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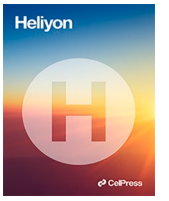

Efficacy and toxicity of different plant extracts over the period of time in *Bracon hebetor* (Say) (Hymenoptera: Braconidae)

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ABSTRACT

Bracon hebetor (Say) is an important parasitoid and played a suitable model role for bio control programs. Pest management through biocontrol approaches such as plant extracts is an ecologically responsive and enthusiastic means of reducing insect pests. The main objective of the present research was to discover the efficiency and susceptibility periods of plant extracts for the assessment of parasitoids. The toxicity of five plants (*Cymbopogon nardus, Azadirachta indica, Syzygium aromaticum, Datura stramonium* and *Parthenium hysterophorus*) extracts were evaluated against *B. hebetor* to detect the possible way forward to controlling insect pests along with the adverse effects on beneficial insects. The data was recorded regarding mortality of *B. hebetor,* after calculated time periods with different intervals of up to 2 days. Datasets were followed by a statistical probe which exhibited significant results. The extracts of *C. nardus, A. indica, S. aromaticum* and *D. stramonium* exhibited non-toxic effects, whereas *P. hysterophorus* indicated low toxicity annotations against investigated parasitoid. These investigations suggested that four plants examined are not hazardous to the parasitoids whereas *P. hysterophorus* somehow has detrimental effects at low toxicity levels. Further development of insecticide resistance mechanisms in the parasitoid favors the enhancement of parasitoid efficacy with plant extracts. The possible selective use of these plant extracts and their effects on the safety period of parasitoids for integration with other approaches in sustainable pest management programs is discussed.

1. Introduction

Imprudent and indiscriminate use of insecticides will result in resistance and disadvantageous, non-target effects and resultant loss of biodiversity [1]. Configurations of chemical control in pest management programs could be injurious to the farming community, exposure to fumigant volatiles and further pesticide scums in foods [2]. Further diets without chemical hassles to enhance the thrust aimed at the pursuit of doable insect control approaches [3,4]. However, plant alleleochemicals in the host diet can not only affect the fitness and survival of the phytophagous insect but also impact the growth, development and survival of parasitoids [5,6].

The use of natural insect enemies as biological control components is a more environmentally sound alternative means of pest management that could potentially reduce the use of chemical control [7]. Biocontrol pest management is an ecologically

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approachable and dynamic means of reducing insect pests and mitigating food security. Further through these techniques, insect pests and plant diseases may be controlled by utilizing microbes, plant extracts, fungi, nematodes, parasites and predators. In arachnids, for instance, mites and spiders are helpful. Parasitoids and predators work on various types of insects and will consume many throughout their lifespan. The exploitation of these beneficial creatures in biological management programs has a prodigious significance owing to ecological value [8].

The Parasitoid wasps group of hymenopteran insects is distinguished biological control representatives for arthropod pests in agricultural and forest ecosystems. They play an important role in suppressing pest population densities [9]. *Bracon hebetor* as ecto-parasitoid has perceived vigorous nature for easy to rear and suitable model mediator organism for biocontrol programs. *Bracon hebetor* plays an important parasitism role in significant insect diaspora belonging to families Noctuidae and Pyralidae [10,11]. These also exhibited suitability to huge storage lodgings where wasps find sufficient food and breeding sources in stored grains including lepidopteron [8,12–17]. In Asia, *B. hebetor* feeds on huge quantities of hosts fitting in order Lepidoptera [18]. It promptly consumes the foodstuff and reduces the blood proteins in larval phases of greater wax moth *Galleria mellonela* [19]. Further it may also attack coleopteran larvae [20] and remained the remarkable ecto-parasitoid of *Heliothus* species [21]. Some species of host insects perform better for parasitoid reproduction, for instance the mediterranean flour moth and stored grain borer than the American bollworm and forest tent caterpillar [22,23]. Prevalent varieties of plant metabolites comprising essential phenolic compounds were discovered that prevent herbivorous insects from nourishing. There are about 2.5 million plant types of estimation and among these over 2000 are used in pest control. More than 1000 revealed entomological significance, about 400 are antifeedants, 300 repellencies, 27 attractants and 31 displayed growth inhibiting characteristics [24]. Plant extracted metabolites play an important role in mediating interactions among plants, insect hosts and their parasitoids. These chemical compounds have detrimental effects on the growth periods of herbivores and their natural enemies.

It has been suggested that plant extracts and essential oils could be used in combination with biological control in insect control programs [25]. On the other hand, integrating the application of parasitoids, predators, pesticides and plant extracts for pest management needs appropriate information for the selective influence of these chemicals on ecological adversaries.

Due to the ecologically significant importance of plant extracts, these have emerged as an imperative alternative use of fumigant insecticides [26]. The pest control techniques may be adopted for an essay, economical and innocuous scheme [27,28]. The effect of metabolites, for instance, *methyl jasmonate* and hexane plant extract of *Inula racemosa* was previously evaluated for *B. hebetor* using a polyphagous pest, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), as its host [29,30]. The main objective of the present research was to evaluate the effectiveness of selective plant extracts and their toxicity levels within the specified time periods against the parasitoid.

2. Materials and methods

In the given research work, the efficacy of plant extracts was determined by the effect on *B. hebetor*. Collection of *B. hebetor* took place from maize fields with the help of field aerial insect nets and experiments and rearing was performed. Greater wax moth (*G. mellonella*) was treated as a host species for the rearing of *B. hebetor*.

Synthetic diet was prepared for the rearing of host species which have sufficient quantities of multi vitamins, macronutrients, oat bran, wheat flour, rice bran, yeast, wax, honey, glycerol and water in the appropriate concentration of ingredients following the protocol of standard diets [31,32].

These components were mixed together with the help of a mixer and poured into the iron trays. After the preparation of a standard diet by following the procedures, the diet was poured into glass jars of five kg. Eggs of wax moths were also placed in these jars, which hatched after about two days. The diet was restocked timely with the break of three days when the larvae consumed it completely, until pupae formed. *Bracon hebetor* adults were taken in to the laboratory to raise wax moth 4th instars larvae and kept under standardized conditions (25 ± 2 °C, 60 ± 5 % R.H. photoperiod of 16 L: 8 D).

