absolutely necessary for successful development of parasitoid progeny [22]. Similarly, a parasitoid's fitness also depends on its ability to locate and recognize its host in a complex environment and to produce a high or optimum number of viable and high-quality progeny from that host.

Understanding of reproductive performance of *B. hebetor* on various host species is necessary to enhance the biological control program for the management of different insect pests attacking vegetables. The present study was undertaken to determine the suitability of different lepidopteran host species for development, oviposition and reproductive performance of *B. hebetor*.

MATERIALS AND METHODS

Parasitoid Source and Rearing: The test parasitoid (*Bracon hebetor*) adults were collected from IPM laboratory, Entomology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. They were associated with infested Greater wax moth (*Galleria mellonella* L.). The parasitoids were cultured and mass-reared on full-grown larvae of *G. mellonella* in the laboratory at 27±2°C temperature, 65 ± 10 %, relative humidity and 14:10 (L: D) hr photoperiod. It was reared on a standard diet containing wheat flour, maize crush, wax, milk, sugar, animal fat and yeast.

Host Species of Prasitoids: Four species of Pyralids (family: Pyralidae), three species of noctiuds (Family: Noctuidae) and two species of other families of Lepidoptera were used in the experiments. Descriptions of host species are presented in Table 1. Larvae of each host species were collected from the respective host crop fields or from laboratory culture.

Brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis* L. were obtained from Brinjal field and reared under laboratory colonies on artificial diet and potato. Larvae of bean pod borer (BPB), *Maruca vitrata* F. were obtained from the country bean field and reared in the laboratory on bean during experimental period. Rice meal moth (RMM), *Corcyra cephalonica* was reared on a mixture of wheat bran. The greater wax moth (GWM) larvae were obtained from laboratory culture of IPM laboratory, Entomology Division, Bangladesh Agricultural

Table 1: List of lepidopteran host species of the parasitoid with their host crops or diet and the mean larval weights (mg ±SE) of 15 representative individuals used in this study

Common name	Scientific name	Family	Larval weight (mg) (mean ±SE)	Host crop/diet
Brinjal shoot and fruit borer (BSFB)	*Leucinodes orbonalis* L.	Pyralidae	85.067±6.331	Brinjal
Bean pod borer (BPD)	*Maruca vitrata* F.	Pyralidae	57.33 ± 2.4	Country Bean
Rice meal moth (RMM)	*Corcyra cephalonica* (Stainton)	Pyralidae	43.067 ± 2.491	Rice meal mixed with wheat bran
Greater wax moth (GWM)	*Galleria mellonella* (Linnaeus)	Pyralidae Subfamily Galleriinae	166.8±5.076	Laboratory culture
Diamond back moth (DBM)	*Plutella xylostella* (L.)	Plutellidae	7.363±0.34	Cabbage
Tomato fruit worm (TFW)	*Helicoverpa armigera* Hubner	Noctuidae	310±11.443	Tomato and chick pea
Okra shoot and fruit borer (OSFB)	*Earias vittella* Fabricius	Noctuidae	74.73±3.89	Okra fruits and shoot
Common cut worm (CCW)	*Spodoptera litura* Fab	Noctuidae	582.67±29.35	Cabbage and sunflower
Yard long bean pod borer (YLPB)	*Euchrysops cnejus* F.	Lycaenidae	71.73 ± 4.604	Yard long bean

Research Institute, Gazipur, Bangladesh. Tomato fruit worm (TFW) *Helicoverpa armigera* larvae were collected from tomato and chick pea field and reared on chickpea leaf and pod. Okra shoot and fruit borer (OSFB), *Earias vittella* larvae were collected from okra field and reared on okra fruits in the laboratory. Diamond back moth (DBM), *Plutella xylostella* (L) larvae were collected from cabbage field and reared on cabbage leaf in laboratory. Common cutworm (CCW), *Spodoptera litura (F.)* and Yard longbean pod borer (YLPB), *Euchrysops cnejus* F. larvae were collected from Cabbage, sunflower and yard long bean field respectively and reared in the laboratory during the experimental period.

