



Effect of supplementary nutrition on the reproduction and mating behaviour of *Habrobracon hebetor* (Hymenoptera: Braconidae)

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Abstract. To improve the mass production of the parasitoid *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae) the effects of supplementary nutrition on its reproduction and mating behaviour were investigated using *Plodia interpunctella* Hübner (Lepidoptera: Pyralidae) larva as a host. The survival of mated male wasps was markedly prolonged after feeding with five different types of nutrients and that of unmated males was markedly prolonged except when provided with yeast solution. Providing female wasps with supplementary nutrition did not affect their longevity. When *H. hebetor* reproduced sexually and was supplied with an abundance of hosts, females produced 101.0 and 96.7 female offspring, respectively, when fed 20% sucrose or 20% honey solutions, however, when provided with only ten hosts the provision of supplementary nutrition did not affect the number of female offspring they produced. The 20% maltose, 20% sucrose and 20% honey solutions significantly promoted the courtship behaviour of male wasps, and the 20% yeast and 20% honey solutions increased the mating success of males paired with virgin females.

INTRODUCTION

Controlling pests using their natural enemies is one of the most important measures proposed for the development of sustainable agriculture (Ahmad & Jam, 2015). The control of pests by natural enemies is in accord with the natural order and processes, includes the protection and utilization of indigenous natural enemies in nature and the release of artificially produced natural enemies (Yang et al., 2006). For improving pest control using natural enemies the most immediate and effective means is to simultaneously release artificially produced natural enemies into nature (Michaud, 2018). However, because of the technology needed, unstable effect and high cost it is not a popular method of pest control (Zhang & Chen, 2014). Therefore, approaches for effectively enhancing the efficiency of artificial breeding and use of natural enemies have been developed by scientists to overcome the obstacles to the use of natural enemy control.

As an ectoparasitoid of the larvae of many kinds of Lepidoptera, *H. hebetor* exerts good control on these insect pests in the field (Benson, 1974; Nay & Perring, 2005). There is information on the population growth and host location by *H. hebetor* (Nikam & Pawar, 1993; Mironidis & Savopoulou-Soultani, 2009; Adarkwah et al., 2010; Mbata

et al., 2017). Previous research show that host species, host density and environmental conditions affect the efficiency of parasitism and reproduction of *H. hebetor* (Magro & Parra, 2001; Eliopoulos & Stathas, 2008; Akinkulore et al., 2009; Faal & Shishehbor, 2013; Alam et al., 2015). Furthermore, the mating experience of *H. hebetor* influences the sex of their offspring as a higher female-to-male ratio is reported when a male with little mating experience mates with a virgin female (Gündüz & Gülel, 2005). *H. hebetor* can also adapt its reproductive strategy by producing more offspring and a higher female-to-male ratio when it parasitizes well developed host larvae (Akinkulore et al., 2009; Al-Taweel et al., 2014; Jarrahi & Safavi, 2016; Majeed et al., 2018).

The conservation and augmentation of indigenous natural enemies plays a significant role in integrated pest management (IPM). In this respect, supplementary nutrition before parasitism can significantly enhance the pest control effect of *Sclerodermus pupariae* Yang et Yao (Hymenoptera: Bethyridae) and prolong its longevity. The enhancement effect of honey on the reproduction and longevity of *S. pupariae* adults is similar to that of feeding on host haemolymph (Gao et al., 2016), and *H. hebetor* fed a 30% honey solution and supplied daily with one mature instar

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larva of *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) produced most progeny (Kabore et al., 2019). Feeding on honeydew can facilitate host finding by insect natural enemies (Hudak et al., 2003; Araj et al., 2011). The effect of supplementary nutrition on the biological behavior of adults of *H. hebetor* is reported (Mironidis & Savopoulou-Soultani, 2009; Majeed et al., 2018), but not its effect on longevity and mating behaviour. In the present paper, we report the effect of providing supplementary nutrition in the form of one of five nutrient solutions on the reproduction and mating behaviour of adult *H. hebetor*. Our findings will help in improving the mass propagation of this parasitoid and its use as a biocontrol agent.