Extraction and standardization was performed by following the concept of preparing plant extracts for insect experimental purposes through proper and timely collection, authentication, adequate drying, and grinding. This is followed by extraction, fractionation, and isolation of the bioactive compound where applicable. Additionally, it includes determination of the quantity and quality of bioactive compounds.

Five different plants (Table 1) were collected from village localities. First of all, the plants were washed with water, air dried separately at room temperature for two weeks. The dried parts were in the oven at 50 °C and kept for 20 min. Fully dried parts were cut into small pieces and grinded with the help of a grinder. Then 50 g of powdered form extract was mixed with 500 ml of hexane and distilled water at a ratio of 1:10 (W/V) in a conical flask. The solution was mixed following the protocol of mixing rotational apparatus,

Table 1
Five plants extracts along with their sources during the studies.

Sr. No.	Plant Names	Scientific Name	Family	Source
1	Citronella	*Cymbopogon nardus*	Poaceae	leaves and stem of lemon grass
2	Parthenium	*Parthenium hysterophorus*	Asteraceae	shrubs of flowering plants of daisy family like sunflower
3	Clove	*Syzygium aromaticum*	Myrtaceae	From the cloves
4	Datura	*Datura stramonium*	Solanaceae	flowering plants, rich source of phosphorus and calcium like jimson wood seed
5	Neem	*Azadirachta indica*	Meliaceae	Obtained from crushing of seeds and fruits of neem

removed traces of solvent and filtered with the help of Whatman filter paper. Finally, extracts were collected separately in a glass flask. Aqueous solutions of plant extract at 2.5, 5, 10 and 20 % were also prepared [33–36]. Therefore, prepared stock solution doses of the appropriate quantity were applied on *B. hebetor*. Paper cards with a length of 5 × 7 inches were used for the separation of larvae. Larvae of wax moths got stability on paper as well as into card cervices after 48 h, and started to form web around card and paper. The cards and their spaces allowed *B. hebetor* for extra parasitism and rearing in huge numbers. Adult females laid eggs in the larval body of the host through the phenomenon of parasitoidism. Larvae feed on the host and pupa is the non-feeding stage. After 3–5 days, the adult gets out of the pupae of the host. Plant extracts were applied, for instance (*S. aromatic, C. nardus, D. stramonium, A. indica* and *P. hysterophorus*) against *B. hebetor* with micro-syringe applicator on the thoracic region of insect samples. After the application of appropriate dose, mortality was noted with specific time intervals. Datasets were generated in three replicates and $\mathbf{LC_{50}}$ values were calculated to evaluate the toxicity levels.

A complete randomized block design (CRBD) was followed for the interpretation. After the collection of datasets, we analyzed the data through a graphical method and since these data fulfill parametric assumptions which showed that the distribution of datasets is normal. The statistical analysis was performed using statistical Analysis of Variance test two-way (ANOVA) and Tukey's multiple comparison test to differentiate between treatments and/or concentrations with software SAS, v. 9.4 and SPSS, v. 9.2. Statistical significance was established at ($p \leq 0.05$). Data was also analyzed by probit analysis using the Polo Plus program (LeOra 2003) to calculate lethal concentrations (LC50s).

3. Results

The applications of five different plant extracts (Table 1) with different concentrations against *Bracon hebetor* were performed (Tables 2–3) along with toxicity levels and datasets after (3h–2 days) were perceived (Table 4).

During the study, evaluation of the biological development and survival rate of parasitoids in five diverse plant hosts (Table 1) were conducted, which fluctuated meaningfully in masses. In the broad-spectrum, entire host kinds being veterans during the investigation had noteworthy consequences on the growth factors of parasitoids (Fig. 1).

3.1. Clove (Syzygium aromaticum)

The mean mortality rate of *B. hebetor* against the application of 125 ppm, 250 ppm, 500 ppm, 1000 ppm and 2000 ppm of *S. aromaticum* was noted (37.60, 44.0, 48.80, 54.0 and 59.60) respectively with F (5, 20) = 86.15 and significance <0.001. Control experiments exhibited 1.80, mean mortality of parasitoid populations (Fig. 2, Table 2). Whereas the mortality rates of the *B. hebetor* after 3, 6, 12, 24 and 48 h were exhibited as 24.67, 36, 43.67, 44.50 and 56 respectively with F (4,20) = 32.48 and significance <0.001 (Figs. 2–3, Tables 2–3). Datasets are statistically significant.

3.2. Citronella (Cymbopogon nardus)

Plant extract *C. nardus* showed mean mortality of *B. hebetor* against the application of 125 ppm, 250 ppm, 500 ppm, 1000 ppm and 2000 ppm were revealed (28.80, 34.0, 37.60, 41.20 and 45.60) respectively with F (5,20) = 56.54 and significance <0.001. Control treatments exhibited 1.40 mean mortality rates (Fig. 2, Table 2). Whereas the mortality rates of the *B. hebetor* after 3, 6, 12, 24 and 48 h were exhibited as 20.67, 23.33, 28.33, 37.17 and 47.67 respectively, with F (4,20) = 33.09, and significance <0.001 (Fig. 3, Table 3). Datasets represented statistically significant values.

Table 2
Means values of different plant extracts against *B. hebetor* with relation to concentrations.