Host's Suitability Study: Experiments were conducted in the laboratory in a no-choice design using petridishes (100 mm) with five wandering stage larva of each host species. Before establishing the experiment, a sample of full-grown larvae of each host species were randomly taken from the rearing jars and larval fresh weights were measured (n= 15) (Table 1). Two days old mated *B. hebetor* females along with male were introduced singly in the petridish and allowed to sting and oviposit for the next 5 days.

Data Collection and Analysis: Observations were made regularly to record numbers of hosts paralyzed, eggs laid by each day on each host, adults produced after 5 days of oviposition, egg-to-adult development time, egg-to-adult survivorship and parasitoid's progeny sex ratio. Each experimental unit was replicated 8 times for each host species. The numbers of hosts paralyzed and parasitized (oviposited-on) each day, the cumulative number of eggs laid and adults produced after 5 days of oviposition, the egg-to-adult development times, egg to adult survivorship and progeny sex ratio (% female of the total emerged adult progeny) were used as response variables to assess the quality and suitability of host species for development and reproduction of *B. hebetor.* Host species was considered as an independent variable for the analysis of response variables. Data for numbers of host paralyzed and parasitized, egg-to-adult survivorship, egg-adult developmental period and progeny sex ratio were analyzed by one-way analysis of variance (ANOVA). Data on cumulative value of eggs and adults were transformed following log (x+1) transformation method and progeny sex ratio and egg-to-adult survivorship data were transformed following arcsine transformation method before performance of ANOVA. Means were compared using Tukey, s Honestly Significant Different Test ($P<0.01$).

The performance of every host species and for the selection of the best host species a dendrogram were prepared through Hierarchical cluster analysis using Ward, s method [23] by SPSS 16 for windows. For cluster analysis 15 characters of life table parameters such as incubation period, larva, pupal, total life cycle period and viability, percentage of paralization and parasitization, female longevity, number of eggs, larvae, pupae and adult per five host larvae.

RESULTS AND DISCUSSION

Results: All 9 host species selected for the study were acceptable to the *Bracon hebetor* females for parasitism and oviposition ($F= 12.752$; df =8, 63; $P < 0.0001$ and $F= 24.633$; df=8, 63; $P<0.0001$). Parasitism was 52-100% on different host species. Significantly the highest parasitism was observed on GWM. Parasitism on larvae of DBM, BSFB, RMM, BPB and OSFB was statistically similar but significantly higher compared to other species except GWM. The lowest parasitism was recorded on YLPB followed by TFW and CCW. Acceptability of three hosts to *B. hebetor* was significantly different.