MATERIALS AND METHODS

Insects

Habrobracon hebetor (Say) and *Plodia interpunctella* were obtained from stock cultures kept in the Laboratory of Insect Physiology and Ecology, School of Plant Protection, Anhui Agricultural University (Hefei, China). *P. interpunctella* was reared indoors on crushed soybean for many generations and healthy 5th instar larvae of the same size were used in this study. *H. hebetor* was reared on larvae of *P. interpunctella* for many generations. This was done by placing twenty 5th-instar larvae of *P. interpunctella* in a 50 mL plastic tube and then adding four to six pairs of 2 to 7 day old adult wasps after which the opening was sealed with white cotton wool.

The tube containing the wasps and hosts was put in a climate cabinet kept at 26–28°C, 70–80% relative humidity and a photoperiod of 12L:12D. After the next generation of parasites pupated, the pupae were each gently introduced into a 10-mL tube, one pupa per tube. Five holes of an approximate diameter of 0.5 mm were made in the lid of each tube for ventilation. Twenty four hours after the adults emerged healthy and vigorous adult wasps of similar size were used in this study.

Nutrient solutions

All five nutrient solutions (specifically, honey, sucrose, maltobiose, glucose, and yeast) were respectively prepared as a 20% solution in water. In addition, one group of controls was fed distilled water and another nothing.

Effect of supplementary nutrition on the longevity of adult *H. hebetor*

First, a 1.5 cm × 7 cm piece of clean filter paper was placed in a 10-mL plastic tube and then 180 µL of nutrition solution added to the filter paper. Second, two unmated adult wasps less than 1 day old were introduced into each tube. The two wasps in a tube consisted of either two unmated females, or two unmated males or one unmated female and one unmated male. The tube with the pair of adult wasps was not included in the experiment if they did not mate within ten minutes. If the male wasp mounted the female and inserted its phallus for more than one second the mating was regarded as successful. The ten tubes containing either two unmated females or two unmated males were each treated as a group and the twenty tubes containing one unmated female and one unmated male were treated as a group, and each group was replicated six times. The tubes containing adult wasps were placed in a climate chamber kept at 26–28°C, 70–80% relative humidity and a photoperiod of 12L:12D. Dead wasps were counted every day until all wasps died. Finally, the average longevity of each group was determined.

Effect of supplementary nutrition on the reproduction of *H. hebetor*

The supplementary nutrition used was identical to that described in the sub-sections above. Less than 1 day old unmated adult wasps were placed singly in a tube containing a small amount of nutrient solution and after 24 h the wasp was taken out of the tube and used to determine the effect of this treatment on its reproduction at 26–28°C, 70–80% relative humidity and a photoperiod of 12L:12D. This was done by providing these wasps each with ten 5th-instar larvae of *P. interpunctella* in a 50-mL plastic tube. For sexual reproduction two pairs of unmated wasps were placed in a tube and if mating did not occur in ten minutes, these wasps were not included in the experiment. None of the wasps failed to mate and only one pair failed to copulate successfully. Only two unmated female wasps were placed in a tube for determining the effect on parthenogenetic reproduction. These females were provided with ten unparasitized healthy larvae every two days up to the day the females died. This experiment was replicated six times. The number of eggs laid was recorded daily and the numbers of adult female and male wasps that emerged were recorded. Then, the sex ratio was calculated, but not for those females that reproduced parthenogenetically as they only produced male offspring.

To determine the reproductive performance when wasps were provided with a limited number of hosts, the wasps fed supplementary nutrition were placed in a 50 mL plastic tube containing ten larvae of *P. interpunctella*. Two pairs of unmated wasps were placed in these tubes and if they did not mate successfully within ten minutes they were not included in the experiment. All of the pairs selected mated successfully within 10 min. For parthenogenetic reproduction two unmated female wasps were placed in a tube. In order to reduce the error associated with insect ageing the period allowed for mating was short. This experiment was replicated six times. The number of eggs was recorded daily and then summed, the numbers of female and male adult progeny was recorded and the sex ratio calculated, but not in the case of parthenogenetic reproduction when only male offspring were produced.