	Concentration							
	Control (Means ± SD)	125 ppm (Means ± SD)	250 ppm (Means ± SD)	500 ppm (Means ± SD)	1000 ppm (Means ± SD)	2000 ppm (Means ± SD)	F-value	Sig.
Clove *(Syzygium aromaticum)*	1.80 ± 0.68	37.60 ± 05.06	44.00 ± 5.92	48.80 ± 7.54	54.00 ± 6.64	59.60 ± 8.50	F (5,20) = 86.15	<0.001
Citronella *(Cymbopogon nardus)*	1.40 ± 0.95	28.80 ± 3.46	34.00 ± 03.11	37.60 ± 2.20	41.20 ± 3.21	45.60 ± 3.67	F (5,20) = 56.54	<0.001
Parthenium (*Parthenium hysterophorus*)	1.60 ± 2.30	50.80 ± 9.27	56.40 ± 8.46	62.40 ± 5.58	66.40 ± 6.15	72.00 ± 4.42	F (5,20) = 75.18	<0.001
Dhatura *(Datura stramonium)*	1.80 ± 0.49	32.00 ± 6.94	43.60 ± 7.78	50.40 ± 4.53	54.80 ± 7.37	58.40 ± 2.28	F (5,20) = 89.05	<0.001
Neem *(Azadirachta indica)*	1.40 ± 0.95	22.00 ± 4.24	26.40 ± 3.18	30.40 ± 5.18	36.80 ± 7.29	42.40 ± 6.23	F (5,20) = 126.67	<0.001

Table 3
Means values of different plant extracts against *B. hebetor* with relation to time of application.

	Time (Hours)						
	3 h (Means ± SD)	6 h (Means ± SD)	12 h (Means ± SD)	24 h (Means ± SD)	48 h (Means ± SD)	F-value	Sig.
Clove *(Syzygium aromaticum)*	24.67 ± 4.46	36.00 ± 4.01	43.67 ± 4.75	44.50 ± 5.37	56.00 ± 5.36	F (4,20) = 32.48	<0.001
Citronella *(Cymbopogon nardus)*	20.67 ± 2.18	23.33 ± 2.75	28.33 ± 4.94	37.17 ± 5.53	47.67 ± 7.28	F (4,20) = 33.09	<0.001
Parthenium (*Parthenium hysterophorus*)	30.00 ± 6.42	44.67 ± 6.86	57.67 ± 7.01	61.50 ± 7.34	64.17 ± 9.78	F (4,20) = 27.80	<0.001
Dhatura *(Datura stramonium)*	25.00 ± 4.53	38.00 ± 5.88	42.33 ± 6.75	44.67 ± 5.68	50.83 ± 5.74	F (4,20) = 22.65	<0.001
Neem *(Azadirachta indica)*	32.00 ± 7.75	26.33 ± 4.33	22.67 ± 3.19	21.50 ± 3.09	30.33 ± 2.46	F (4,20) = 15.70	<0.001

3.3. Parthenium (Parthenium hysterophorus)

Plant extract *P. hysterophorus* revealed the mean mortality of the tested parasitoid against the application of 125 ppm, 250 ppm, 500 ppm, 1000 ppm and 2000 ppm were calculated (50.80, 56.40, 62.40, 66.40 and 72.00) respectively with F (5,20) = 75.18 and *P*-values < 0.001. Control treatments exhibited 1.60 mean mortality rates (Fig. 2, Table 2). Whereas the mortality rates of the *B. hebetor* after 3, 6, 12, 24 and 48 h were exhibited as 30.00, 44.67, 57.67, 61.50 and 64.17 respectively, with F (4, 20) = 27.80, and significance <0.001 (Fig. 3, Table 3). Datasets exhibited statistically significant values, respectively.

3.4. Datura (Datura stramonium)

Plant extract *D. stramonium* discovered the mean mortality of experimented parasitoid against the application of 125 ppm, 250 ppm, 500 ppm, 1000 ppm and 2000 ppm was calculated (32.00, 43.60, 50.40, 54.80 and 58.40) respectively with F (5,20) = 89.05 and significance <0.001. Control treatments exhibited 1.80 mean mortality rates (Fig. 2, Table 2). Whereas the mortality rates of the *B. hebetor* after 3, 6, 12, 24 and 48 h represented statistically significant values like 25.00, 38.00, 42.33, 44.67 and 50.83 respectively, with F (4, 20) = 22.65, and significance <0.001 (Fig. 3, Table 3).

3.5. Neem (Azadirachta indica)

The mean mortality of *B. hebetor* against the application of 125 ppm, 250 ppm, 500 ppm, 1000 ppm and 2000 ppm was calculated (22.00, 26.40, 30.40, 36.80 and 42.40) respectively with F (5,20) = 126.67 and significance <0.001. Control treatments exhibited 1.40 mean mortality rates (Fig. 2, Table 2). Whereas the mortality rates of the *B. hebetor* after 3, 6, 12, 24 and 48 h represented significant values such as 32.00, 26.33, 22.67, 21.50 and 30.33 respectively with F (4, 20) = 15.70, and significance <0.001 (Fig. 3, Table 3).

The plant extracts concentrations of *P. hysterophorus* exhibited diminutive values of LC_{50} (4.440, 3.056, 1.889, 1.575 and 1.392 mg/L) which proved to be minute toxicity levels against studied parasitoid followed by *D. stramonium* (5.396, 3.793, 3.251, 3.016 and 2.460 mg/L), *S. aromaticum* (5.429, 4.018, 3.138, 3.041 and 1.966 mg/L) and *A. indica* (4.429, 5.416, 5.815, 6.525 and 4.790 mg/L) while *C. nardus* (6.199, 5.990, 5.242, 4.086, 2.762 mg/L) at variable time interludes of 3 h to 2 days (Table 4).

4. Discussion

The demonstrations in the exceeding results, *P. hysterophorus* exhibited high noxious effects on the biological mediation in this arena. Consequently, these kinds of products will be avoided because of lethal properties for the natural antagonists of the insect pest. Plant extracts with negligible to low toxicity may be utilized, such as (*S. aromatic, C. nardus, D. stramonium,* and *A. indica*) have compatibility with parasitoids in integration of insect controlling programs. The chemical and biological control in combination of strategies is an essential icon of integrated pest management (IPM) programs [2].