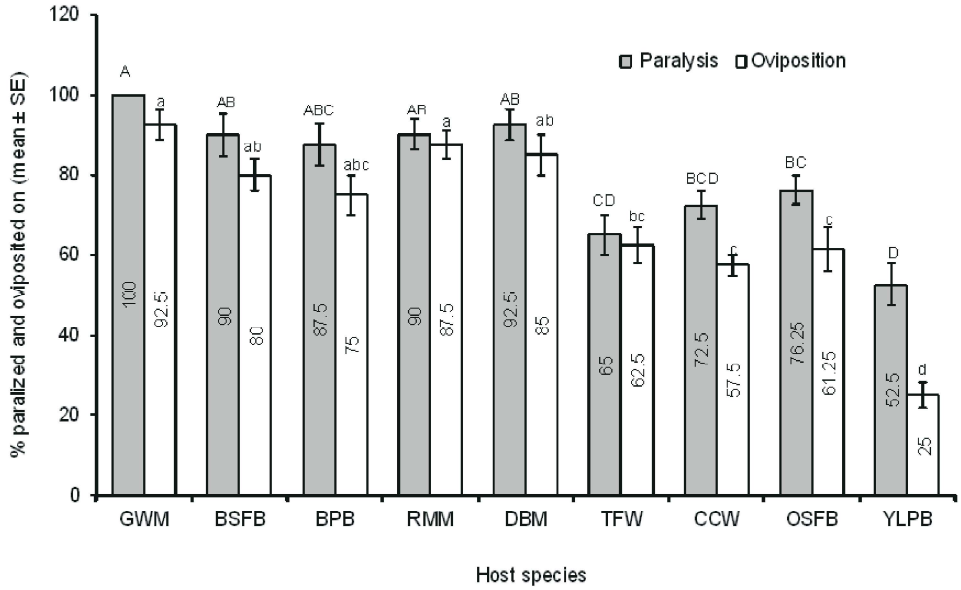

Fig. 1: Percentage of hosts paralyzed and oviposited by *B. hebetor* females on 9 different lepidopteran host species. Bars of the same type followed by the same lowercase (oviposition) or uppercase (paralysis) letters are not significantly different at $\alpha = 0.01$ using Tukey, s Honestly Significant Different Test. Vertical lines in the bar indicate the standard error of mean

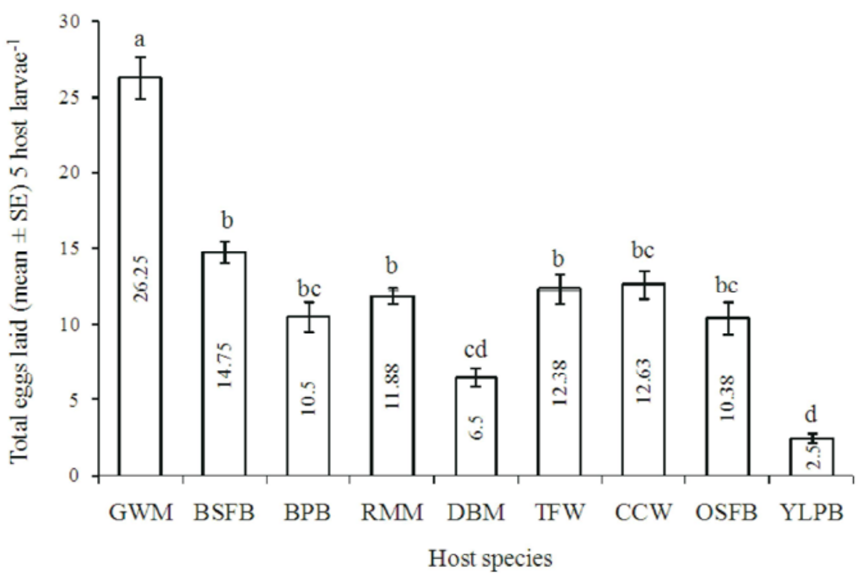

Fig. 2: Mean total oviposition of *B. hebetor* females during 5 days oviposition periods on 9 different lepidopteran host species. Bars followed by same letters are not significantly different using Tukey, s Honestly Significant Different Test

The range of oviposition on 9 host species was 25-92%. The highest oviposition was observed on GWM, which was statistically similar to only RMM and significantly higher compared to other host larvae. Significantly the lowest parasitism was observed on YLPB followed by CCW, OSFB, TFW and BPB (Fig. 1). The findings of the present study reveal that the entire host species tested might be recorded as acceptable host. When a parasitoid accepted a host for paralyzing and ovipositing may be defined as acceptable host [24].