Effect of supplementary nutrition on the mating behaviour of *H. hebetor*

To determine the effect of supplementary nutrition on the mating behaviour of males paired with virgin females a 1–2 day old unmated male wasp was placed in a 10 mL transparent tube and then a same aged unmated female wasp. The courtship of the male, the time spent mating and duration of mating were recorded over a period of ten minutes. The courtship frequency of males was measured in terms of the number of times a wasp fanned its wings (Huang et al., 2018), which was divided into four grades (from weak to strong), namely, 0 signified no wing-fanning, 1 signified weak (lasted less than 2 s), 2 moderate (lasted ≥ 2 but < 4 s) and 3 strong (lasted ≥ 4 s). After observation for 10 min the female wasp was gently removed and the male wasp left alone in the tube for 20 min. Almost immediately, the male paired again with another virgin female, which was again observed for 10 min, and so on. The maximum number of time a male paired with virgin females was eight. This experiment was replicated six times and the total number of observations was 48. The environmental conditions during the observations were 24–26°C, 70–80% relative humidity and away from direct sunlight.

To determine the effect of supplementary nutrition on the mating behaviour of a female paired with a virgin male, one 1–2 day old unmated female was placed in a 10-mL transparent tube and then an unmated male of the same age. The courtship of the male, mating times and duration of mating were recorded using the method described above. Each female was paired with up to

Table 1. Effect of supplementary nutrition on the longevity of adults of *H. hebetor* (27°C ± 1°C).

Nutrient solution	Mean longevity (days) ± SD			
	Mated female	Mated male	Virgin female	Virgin male
20% honey	7.68 ± 0.26 b CD	7.93 ± 0.44 a A	8.07 ± 0.58 b B	7.03 ± 0.47 a AB
20% sucrose	7.95 ± 0.70 b BC	7.53 ± 0.35 bc AB	9.23 ± 0.33 a A	7.34 ± 0.39 a A
20% maltose	8.79 ± 0.39 a A	7.72 ± 0.33 ab A	7.28 ± 0.48 c C	6.58 ± 0.38 b BC
20% glucose	7.17 ± 0.35 c D	6.83 ± 0.25 d C	8.27 ± 0.43 b B	6.48 ± 0.44 b BCD
20% yeast	8.57 ± 0.17 a AB	7.20 ± 0.13 cd BC	8.49 ± 0.27 b B	6.02 ± 0.25 c CDE
Water	7.98 ± 0.22 b BC	7.08 ± 0.23 d BC	6.90 ± 0.44 c C	5.63 ± 0.40 c E
Control	8.47 ± 0.27 a AB	4.52 ± 0.25 e D	9.37 ± 0.25 a A	5.85 ± 0.29 c DE

Note: Values of F, df and P are listed as follows: (1) Mated female: F = 13.594; df = 6, 41; P < 0.0001; (2) Mated male: F = 88.539; df = 6, 41; P < 0.0001; (3) Virgin female: F = 30.015; df = 6, 41; P < 0.0001; (4) Virgin male: F = 16.236; df = 6, 41; P < 0.0001.

four virgin males. In order to reduce the error due insect age, the observations were carried out over a period of 12 h and replicated six times giving a total number of observations of 24. The experimental conditions were also the same as mentioned above.

Statistical analysis

Data were analysed using the analysis of variance in the DPS 2000 program (Tang & Feng, 2002). Means were compared and separated using Duncan's new multiple range method at significance levels of 0.05 and 0.01, respectively. Means (± SD) in the same column followed by different lower case and capital letters were significantly different at the P = 0.05 and 0.01 levels, respectively. Means (± SD) of untransformed data are presented.

RESULTS

Effect of supplementary nutrition on the longevity of adult *H. hebetor*

After feeding with different supplementary nutrients, the number of dead adult wasps was counted and recorded daily and used to determine mean longevity. As recorded in Table 1, there was no obvious effect of the different supplementary nutrients in prolonging the longevity of virgin female *H. hebetor*, in fact, their life expectancy was lower than that of the control except for the 20% sucrose solution. Mean longevity of mated females fed additional nutrients were significantly lower than those of the control,

except for those provided with 20% maltose and 20% yeast solutions. In summary, the supplementary nutrition did not prolong the longevity of female wasps.

Supplementary nutrition, however, prolonged male longevity. The longevity of mated males provided with nutrients and water were significantly longer than that of the control and that of unmated males were significantly longer than that of the control, except for the 20% solution of yeast. Overall, males provided with supplementary nutrition lived for longer, especially the mated males. Of the nutrient solutions provided, 20% honey, 20% maltose and 20% sucrose very significantly prolonged the mean longevity of both mated and unmated males (P < 0.01).