The current findings revealed that *Bracon* species have the capacity to parasitize [37] diversified host species including lepidopetera and coleoptera. The range for parasitizing ability of such species who are phylogenetically detached could possibly be the first step of parasitical magnitude [38,39]. The present findings measured the reproduction, development and existence levels of *B. hebetor* in five diverse plant extracts and variation in masses. Species with host behavior during the findings had substantial consequence on the inclusive development of the parasitoid. The process of host selection for the parasitoids might be contingent of phylogenetic remoteness [40]. *Bracon hebetor* is characterized by a wide-ranging host collection of agricultural products. The host fitness of the parasitoids may deviate significantly according to competence [41] and it becomes imperative to determine the most suitable host for a mass rearing program. The investigation research of the biological parameters of parasitoid *B. hebetor* on different lepidopteran hosts has been studied in former research [22,41]. Auxiliary, wax moth larvae as a model for susceptibility testing and acute toxicity trials [19].

Plant extracts and essential oils have numerous kinds of accomplishment comprising repellent and anti-feeding approaches, cuticle

Table 4
LC_{50} values of different plant extracts against *B. hebetor* (n = 100), SE (Standard Errors), χ 2 (Chi square).

	Plant Extracts																		
	Clove *(Syzygium aromaticum)*				Citronella *(Cymbopogon nardus)*				Parthenium (*Parthenium hysterophorus*)				Datura *(Datura stramonium)*				Neem *(Azadirachta indica)*			
Time	**LC_{50}**	**Slopes ± SE**	**χ2**	**Sig.**	**LC_{50}**	**Slopes ± SE**	**χ2**	**Sig**	**LC_{50}**	**Slopes ± SE**	**χ2**	**Sig**	**LC_{50}**	**Slopes ± SE**	**χ2**	**Sig**	**LC_{-50}**	**Slopes ± SE**	**χ2**	**Sig**
3 h	5.429	0.257 ± 0.036	17.226	.002	6.199	0.240 ± 0.038	13.874	.008	4.440	0.311 ± .036	16.139	.003	5.396	.256 ± .036	16.527	<.002	4.429	.270 ± .034	24.103	<.001
6 h	4.018	0.263 ± 0.034	31.720	<.001	5.990	0.224 ± 0.036	17.515	.002	3.056	0.282 ± 0.033	46.455	<.001	3.793	.265 ± .033	35.368	<.001	5.416	.236 ± .035	20.248	<.001
12 h	3.138	0.293 ± 0.033	41.445	<.001	5.242	0.225 ± 0.034	25.056	<.001	1.889	0.352 ± 0.034	68.679	<.001	3.251	.303 ± .033	38.137	<.001	5.815	.247 ± .037	14.329	.006
24 h	3.041	0.301 ± 0.033	29.072	<.001	4.086	0.224 ± 0.033	29.480	<.001	1.575	0.362 ± 0.035	66.293	<.001	3.016	.301 ± .033	25.365	<.001	6.525	.209 ± .036	7.733	.102
48 h	1.966	0.307 ± 0.033	46.480	<.001	2.762	0.269 ± 0.032	39.663	<.001	1.392	0.386 ± 0.036	61.610	<.001	2.460	.347 ± .034	30.768	<.001	4.790	.246 ± .034	11.096	.026

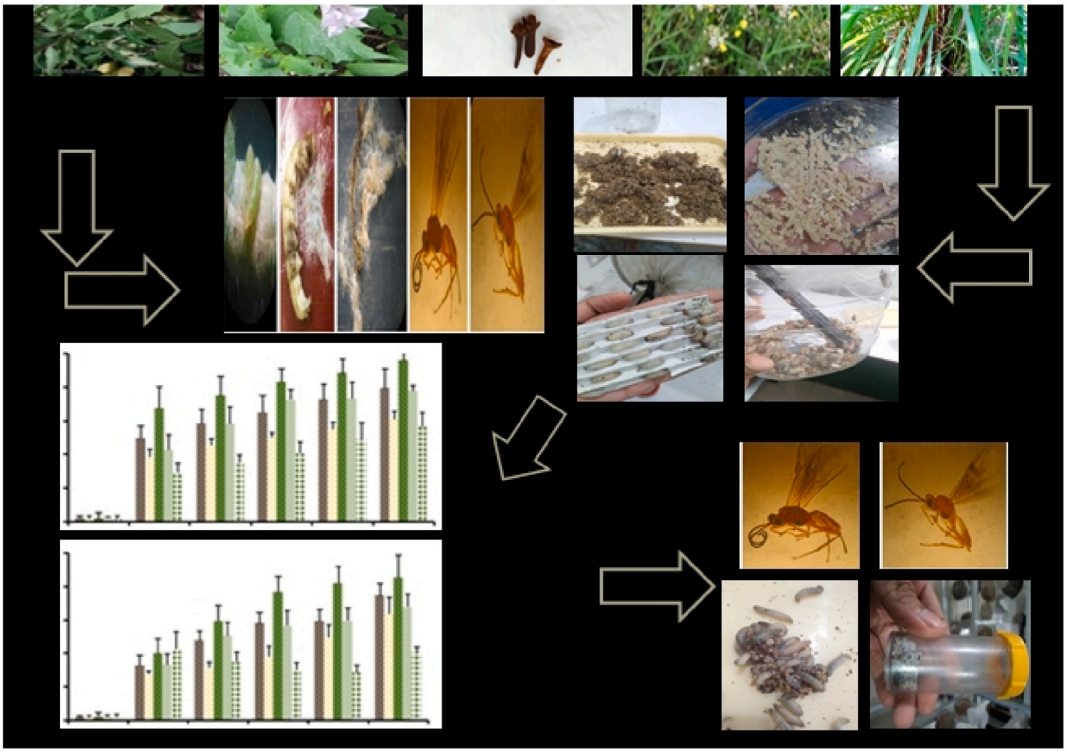

Fig. 1. Representation of procedural experimentations of *Bracon hebetor* populations against plant extracts.