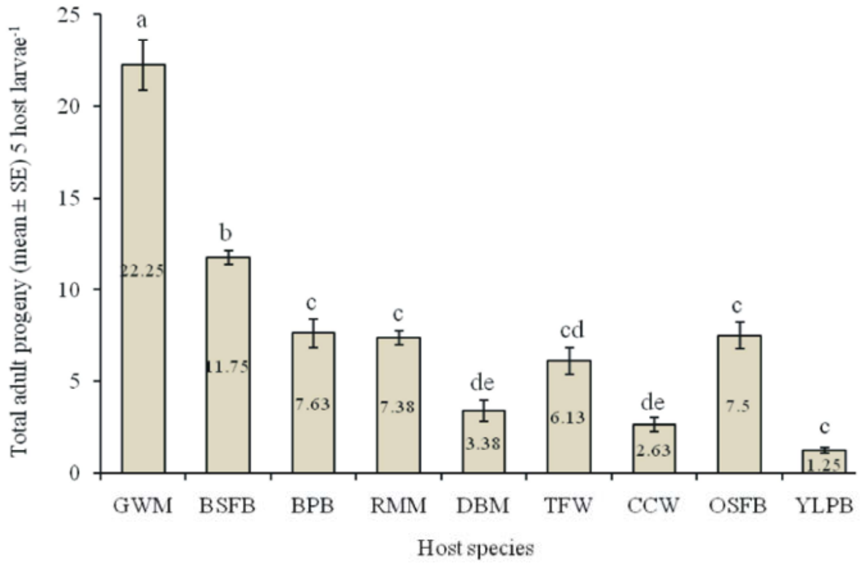

Fig. 3: Mean total adult *B. hebetor* produced per female resulting from eggs laid during 5-d oviposition periods with 9 different lepidopteran host species. Bars followed by same letters are not significantly different using Tukey, s Honestly Significant Different Test

Significantly the highest number of eggs (26.25) was recorded from GWM (F= 53.611; df=8, 63; P <0.0001). The second lowest egg number was found on BSFB (14.75±1.4) followed by RMM, TFW and CCW. Number of eggs on those host larvae was statistically similar but significantly higher compared to only DBM and YLPB. Significantly the lowest number eggs were laid by *B. hebetor* female on YLPB (2.5±0.3) followed by DBM (Fig. 2).

Significantly the highest number of adult progeny (22.25±1.36) was produced on GWM, followed by BSFB (11.75±1.04) and OSFB (7.5 ± 2.07). Their differences were significant during the period (F= 82.848; df = 8, 63; P <0.0001) (Figure 3). However, there were no significant differences in the mean numbers of adult progeny produced on parasitized BPB*,* RMM, TFW and OSFB which were statistically similar but significantly higher compared to only DBM, CCW and YLPB. The lowest number of adult was found on YLPB followed by CCW and DBM (Fig. 3).

The egg-to-adult development times for *B. hebetor* varied significantly from 8.55-11.44 days on 9 host species (F = 7.956; df=8, 63; P <0.0001). The parasitoid took the lowest time (8.55±0.5 days) to develop adult from egg on OSFB, which was statistically similar to all other host species larvae except CCW and YLPB. The highest days (11.44±0.22) was required to develop adults from eggs on CCW followed by YLPB (Table 2).

The duration of egg stage ranged 1.28-1.77 days on 9 host specie larvae (F=4.363, *df=8*, P= 0.0003). The maximum duration of egg stage (1.77±0.103 days) was recorded from CCW which was statistically similar to GWM. The lowest duration of egg stage was found on RMM which was statistically similar to all other host species except CCW (Table 2).

Significantly the highest duration of larval stages of the parasitoid was recorded from the host CCW (F=4.611; df=8, 63; P= 0.0002). The larval stage on other 8 hosts was statistically similar. The maximum duration of *B. hebetor* pupa was observed on CCW followed by YLPB and GWM (F=6.726; df=8, 63; P< 0.001). The pupal stage on those three host species was not significantly different. The lowest pupal duration was recorded from DBM, which was statistically similar to OSFB, TFW, RMM, BPB and BSFB (Table 2).

The lowest percentage of adult female progeny was recorded from BSFB which was numerically similar to the female percentage recorded from other host species except YLPB (F = 2.121; df=8, 63; P = 0.0466) (Fig. 4).