Effect of supplementary nutrition on the reproductive performance of *H. hebetor*

Supplied with an abundance of hosts

After feeding with different supplementary nutrients, the number of ovipositions was recorded daily (Table 2). The number of ovipositions recorded for mated wasps provided with the five nutrient solutions and water was more than that for the control, with a very significant effects recorded for 20% maltose and 20% sucrose (P < 0.01). Of the five nutrients, the 20% sucrose resulted in the best production of female and female plus male offspring of 101.0 and

Table 2. Effect of supplementary nutrition on fecundity of adults of *H. hebetor* supplied with an abundance of hosts (27°C ± 1°C).

Treatment	Sexual reproduction					Parthenogenesis	
	Oviposition number ± SD	Female number ± SD	Male number ± SD	Total number of adults ± SD	Sex ratio ± SD	Oviposition number ± SD	Male number ± SD
20% honey	613.0 ± 131.8 a AB	96.7 ± 43.5 a A	126.5 ± 45.4 a A	223.2 ± 45.2 a A	0.87 ± 0.43 a A	546.2 ± 125.6 a A	245.2 ± 60.1 a A
20% sucrose	631.5 ± 97.1 a A	101.0 ± 15.4 a A	127.7 ± 39.5 a A	230.3 ± 40.4 a A	0.84 ± 0.21 a A	583.0 ± 91.4 a A	246.3 ± 33.3 a A
20% maltose	643.5 ± 83.5 a A	95.3 ± 40.6 a A	116.3 ± 39.8 a A	211.7 ± 53.3 ab A	0.88 ± 0.37 a A	485.5 ± 162.4 a A	214.2 ± 55.0 a A
20% glucose	614.8 ± 84.6 a AB	73.2 ± 8.1 a A	130.3 ± 50.2 a A	203.5 ± 51.0 ab A	0.65 ± 0.28 a A	630.0 ± 127.8 a A	254.0 ± 63.0 a A
20% yeast	591.5 ± 79.9 a AB	80.5 ± 33.7 a A	99.5 ± 30.5 a A	180.0 ± 44.8 ab A	0.89 ± 0.42 a A	577.5 ± 89.3 a A	251.8 ± 43.8 a A
Water	575.5 ± 67.1 a AB	95.7 ± 21.2 a A	97.3 ± 23.9 a A	193.0 ± 44.2 ab A	0.99 ± 0.11 a A	538.0 ± 127.4 a A	217.7 ± 59.7 a A
Control	448.0 ± 129.0 b B	71.8 ± 19.8 a A	89.5 ± 34.3 a A	161.3 ± 44.3 b A	0.90 ± 0.35 a A	588.8 ± 137.5 a A	252.5 ± 81.9 a A

Note: Values of F, df and P are listed as follows: (1) Sexual reproduction: Oviposition number, F = 2.668; df = 6, 41; P = 0.0308; Female number, F = 1.075; df = 6, 41; P = 0.3960; Male number, F = 1.134; df = 6, 41; P = 0.3636; Total number of adult, F = 1.652; df = 6, 41; P = 0.1622; Sex ratio, F = 0.5890; df = 6, 41; P = 0.7371; (2) Parthenogenesis: Oviposition number, F = 0.805; df = 6, 41; P = 0.5729; Male number, F = 0.505; df = 6, 41; P = 0.8005.

Table 3. Effect of supplementary nutrition on fecundity of *H. hebetor* adults supplied with only ten hosts (27°C ± 1°C).

Treatment	Sexual reproduction				Parthenogenesis
	Female number ± SD	Male number ± SD	Total number of adults ± SD	Sex ratio ± SD	Male number ± SD
20% honey	21.7 ± 3.1 a A	15.5 ± 3.7 abc AB	37.2 ± 6.0 ab A	1.5 ± 0.3 ab A	43.0 ± 13.8 a A
20% sucrose	18.7 ± 6.1 a A	20.2 ± 7.2 a A	38.8 ± 4.1 a A	1.1 ± 0.6 b A	39.0 ± 8.6 a A
20% maltose	17.3 ± 9.4 a A	15.3 ± 5.2 abc AB	32.7 ± 7.5 ab A	1.2 ± 0.7 ab A	42.7 ± 12.4 a A
20% glucose	16.5 ± 7.5 a A	14.3 ± 1.8 abc AB	30.8 ± 8.4 ab A	1.2 ± 0.5 b A	39.2 ± 11.5 a A
20% yeast	21.7 ± 4.3 a A	17.7 ± 4.9 ab AB	39.3 ± 8.0 a A	1.3 ± 0.3 ab A	41.2 ± 11.4 a A
Water	17.8 ± 3.4 a A	12.8 ± 6.4 bc AB	30.7 ± 7.0 ab A	1.7 ± 0.8 ab A	38.8 ± 10.1 a A
Control	18.8 ± 3.8 a A	10.3 ± 3.1 c B	29.2 ± 6.4 b A	1.9 ± 0.5 a A	40.5 ± 11.5 a A