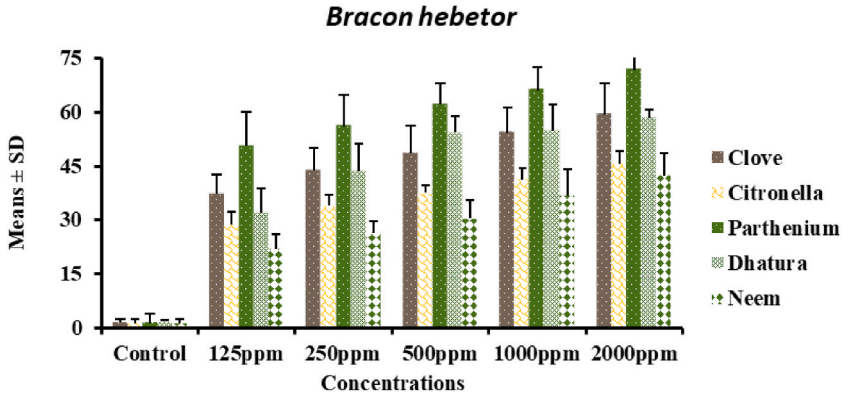

Fig. 2. Representation of mean mortality of *Bracon hebetor* populations against plant extracts at diverse concentrations of plant extracts.

and molt shedding distraction as well as developmental resistivity [42]. Lemon and eucalyptus extracts and oils worked as fumigation for mites [43,44]. Neem oil affords nauseating, hormonal disturbance and anti-feeding performance. Neem, *A. indica* extracts comprising *Salannin* delivers repellant stuffs [45]. Dependency of insect mortality is based on concentration of the dose and acquaintance of time delivered. Owing to the application of essential oils at different concentrations, a variable mortality of *B. hebetor* was perceived. Neem, *A. indica* demonstrated no effects on parasitoids summarized (Schmutter et al., 1992) and exhibited low toxicity than cypermethrin owing severe consequence on *B. hebetor* [46]. Neem, *A. indica* kernels assessed the repellency with no side effects on mites and bees [47]. Neem, *A. indica* and canola *Brassica napus* can be utilized for the selective control of the population of parasitic mites on bees [48]. Additionally, the chemical *azadirachtin* in the neem plant, *A. indica*, is the dynamic vital component for control of pests, [49]. Consequently, plant extracts are a decent substitute for managing *Varroa* mites [11] along with other insect pests. Clove, *S. aromaticum,* oil operated with about ninety percent reduction in ova emerging and a hundred percent larval reduction for the greater wax moth [50]. No side effects established by exploiting plant extracted oils on parasites [51]. Subsequently, the development of chemical resistance in parasitoids may also favor the suitability of these botanicals and under a planned insecticide resistance management approach, insecticide resistance should be monitored regularly aimed at best constructive use of both botanicals and

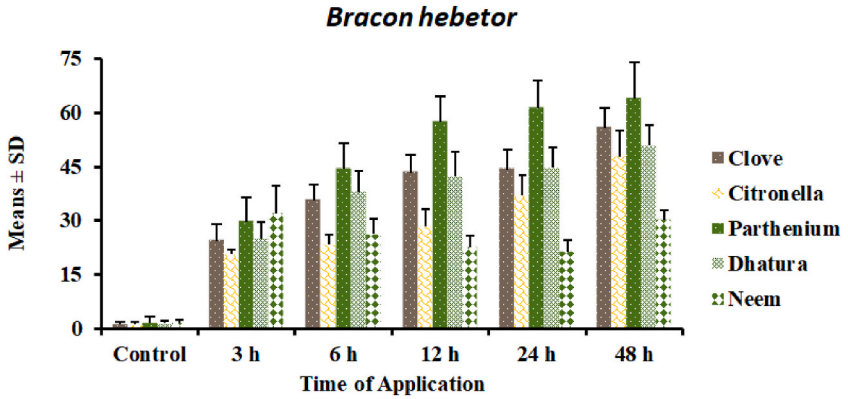

Fig. 3. Representation of mean mortality of *Bracon hebetor* populations against plant extracts at various time intervals.

parasitoids potential in pest management tactics for the control of insect pests.

Insecticide resistance to beneficial insects is an important component of pest-management programs [52,53]. Although resistance to chemicals in beneficial insects is less well documented, nevertheless it has been revealed in various insects [54–56]. *Bracon hebetor* is one of the most important and effective hymenopterans that have developed significant resistance to many frequently used pesticides [57,58]. *Bactrocera hehetor* resilient strains into an integrated biochemical approach are necessary because this may expedite improvement of resistance in associated parasitoids [59].

Plant extracts are used to control insects. Due to the co-occurrence of non-target insects with target insects, it is impossible to avoid parasitoid exposure to chemicals [60]. These chemicals can limit the biocontrol services [61,62]. Assessments of the toxicity and resistance caused by the chemicals applied to *B. hebetor* have also been reported in previous research [63,64]. However, it is not known if toxic effects of chemicals or their metabolites can be passed directly from insects to adult parasitoids. In another study such as *Trichogramma* [65], pesticides adversely impact beneficial insects and limit their application. The use of insecticide-resistant benefits can support accomplishing better results. For instance, the release of the insecticide-resistant *Trichogramma* resulted in increased yield and reduced pesticide application [66,67]. Various studies reported that resistant *Trichogramma* strains were used to control pests to accomplish better insect management [68]. Summarily, the development of sound, bio biopesticide application strategies aimed at limiting toxic effects on released biocontrol fauna. The research presented in this manuscript is preliminary studies with special focus on parasitoid. However, the host toxicity exploration, compatibility studies and detailed resistance mechanism will interpret in future experiments.

5. Conclusion

Botanicals such as plant extracts have great prospects for utilization in integrated insect control. The outcomes of the investigations exhibited that ecologically innocuous handling should be selected in applied pest management programs with biological control fauna. *Cymbopogon nardus, A. indica, S. aromaticum* and *D. stramonium* revealed comparatively low toxicity levels and are quite safer for beneficial insects, and *P. hysterophorus* is more toxic to parasitoids at low levels. Plant extracts have proved to be the best result for integration with parasitoids to control field insect pests. The findings of the present study indicated that all plant extracts except *P. hysterophorus* are promising as safe natural products for insect control and for sustainable pest protection. Also, these extracts proved to be cheap, harmless to the parasitoids and environmentally friendly and fit well into pest management programs for alternatives and or with other control measures. The detailed insect resistance mechanism in host parasitoid interaction will be accomplished in future studies.