There was a significant differences in hatchability or egg viability among host species (F=6.62; df=8, 63; P <0.0001). Significantly the lowest egg viability was recorded from the host YLPB. The egg viability on the other eight host species varied from 89.03 to 97.09. The variations were not significant (Table 3). Larval viability differed significantly among host species

Table 2: Duration of different biological aspects of *Bracon hebetor* reared on larvae of nine lepidopteran host species

	Average duration (days)			
Treatment	Egg	Larva	Pupa	Egg-adult
Greater wax moth(GWM)	1.51 ± 0.093 ab	3.16± 0.184 b	5.10 ± 0.272 abc	9.72 ± 0.474 b
Brinjal shoot and fruit borer (BSFB)	1.29 ± 0.107 b	3.26 ± 0.129 b	4.73 ± 0.125 bc	9.28 ± 0.276 b
Bean pod borer (BPB)	1.30 ± 0.046 b	3.10 ±0.141 b	4.51 ± 0.087 c	8.92 ± 0.146 b
Rice meal moth (RMM)	1.28 ± 0.040 b	3.33 ±0.140 ab	4.75 ± 0.111 bc	9.35 ±0.207 b
Diamondback moth (DBM)	1.37 ± 0.070 ab	3.19 ± 0.142 b	4.40 ± 0.076 c	8.96 ± 0.154 b
Tomato fruit worm (TFW)	1.38 ± 0.090 ab	3.10 ±0.195 b	4.80 ± 0.131 abc	9.29 ±0.165 b
Common cutworm (CCW)	1.77 ± 0.103 a	4.13 ±0.104 a	5.61 ± 0.189 a	11.44 ± 0.221 a
Okra shoot and fruit borer (OSFB)	1.19 ± 0.066 b	3.11 ± 0.119 b	4.63 ± 0.111 bc	8.55 ± 0.497 b
Yard longbean pod borer (YLPB)	1.33 ± 0.092 ab	3.36 ± 0.174 ab	5.41 ± 0.208 ab	10.11 ± 0.340 ab

Means followed by the same letter in a column are not significantly different using Tukey, s Honestly Significant Different Test (P = 0.01).

Table 3: Percentage of survival of immature stages and the total development time of *Bracon hebetor* reared on nine lepidopteran host species

	Survivorship (%)			
Treatment	Egg	Larva	Pupa	Egg-adult
Greater wax moth (GWM)	97.09 ± 0.89 a	92.15 ± 2.25 a	94.74 ± 1.32 ab	84.85 ± 2.87 a
Brinjal shoot and fruit borer (BSFB)	95.10 ± 1.09 a	91.05 ± 1.92 a	92.95 ± 2.24 ab	80.31 ± 2.25 ab
Bean pod borer (BPB)	942 ± 2.15 a	90.40 ± 2.70 a	86.61 ± 2.99 abc	72.83 ±2.41abc
Rice meal moth (RMM)	91.75 ± 2.21 a	85.28 ± 2.07 a	79.64 ± 2.28 bcd	62.37 ±3.07 bcd
Diamondback moth (DBM)	94.75 ± 2.62 a	71.00 ± 3.63 a	75.00 ± 6.09 cd	51.39 ± 4.50 d
Tomato fruit worm (TFW)	89.03 ± 1.45 a	73.99 ± 3.37 a	68.83 ± 3.94 d	48.58 ± 2.45 d
Common cutworm (CCW)	91.47 ± 2.38 a	45.57 ± 4.3 b	50.89 ± 5.75 e	21.39 ±2.80 e
Okra shoot and fruit borer (OSFB)	91.47± 1.46 a	87.27 ± 1.94 a	91.23 ± 2.11 ab	72.58 ± 1.22 abc
Yard long bean pod borer (YLPB)	71.88± 6.85 b	77.08 ± 8.87 a	100 ± 0.0 a	54.17 ± 7.55 cd