Note: Values of F, df and P are listed as follows: (1) Sexual reproduction: Female number, F = 0.729; df = 6, 41; P = 0.6293; Male number, F = 2.512; df = 6, 41; P = 0.0398; Total number of adults, F = 2.271; df = 6, 41; P = 0.0590; Sex ratio, F = 1.713; df = 6, 41; P = 0.1470; (2) Parthenogenesis: Male number, F = 0.138; df = 6, 41; P = 0.9902.

230.3, respectively, followed by 20% honey with 96.7 and 223.2, respectively. Furthermore, none of the five nutrient solutions significantly affected the production of offspring by unmated wasps.

Supplied with ten host larvae

In this experiment, the parent wasp was initially fed one of the supplementary nutrients for 24 h and then provided with hosts for parasitism. The number of offspring was determined at emergence (Table 3). The number of females and the sex ratio of the offspring of unmated wasps were not significantly affected by providing them with any of the five nutrient solutions. Number of male and total number of offspring produced by mated wasps provided with 20% yeast and 20% sucrose solutions were significantly more than that of the control. Overall, the mated wasps provided with 20% honey and 20% yeast solutions produced more females and total progeny. Furthermore, the unmated females provided with the nutrient solutions did not produce significantly more male progeny than the control. Nevertheless, those provided with 20% honey, 20% maltose and 20% yeast solutions produced relatively more progeny.

Effect of supplementary nutrition on the mating behaviour of *H. hebetor*

The effect of supplementary nutrition on the mating behaviour of *H. hebetor* is presented in Table 4. The courtship intensity of males with unmated females did not differ significantly from that recorded for the control. A higher courtship frequency and stronger desire for mating, however, were recorded for males provided with 20% sucrose, 20% honey and 20% maltose solutions. Moreover, the

sexual activity of those provided with 20% yeast and 20% honey solutions was markedly higher. The average mating frequencies of the males provided with these two nutrient solutions were more than nine times and the duration of mating was 162.0 s and 155.8 s respectively. The average durations of mating recorded for *H. hebetor* provided with nutrient solutions did not differ significantly from that recorded for the control.

When wasps previously provided with 20% maltose, 20% honey and 20% sucrose solutions, were mated with unmated males the courtship behaviour of the males was significantly more marked than that of wasps provided with the other nutrient solutions and the control, as the courtship frequencies were 69.8, 67.8 and 66.2, respectively (Table 5). There was no significant increase in mating by the wasps provided with these nutrient solutions compared with the control. The duration of mating of males previously provided with 20% glucose solution was the longest, whereas that of those provided with 20% sucrose and 20% yeast solutions were shorter than that of the control.

DISCUSSION

This research indicates ways in which the mass production of *H. hebetor* can be improved. Providing males with sucrose, honey, maltose or glucose solutions prolongs the length of time for which they survive, but not the females. When this wasp is kept indoors, it is difficult to keep the female and male wasps separately and most of the wasps successfully mated in the mixed female and male cultures, so we recommend providing the wasps with either a 20% maltose or 20% yeast solution. Recently, it was reported

Table 4. Effect of supplementary nutrition on mating behaviour of males of *H. hebetor* mated with virgin females (25°C ± 1°C).