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Ethics approval

In addition, the manuscript meets all applicable standards with regard to the ethics of experimentation and research, and there is no duplicate publication, fraud, plagiarism, or concerns about animal or human experimentation.

Consent for publication

All authors are aware of the order of authorship and publication.

Author contribution statement

Bilal Rasool and Muhammad Asrar: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.
Irum Bakht: Performed the experiments; Wrote the paper.
Saddam Hussain, Dilbar Hussain and Zeeshan Javed: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data and wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] B.R. Champ, C.E. Dyte, FAO global survey of pesticide susceptibility of stored grain pests, FAO Plant Protect. Bull. 25 (1977) 49–67.
[2] C.A. Damalas, I.G. Eleftherohorinos, Pesticide exposure, safety issues, and risk assessment indicators, Int. J. Environ. Res. Publ. Health 8 (2011) 1402–1419.
[3] C. Wesseling, M. Corriols, V. Bravo, Acute pesticide poisoning and pesticide registration in Central America, Toxicol. Appl. Pharmacol. 207 (2005) 697–705.
[4] D. Spadaro, M.L. Gullino, State of the art and future prospects of the biological control of postharvest fruit diseases, Int. J. Food Microbiol. 91 (2004) 185–194.
[5] P. Barbosa, J.A. Saunders, J. Kemper, R. Trumbule, J. Olechno, P. Martinat, Plant allelochemicals andinsect parasitoids effects of nicotine on *Cotesia congregata* (say) (Hymenoptera: Braconidae) and *hyposoterannulipes* (cresson) (Hymenoptera: Ichneumonidae), J. Chem. Ecol. 12 (6) (1986) 1319–1328.
[6] M.P. Zimmerman,, D.M. Chan, K.M. Kester, R.C. Rael, S.L. Robertson, The effects of allelochemical transfer on the dynamics of hosts, parasitoids, and competing hyperparasitoids, Nat. Resour. Model 34 (2021), e12311, https://doi.org/10.1111/nrm.12311.
[7] Y.G. Lou, G. R. Zhang, W. Q. Zhang, Y. Hu, J. Zhang, Biological control of rice insect pests in China, Biol. Control 67 (2013) 8–20.
[8] M.B.S. Brower, S.A. Shad, Biological control in integrated management of insects in stored products, J. Asia Pac. Entomol. 20 (1996) 457–462.
[9] Z. Wang, L. Yin-quan, Min Shi, H. Jian-hua, C. Xue-xin, Parasitoid wasps as effective biological control agents, J. Integr. Agric. 18 (4) (2019) 705–715, https://doi.org/10.1016/S2095-3119(18)62078-7.
[10] H.K.M. Dweck, N.S. Gadallah, E. Darwish, Structure and sensory equipment of the ovipositor of *Habrobracon hebetor Say* (Hymenoptera: Braconidae), Micron 39 (8) (2008) 125–126.
[11] M.A. Bakar, M.A. Aqueel, A.B.M. Raza, M.I. Ullah, M. Arshad, M. Sohail, O. Molina, J. Choa, Evaluation of few essential oils for the management of parasitic bee mites, *Varroa destructor* (Acari: varroidae) in *Apis mellifera* colonies, Pakistan J. Zool. 49 (2017) 2005–2010.
[12] M.N. Ghimire, T. W. Phillips, Mass rearing of *Habrobracon hebetor* Say (Hymenoptera: Braconidae) on larvae of the Indian meal moth, *plodia Interpunctella* (Lepidoptera: Pyralidae) effects of host density, parasitoid density, and rearing containers, J. Stored Prod. Res. 46 (2010) 214–220.
[13] J.A. Reinert, E.W. King, Action of *Bracon hebetor* Say as a parasite of *Plodia interpunctella* at controlled densities, Ann. Entomol. Soc. America 64 (1971) 1335–1340.
[14] K.V. Krombein, P.D. Hurd, D.R. Smith, B.D. Bruks, Catalog of Hymenoptera in America North of Mexico, Smit. Inst. Pres., Washington, DC, 1979.
[15] D.W. Hagstrum, B.J. Smittle, Host-finding ability of *Bracon hebetor* and its influence upon adult parasite survival and fecundity, Environ. Entomol. 6 (1977) 437–439.
[16] M.S. Khalil, A.B.M. Raza, M. Afzal, M.A. Aqueel, H. Khalil, T. Hance, Effects of different host species on the life history of *Bracon hebetor*, Anim. Biol. Leiden 66 (2016) 403–414.
[17] O.W. Richards, W.S. Thomson, A contribution to the study of the genera *Ephestia*, Gn. (including Strymax, Dyar), and Plodia, Gn. (Lepidoptera, Phycitidae), with notes on parasites of the larvae, Transac. Royal Entomol. Soc. London. 80 (1932) 169–247.
[18] M. Amir, H. Chi,, Demography of *Habrobracon hebetor* (Hymenoptera: braconidae) on two pyralid hosts (Lepidoptera: Pyralidae), Ann. Entomol. Soc. America 99 (2006) 84–90.
[19] K. Ignasiak, A. Maxwell, *Galleria mellonella* (greater wax moth) larvae as a model for antibiotic susceptibility testing and acute toxicity trials, B.M.C. Res. Notes. 29 10 (1) (2017) 428, https://doi.org/10.1186/s13104-017-2757-8.
[20] K. Kuramitsu, K. Komizo, Parasitism of three attelabid weevils by *Bracon* (uncobracon) *apoderi* watanabe (Hymenoptera: Braconidae) in kyushu, J. Apan. Entomol. Sci. 17 (2014) 440–442.
[21] M.F. Doury, P.J. Ode, M.R. Strand, Physiological and biochemical analysis of factors in the female venom gland and larval salivary secretions of the ectoparasitoid wasp, Eup. Anim. Beh. 49 (1997) 589–600.
[22] S.R. Margo, J.R.P. Parra, Biology of the ectoparasitoid *Bracon hebetor* Say on seven lepidopteran species, Scientia Agri. 58 (2001) 693–698.
[23] D.H. Rafiei, M.J. Hejazi, G.G. Nouri, M. Saber, Toxicity of Some Biorational and Conventional Insecticides to Cotton Bollworm, *Helicoverpa Armigera* (Lepidoptera: Noctuidae) and its ectoparasitoid, Habrobracon hebetor (Hymenoptera: Braconidae), J. Entomol.Soc. Iran 28 (1) (2008) 27–37.
[24] S.S. Purohit, S.P. Vyas, Medicinal Plant Cultivation: A Scientific Approach: Including Processing and Financial Guidelines, Agrob, 2004.
[25] J.O.W. González, R.A. Laumann, S. Da-Silveira, M.C.B. Moraes, M. Borges, A.A. Ferrero, Lethal and sublethal effects of four essential oils on the egg parasitoids *Trissolcus basalis*, Chemosphere 92 (2013) 608–615.
[26] F. Ercan, H. Bas, M. Koc, D. Pandir, S. Oztemiz, Insecticidal activity of essential oil of *prangosferulacea* (umbelliferae) against *ephestiakuehniella* (Lepidoptera: Pyralidae) and *Trichogrammaem bryophagum* (hymenoptera: trichogrammatidae), Turk, J. Agric. Fores. 37 (2013) 719–725.
[27] C.H. Bischof, W.H. Cross, H.C. Mitchell, The effects of parasitism by *Glyptapanta lesliparidis (*Hym: braconidae) on the haemolymph and total body composition of gypsy moth larvae (Lymantridae: Lepidoptera), J. Econ. Entomol. 62 (1996) 889–896.