Means followed by the same letter in a column are not significantly different using Tukey, s Honestly Significant Different Test (P=0.01)

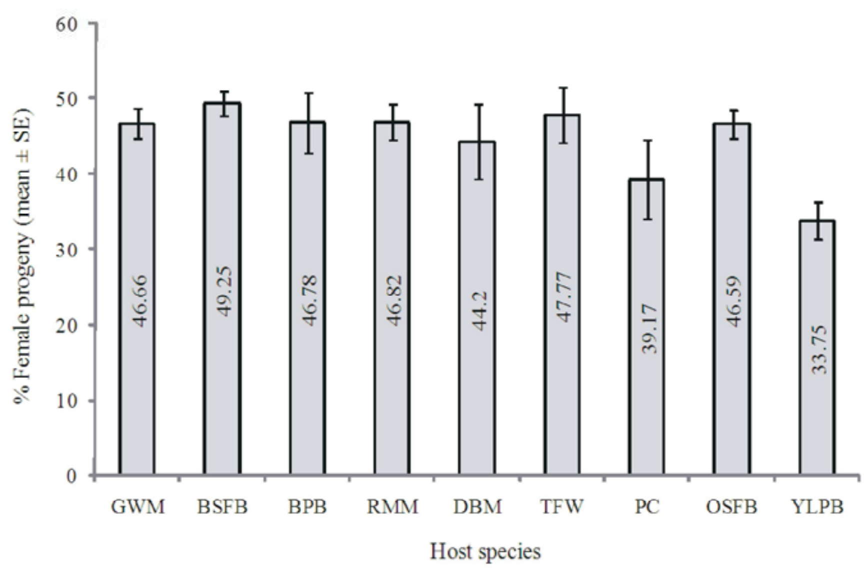

Fig. 4: Parasitoid secondary sex ratio (% females) of *B. hebetor* adult progeny reared on 9 different lepidopteran host species. Bars followed by same letters are not significantly different using Tukey, s Honestly Significant Different Test.

(F= 13.616; df=8, 63; P <0.0001). The highest viability of larvae (92.15%) was found on GWM, which was statistically similar to BSFB, BPB, RMM, OSFB and YLPB. Significantly the lowest survivality of the parasitoid was recorded from the host TFW (Table 3). Pupal viability was high for all the treatments, with significant difference among them (F= 19.319; df=8, 63; P <0.0001). Pupal viability was maximum on GWM which statistically similar

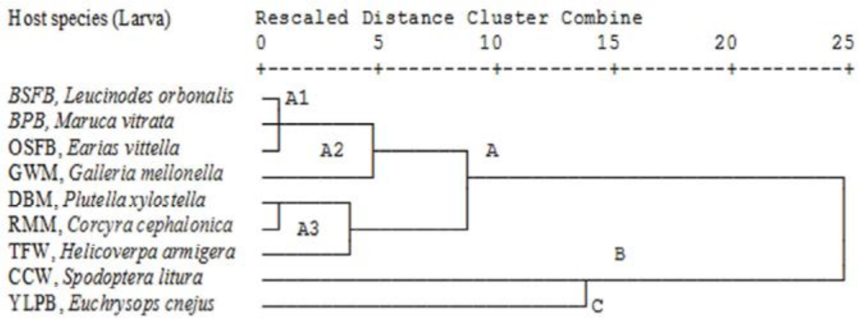

Fig. 5: Dendrogram of different host larvae according to life table parameters of *Bracon hebetor* reared on different host larvae (Ward's method)

to BSFB, BPB, OSFB and YLPB. The lowest survival was observed on CCW followed by TFW, DBM and RMM (Table 3). The whole developmental cycle (Egg-to-adult) survivorship was significantly affected by host species ($F= 28.6$; $df=8, 63$; $P<0.0001$).The whole developmental cycle (egg-to-adult) survivorship was maximum on GWM followed by BSFB, BPB and OSFB, Their differences were not significant. The lowest developmental cycle was found in larvae of CCW followed by TFW, YLPB and DBM (Table 3).