Treatment	Courtship frequency ± SD	Courtship intensity ± SD	Mating frequency ± SD	Total time spent mating (s) ± SD	Average duration of a mating (s) ± SD
20% honey	91.2 ± 20.1 ab AB	1.72 ± 0.3 a A	9.16 ± 2.9 ab A	155.8 ± 55.1 a A	16.9 ± 2.3 a A
20% sucrose	114.3 ± 45.7 a A	1.65 ± 0.5 a A	6.83 ± 2.2 ab A	127.7 ± 39.8 ab A	19.4 ± 6.4 a A
20% maltose	90.3 ± 39.7 ab AB	1.43 ± 0.4 a A	7.83 ± 2.4 ab A	152.2 ± 54.8 a A	19.4 ± 3.2 a A
20% glucose	72.2 ± 29.6 ab AB	1.36 ± 0.4 a A	7.67 ± 3.1 ab A	148.2 ± 47.2 a A	21.2 ± 7.8 a A
20% yeast	84.3 ± 34.1 ab AB	1.56 ± 0.4 a A	9.67 ± 1.9 a A	162.0 ± 33.8 a A	16.9 ± 2.7 a A
Water	49.2 ± 26.6 b B	1.20 ± 0.5 a A	5.83 ± 3.1 b A	85.3 ± 37.5 b A	16.5 ± 6.7 a A
Control	76.5 ± 30.4 ab AB	1.42 ± 0.5 a A	8.83 ± 3.4 ab A	138.8 ± 32.9 ab A	16.7 ± 4.1 a A

Note: Values of F, df and P are listed as follows: (1) Courtship frequency: F = 2.176; df = 6, 41; P = 0.0689; (2) Courtship intensity: F = 1.005; df = 6, 41; P = 0.4378; (3) Mating frequency: F = 1.446; df = 6, 41; P = 0.2254; (4) Mating duration: F = 2.116; df = 6, 41; P = 0.0761; (5) Mating duration every time: F = 0.767; df = 6, 41; P = 0.6009.

Table 5. Effect of supplementary nutrition on mating behaviour of males of *H. hebetor* mated with virgin females (25°C ± 1°C).

Treatment	Courtship frequency ± SD	Courtship intensity ± SD	Mating frequency ± SD	Total time spent mating (s) ± SD	Average duration of mating (s) ± SD
20% of honey	66.2 ± 25.2 a A	1.28 ± 0.3 ab AB	1.33 ± 0.5 a A	21.0 ± 10.1 a A	16.2 ± 5.3 a A
20% of sucrose	67.8 ± 24.7 a A	1.73 ± 0.5 a A	1.17 ± 0.4 a A	18.0 ± 7.0 a A	15.3 ± 1.4 a A
20% of maltose	69.8 ± 21.9 a A	1.18 ± 0.6 ab AB	1.17 ± 0.4 a A	26.5 ± 18.4 a A	23.7 ± 12.7 a A
20% of glucose	28.2 ± 23.7 b B	1.18 ± 0.6 ab AB	1.67 ± 0.5 a A	28.0 ± 9.6 a A	17.2 ± 3.1 a A
20% of yeast	33.3 ± 14.1 b B	0.90 ± 0.3 b AB	1.17 ± 0.4 a A	18.5 ± 5.9 a A	16.0 ± 1.7 a A
Clear water	22.2 ± 13.1 b B	0.82 ± 0.8 b B	1.33 ± 0.5 a A	24.8 ± 14.3 a A	18.5 ± 5.6 a A
Control	32.8 ± 6.4 b B	1.20 ± 0.3 ab AB	1.33 ± 0.5 a A	21.0 ± 7.4 a A	16.8 ± 7.5 a A

Note: Values of F, df and P are listed as follows: (1)Courtship frequency: F = 6.933; df = 6, 41; P = 0.0001; (2)Courtship intensity: F = 2.068; df = 6, 41; P = 0.0823; (3)Mating frequency: F = 0.851; df = 6, 41; P = 0.5399; (4)Total time spent mating: F = 0.740; df = 6, 41; P = 0.6208; (5) Average duration of mating: F = 1.159; df = 6, 41; P = 0.3501.

that *H. hebetor* can be mass produced using the larvae of *C. cephalonica* and *Galleria mellonella* L. (Lepidoptera: Pyralidae) as hosts (Magro & Parra, 2001; Chen et al., 2012; Kryukov et al., 2013), but it is unknown to what extent the production could be increased by providing food for the adults in the form of nutrient solutions. In view of their enormous potential fecundity, the emphasis should be put on effectively providing a nutrient resource for the adult wasps and improving the survival of the larvae of *H. hebetor*. Because a supplementary nutrient based on yeast, effectively increases the number of offspring produced, this is the most appropriate nutrient to provide when the supply of hosts is limited. We recommend 20% sucrose or 20% honey solutions when the parasitic wasp is provided with an abundance of hosts, but 20% yeast or 20% honey solutions should be provided when the availability of hosts is limited.