[28] S. Coudron, M. Ashfaq, R.R. Khan, H.A.A. Khan, Host regulating factors associated with parasitic Hymenoptera, Kuw. J. Sci. Eng. 38 (1991) 185–192.
[29] M. Kaur, S. Isha, K. Rakesh, I.P. Singh, S. Kaur, Biological effects of secondary metabolites of Inula racemosa on the parasitoid, Bracon hebetor 169 (8) (2021) 743–749, https://doi.org/10.1111/eea.13070.
[30] L. Chen, J. Song, J. Wang, M. Ye, Q. Deng, X. Wu, X. Wu, B. Ren, Effects of *methyl jasmonate* fumigation on the growth and detoxification ability of *Spodoptera litura* to xanthotoxin, Insects 14 (145) (2023) 2, https://doi.org/10.3390/insects14020145.
[31] M. Hickin, et al., Optimization of a diet for the greater wax moth (Lepidoptera: Pyralidae) using full factorial and mixture design, J. Econ. Entomol. 114 (3) (2021) 1091–1103, https://doi.org/10.1093/jee/toab039.
[32] M. S. Hala, et al., Low cost artificial diet for rearing the greater wax moth, *Galleria mellonella* L.(Lepidoptera: Pyralidae) as a host for entomopathogenic nematodes, Egyp. J. Biol. Pest Cont. 22 (1) (2012) 15–17.
[33] K.P. Ingle, et al., Phytochemicals: extraction methods, identification, and detection of bioactive compounds from plant extracts, J. Pharm. Phytochem. 6 (2017) 32–36.
[34] A. Altemimi, et al., Phytochemicals: extraction, isolation, and identification of bioactive compounds from plant extracts, Plants 6 (2017) 42.
[35] A.R. Abubakar, M. Haque, Preparation of medicinal plants: basic extraction and fractionation procedures for experimental purposes, J. Pharm. BioAllied Sci. 12 (1) (2020) 1–10, https://doi.org/10.4103/jpbs.JPBS_175_19.
[36] M. Muhammed, et al., Insecticidal effects of some selected plant extracts against *Anopheles stephensi* (Culicidae: Diptera), Malar. J. 21 (2022) 295, https://doi.org/10.1186/s12936-022-04320-5.
[37] G.N. Mbata, S. Warsi, *Habrobracon hebetor* and *Pteromalus cerealellae* as tools in post-harvest integrated pest management, Insects 10 (2019) 85.
[38] B.J. Visser, W.T. Labruyere, W. Spanjer, T. Piek, Characterization of two paralysing protein toxins (A-MTX and B-MTX), isolated from a homogenate of the wasp *Microbracon hebetor* (Say), Comp. Biochem. Phys. 75 (1983) 523–530.
[39] S.J. Moreau, S. Asgari, Venom proteins from parasitoid wasps and their biological functions, Toxicology 7 (2015) 2385–2412.
[40] J.R. Lopez, J.A.S. Garcia, L.M. Martinez, J.I. Figueroa, Parasitoids of *Anthonomus sisyphus* clark (Coleoptera: Curculionidae) in red nanche fruits (Malpighia mexicana) in oaxaca, Mexico, Southwestern Entomol 36 (2011) 351–361.
[41] S.A. Landge, S.M. Wakhede, S.M. Gangurde, Comparative biology of *Bracon hebetor* say on corcyra *cephalonica stainton* and *Opisina arenosella* walker, Int. J. Plant Protect. 2 (2009) 278–280.
[42] S. Cosimi, E. Rossi, P.L. Cioni, A. Canale, Bioactivity and qualitative analysis of some essential oils from Mediterranean plants against stored-product pests: evaluation of repellency against *Sitophilus zeamais* Motschulsky, *Cryptolestes ferrugineus* (Stephens) and *Tenebrio molitor*, J. Stor. Prod. Res. 45 (2009) 125–132.
[43] Y.C. Su, C.L. Ho, E. Wang, S.T. Chang, Antifungal activities and chemical compositions of essential oils from leaves of four eucalypts, Taiw. J. Sci. 21 (2006) 49–61.
[44] S. Miresmailli, R. Bradbury, M.B. Isman, Comparative toxicity of *Rosmarinus officinalis* L. essential oil and blends of its major constituents against *Tetranychus urticae* Koch (Acari: tetranychidae) on two different host plants, Pest Mang. Sci. 62 (2006) 366–371.
[45] W.M. Blaney, et al., Antifeedant effects of azadirachtin and structurally related compounds on lepidopterous larvae, Entomol. Exp. App. 55 (1990) 149–160.
[46] Z. Abedi, M. Saber, G. Gharekhani, A. Mehrvar, S.G. Kamita, Lethal and sublethal effects of azadirachtin and cypermethrin on *Habrobracon hebetor* (hymenoptera: braconidae), J. Econ. Entomol. 107 (2014) 638.
[47] R. González-Gómez, et al., Repellency of the oily extract of neem seeds *Azadirachta indica* against *Varroa destructor* (Acari: varroidae), Exp. Appl. Acar. 56 (2012) 261–270.
[48] A.P. Melathopoulos, M.L. Winston, R. Whittington, H. Higo, M. Le-Doux,, Field evaluation of neem and canola oil for the selective control of the honey bee (Hymenoptera: apidae) mite parasites *Varroa jacobsoni* (Acari: varroidae) and *Acarapis woodi* (Acari: tarsonemidae), J. Econ. Entomol. 93 (2000) 559–567.