Although *G. mellonella* (GWM) brought out a high level of oviposition by *B. hebetor,* parasitoid survival was higher on both populations of this host compared to other pyralid species (Table 3). Although few eggs were laid on *Plutella xylostella* (DBM) and *Echrysops cnejus* (YLPB) larvae, these two hosts had higher percentage of parasitoid survival compared to other nonpyralid host species (Table 3). Similarly, *H. armigera* (TFW) supported a significantly higher percentage of parasitoid survival (48.58 %± 2.45) compared to another noctuid species *S. litura* (CCW) (21.39 % ± 2.8) (Table 3).

Cluster Analysis: Different host larvae were set in clusters according to the 15 characters of the life table parameters of *Bracon hebetor* reared on these nine host larvae (Figure 5). Cluster A included subcluster A_1(BSFB, BPB, OSFB) as mid suitable group; A_2 (GWM) as most suitable A_3 as less suitable group; Cluster B and Cluster C as least suitable host larvae (Fig. 5).

DISCUSSION

The present study showed a higher percentage of pyralid host larvae were paralyzed and subsequently parasitized compared to *E. cnejus* (YLPB) and noctuid host species. Nevertheless, no significant differences among the pyralid host species were observed for these parameters. These results are in agreement with the earlier work by Heimpel *et al*. (1997) in which *B. hebtor* females performed equally on a pyralid host, *P. interpunctella* and not on the noctuid host, *H. virescens* [17]. There are several factors that might have influenced the lower level of parasitoid performance on noctuid hosts. First, noctuid larvae moved vigorously in the petridish arenas in response to host-seeking actions of *B. hebetor* females compared to other host species and the noctuids may have depleted the energy necessary for pursuit by the wasps. Second, noctuid larvae were much larger and heavier than other hosts and *B. hebetor* venom may have been depleted more quickly when they attempted to subdue the larger prey. Third, the possible mechanisms of venom detoxification and the understanding to *B. hebetor* venom may differ with the host species and size [13].

Although 50% of the paralyzed *E. cnejus* and noctuid host larvae were parasitized, *B. hebetor* produced few adult progeny from the *E. cnejus* and *S. litura* species. However, *B. hebetor* was able to develop and produce a significantly higher number of adult progeny from *H. armigera* compared with other noctuid host species. This variation in progeny production could be caused by venom selectivity that may require higher levels of venom to effectively paralyze the host or that may induce another physiological response, so that parasitoid larvae could successfully complete development. Host size can affect levels of parasitism by *B. hebetor*. A full-grown larva of *P. xylostella* weighs 7 mg, by far the smallest host tested, whereas *S. litura* larva weighs 582 mg, by far the largest host that was used in these studies. The result indicated that *B. hebetor* females may alter their clutch size in response to host size during oviposition to avoid laying more eggs than the host can support. These findings are in agreement with Yu *et al*.(2003) in which *B. hebetor* females never laid 7 or 12 eggs/day when they confronted only one host larva of the tortricid, *Adoxophy esorana*, or the pyralid *P. interpunctella* [25]. Despite high oviposition in response to large host larvae, it was observed low parasitoid survival rates in the larger hosts like *S. litura* (CCW). These results are in agreement with Mackauer (1986) result that the biology of *Spodoptera litura* and their pupal survival rate was only 18% and the adult emergence was 85% [26]. The results suggested that parasitoid fitness may be influenced not only by the host size at oviposition but also by its nutritional adequacy or other host quality factors for parasitoid growth and development after oviposition [27].