At present, *H. hebetor* is used to control some Lepidopteran pests, such as *Ostrinia furnacalis* Guenée (Lepidoptera: Pyralidae), *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), *Ephestia elutella* (Hübner) (Lepidoptera: Pyralidae) and *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae), etc. (Chen et al., 2011; Saxena et al., 2012; Ghimire & Phillips, 2014; Borzoui et al., 2016). As it is difficult to establish a stable population of parasitic wasps in the field or a warehouse by means of a single release of the wasp, they have to be released many times to achieve control. To effectively enhance the control of insects by natural enemies in nature, we recommend that the wasp should be provided with 20% honey solution before release. The honey solution provides male wasps with a source of energy for finding mates and females with nutrients for developing eggs. Furthermore, honey solution improves mating, increases the number of offspring produced and results in a more favourable sex ratio.

The provision of supplementary nutrients results in an obvious effect on the lifespan and reproduction of many insects (Harvey et al., 2012; Chau et al., 2019) and also markedly enhances the rate of parasitism of many parasitoids (Vaello et al., 2018). The reproductive strategy of males is to locate and mate with as many females as possible (Majeed et al., 2018). Male wasps usually spend more time than the females flying and fanning their wings, so providing a high energy source, such as sucrose, is likely to

prolong their life span and so increase their probability of mating.

The reproductive strategy of females of *H. hebetor* is during the larval stage to accumulate the nutrients they need for producing eggs and in the adult stage to search for suitable hosts and lay as many eggs as possible. Therefore, providing them with supplementary nutrients had no noticeable effect on their life span. Most females of *H. hebetor* usually mate only once, with just a few mating twice or three times (Majeed et al., 2018). When the female wasps were paired with unmated males, the provision nutrient supplements significantly promoted the courtship behaviour of the males, but did not significantly affect their mating success.

Furthermore, artificial supplements are reported to alter the lifespan and fecundity of parasitic wasps. Askari Seya-hoei et al. (2018) report that providing carbohydrates in the absence of host larvae significantly prolonged the lifespans of both mated and virgin *H. hebetor*. Male and female *Cotesia vestalis* Haliday (Hymenoptera: Braconidae) that fed on *Cosmos sulphureus*, *Lantana camara* and *Coriandrum sativum* survived significantly longer than those provided with water or *Zinnia elegans* (Chau et al., 2019). Our results indicate that supplementary nutrition prolongs the lifespan of male wasps, but not female wasps, and the lifespan of unmated females is shorter than that of the control. We don't know why providing some of the solutions resulted in a shortening of female longevity. Similarly, adult *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae) can survive as well on diets of orange or peach juice as on honey. In contrast, providing guava juice results in a reduction in longevity (Sivinski et al., 2006; Benelli et al., 2017). Compared with those fed honey, sugar and date syrups, *H. hebetor* females fed 50% honey solution laid significantly more eggs and produced more progeny (Ashraf et al., 2017). Our results were similar, i.e., *H. hebetor* females fed on honey produced more progeny. Of the following supplements: honey, glucose, galactose and sucrose, female *Ooencyrtus nezarae* Ishii (Hymenoptera: Encyrtidae) fed on honey were the most fecund (Teraoka & Numata, 2000).

Effective production of natural enemies is the key to the successful application of insect pest control. Some research indicates that honey solution is more effective than a sucrose solution in prolonging the life span of *H.*

hebetor (Majeed et al., 2018), and this is more pronounced for females than males. Our results, however, indicate the opposite as providing a nutrient solution resulted in a greater lengthening of the lifespan of male wasps than of female wasps. This difference might be due to the age of the insects, feeding method, nutrient concentration or experimental error, etc. Therefore, to provide optimal conditions for the rearing and reproduction of *H. hebetor*, further research work is needed on the effect of temperature, nutrient composition and feeding frequency on the life span and reproductive behaviour of adult wasps.

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