[49] T.S. Djenontin, V.D. Wotto, F. Avlessi, P. Lozano, D.K. Sohounhloué, D. Pioch,, Composition of *Azadirachta indica* and *Carapa procera* (Meliaceae) seed oils and cakes obtained after oil extraction, Indus Crop Prod. 38 (2012) 39–45.
[50] S.S. Moawad, H.H. El-Behery, I. M. Ebadah,, Effect of volatile oils on some biological aspects of *Galleria mellonella L.* and its parasitoid species, *Bracon hebetor* say (Hymenoptera: braconidae), Egyp. J. Biol. Pest Cont. 25 (2015) 603.
[51] N.Z. Azimi, A. Kamal,, The impact of several plant extracts and Eessential oils on pistachio psylla *Agonoscena pistaciae* and its natural enemy, *Chrysoperla carnea*, J. Nut. 9 (2018) 159–168.
[52] R.L. Metcalf, W. H. Luckmann,, Introduction to Insect Pest Management, second ed., Wiley, New York, 1982.
[53] B.A. Croft. Arthropod Biological Control Agents and Pesticides, Wiley, New York, 1990.
[54] J. Schoones, J.G. Gilionmee, The toxicity of methidathion to parasitoids of red scale, *Aonidiella aurantii* (Hemiptera: diaspididae), J. Entomol. Soc. S. Afr. 45 (1982) 261–273.
[55] A. Havron, D. Rosen, H. Prag, Y. Rossler, Selection for pesticide resistance in Aphytis *holoaxantthus* a parasite of Florida red scale, Entomol. Exp. Appl. 61 (1991) 221–228.
[56] M.A. Hoy, et al., Release, dispersal, and recovery of a laboratory-selected strain of the walnut aphid parasite *Trioxys pallidus* (Hymenoptera: aphidiidae) resistant to azinphosmethyl, J. Econ. Entomol. 83 (1990) 89–96.
[57] J.L. Zettler, L.L. McDonlald, L.M. RedIinger, R.D. Jones, *Plodia interpunctella* and *Cadra cautella* resistance in strains to malathion and synergized pyrethrins, J. Econ. Entomol. 66 (1973) 1049–1050.
[58] P.J.O. Brien, G.W. Elzen, S.B. Vinson, Toxicity of azinphosmethyl and chlordimeform to parasitoid *Bracon mellitor* (Hymenoptera: braconidae): lethal and reproductive effects, Environ. Entomol. 14 (1985) 891–894.
[59] B.A. Croft, J.G. Morse, Research advances on pesticide resistance in natural enemies, Entomophaga 24 (1979) 3–11.
[60] Y.J. Yang, C. Y. Wang, H. X. Xu, J. C. Tian, Z. X. Lu, Response of *Trichogramma spp.* (Hymenoptera: Trichogrammatidae) to insecticides at concentrations sublethal to *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae), J. Econ. Entomol. 113 (2019) 646–653.
[61] M.L. Narayana, T.R. Babu, Evaluation of five insect growth regulators on the egg parasitoid *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae) and the hatchability of *Corcyra cephalonica* Staint (Lep., Galleriidae), J. Appl. Entomol. 113 (2010) 56–60.
[62] B. Halappa, J. S. Awaknavar, D. Archana, Toxicity of different insecticides to *Trichogramma chilonis* Ishii (Trichogrammitidae: Hymenoptera) under laboratory condition, Res. Crops 13 (2012) 652–655.
[63] X. Zhao, C. Wu, Y. Wang, T. Cang, L. Chen, R. Yu, Q. Wang, Assessment of toxicity risk of insecticides used in rice ecosystem on *Trichogramma japonicum*, an egg parasitoid of rice lepidopterans, J. Econ. Entomol. 105 (2012) 92–101.
[64] J.W. Press, et al., Survival and reproduction of *Bracon hehetor* on insecticide-treated Ephestia cautella larvae, J. Georgia Entomol. Soc. 16 (1981) 231–234.
[65] K. Ko, Y. Liu, M. Hou, B. Dirk, Z. Feng, S. Kai, Toxicity of insecticides targeting rice Planthoppers to adult and immature stages of *Trichogramma chilonis* (Hymenoptera: trichogrammatidae), J. Econ. Entomol. 108 (2015) 69–76.
[66] S. K. Jalali, S. P. Singh, T. Venkatesan, K. S. Murthy, Y. Lalitha, Development of endosulfan tolerant strain of an egg parasitoid *Trichogramma chilonis* Ishii (Hymenoptera: trichogrammatidae), Indian J. Exp. Biol. 44 (2006) 584–590.
[67] C.R. Ballal, R. Srinivasan, S. K. Jalali, Evaluation of an endosulfan tolerant strain of *Trichogramma chilonis* on cotton, Biocontrol 54 (2009) 723–732.
[68] T. Venkatesan, S.K. Jalali, Development, characterization and field assessment of multiple insecticides and high temperature tolerant strain of an egg parasitoid, *Trichogramma chilonis* Ishii against, crop, in: pests, New Horizons in Insect Science: towards Sustainable Pest Management, Springer, 2015, pp. 327–345.