In this study, *G. mellonella* (GWM) was the best host compared with other host species in respect with the highest parasitoid survival, total egg laid with higher number of adult progeny moderate developmental time (Fig. 4), which was a much larger host compared to other pyralid species (Table 1). Furthermore, average daily fecundity was much higher on *G. mellonella* (26 eggs) as compared to other hosts (Fig. 2). This difference may be explained by the possibility that *B. hebetor* females prefer to attack large hosts and lay more eggs on them, because large host should have more resources available to support their progeny [28]. *Galleria mellonella* was not a best host because of low survival rate and lowest total adult production and longest developmental time [13, 18]. Their results are not in agreement with the present findings probably due to different parasitoid strain and different experiment procedure. The parasitoid performed better on stored product pests than field crop pests because the activity of the enzyme proteases and α-amylase were higher in stored product pests than field insect pests [19].

The present findings indicated that parasitoid development increased with host size because parasitoid development is a compensation response to limited host resources, both qualitatively and quantitatively, such that wasps either develop slowly or use host resources with maximum efficiency, or they develop quickly and use host resources with reduced efficiency [29]. Fast development may carry the fitness advantage of avoiding predation and disease through reduced exposure, but it also may result in a loss of fitness from ultimately smaller adult size and the concurrent lower reproductive ability compared with larger adults.

The secondary sex ratio of *B. hebetor* progeny, which is the proportion of the total emerged adult parasitoids from a given mother that are female or male, was influenced by the host species. A male-biased progeny emerged from host species in this study (> 50% male). male bised sex ratio [18, 28] and female biased sex ratio (>50% female) was observed [13, 18]. This sex ratio could be explained by the fact that after oviposition of several clutches of eggs during the first few weeks the *B. hebetor* females probably became depleted of their sperm reserves from the initial mating and thus could produce only males from unfertilized eggs. Sex ratio shift with age beyond the last insemination. Furthermore, *B. hebetor* females generally mate once in their lifetimes and when mated females became sperm-depleted they usually were able to produce only sons and continued to lay similar numbers of eggs per day after depleting sperm reserves as before sperm was depleted [30, 31, 32]. The male biased sex ratio may be the result of a variety of factors, including sperm depletion, sperm death, physiological aging, active sperm digestion by the female, sperm disintegration while stored in the spermathecae, the number of copulations and the differential mortality of the sexes during larval development [32, 33, 34].

The cluster analysis results revealed that grouping within every cluster might be due to the different characters of life table parameter of *Bracon hebetor* reared on various host larvae. Results of the comparative life table parameters of *B. hebetor* on different host larvae indicated that cluster B and C were the least suitable host larvae and subcluster A_2 was the most suitable host larvae followed by subcluster A_1 (Fig. 5).

CONCLUSION

The results from this study showed that the growth, development and survival of a gregarious polyphagous ecto-endo parasitoid vary with the host species. In this study, *B. hebetor* females paralyzed and oviposited on most or all individuals of each host species that was presented and they reproduced to some degree on all hosts. In general, host suitability for *B. hebetor*is characterized by response data such as mean daily fecundity, parasitoid survival to adult, development time and parasitoid sex ratio. This study showed that Wax moth, *G. mellonella* was the most suitable host followed by BSFB, *Leucinodes orbonalis* and other pyralid species and Yard long bean pod borer, *E. cnejus* which was the least suitable host of those tested of the noctuid species, *E. vittella*a marginally suitable host and *S. litura* species was less suitable host. Although *B. hebetor* might be considered relatively polyphagous because it can parasitize and successfully develop on moth larvae from several families of Lepidoptera order.

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Abbreviation

BSFB	Brinjal shoot and fruit borer	*G. mellonella*	*Galleria mellonella*
BPD	Bean pod borer	OSFB	Okra shoot and fruit borer
B. hebetor	*Bracon hebetor*	RMM	Rice meal moth
CCW	Common cut worm	TFW	Tomato fruit worm
DBM	Diamond back moth	YLPB	Yard long bean pod borer
GWM	Greater wax moth		

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