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Abundance of important parasitoids in the vegetable ecosystem and their prospects in integrated pest management

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Abstract
Intensive surveys were conducted during 2009-18 at Varanasi and its adjoining districts of Uttar Pradesh for recording the major insect pests and their associated hymenopteran parasitoids in the major groups of vegetables *viz*., solanaceous, cruciferous, cucurbitaceous, malvaceous and leguminous. A critical study revealed that all of these recorded parasitoids (*Trathala flavo orbitalis*, *Pediobius foveolatus*, *Pristomerus euzopherae*, *Apanteles oblique*, *Meteorus* sp., *Campoletes chloridae*, *Neochrysocharis formosa*, *Aenasius arizonensis*, *Chelonus blackburni*, *Agathis* spp., *Cotesia plutellae*, *Microplitis tuberculifer*, *Diaeretiella rapae*, *Apanteles paludicole*, *Cotesia glomerata*, *Dinarmus basalis*), *Brachymeria lasus* and *Pristomerus euzopherae* showed greatest affinity (70.59%) towards lepidopteran pests (*Leucinodes orbonalis*, *Euzophera perticella*, *Spilosoma obliqua*, *Helicoverpa armigera*, *Earias vittella*, *E. insulana*, *Plutella xylostella*, *Spodoptera litura*, *Sphenarches caffer*, *Diaphania indica*), followed by coleopteran (*Henosepilachna vigintioctopunctata*, *Epilachna dodecastigma*, *Callosobruchus chinensis*, *C. analis*, *C. maculatus*) and hemipteran hosts (*Phenacoccus solenopsis*, *Myzus persicae*, *Brevicoryne brassicae*, *Lipaphis erysimi*) (11.77% each). However, only one parasitoid (5.88%) *viz*., *Neochrysocharis formosa* had a dipteran host *i.e.*, *Liriomyza trifolii*. Considering the month wise distribution and abundance of these parasitoids, the highest diversity of parasitoids (53.33%) in terms of species occurred during the months of February, March and September, coinciding with the spring and autumn seasons in northern India followed by August (46.67%). However, only one parasitoid *i.e*., *P. euzopherae* was recorded in the month of May. The host range, seasonal incidences, level of parasitization and the probable role of the recorded parasitoids in biointensive integrated pest management (BIPM) systems are discussed briefly.

Keywords: Insects pests, parasitoids, abundance, percent parasitization, vegetable ecosystem

Introduction
Vegetables play a major role in Indian agriculture as they ensure food and nutritional security of the country apart from enhancing per capita income of the farmers. Globally, India ranks second in vegetable production with a contribution of 15.4% [2]. Amongst the vegetables, solanaceous (brinjal, tomato, chillies), cruciferous (cabbage, cauliflower, knolkhol), cucurbitaceous (pumpkin, bottle gourd, pointed gourd, ridge gourd etc.), malvaceous (okra) and leguminous (cowpea, pea, French bean) vegetables comprise around 90% of the vegetable production of the country. Insect pests and diseases are the major biotic constraints for vegetable production. The crop losses in the country due to various insect pests range on an average from 10-30 percent. Apart from causing direct damage, many of them also act as vectors for several viral diseases which have aggravated the problem still further [14]. Several synthetic insecticides are recommended and also highly effective for control of these vegetable pests but their adverse effects in the context of environmental pollution, resurgence of other sucking pests and resistance to the various agrochemicals as also the lethal effects to non-target organisms cannot be ruled out. Demand for biological pest control is ever increasing due to their unique benefits like target specificity, environmental safety, production of uncontaminated food stuff and restoring sustainability in the agro-ecosystems [19]. Therefore these methods for biological pest control are appreciated by the environmentalists as well as general public at large and the demand for organically grown vegetables is ever-growing. Although a vegetable ecosystem is rich in natural enemies' complex, few studies have been systematically done to record and mass multiply them paving the way for their exploitation for IPM. In general about 66 percent of all successful biocontrol programmes have involved parasitoids [6].

Parasitoids have a great variety of lifestyles as they are free-living as adults and parasitic as larvae; the larvae feed on their hosts, which are mostly insects of various developmental stages [27]. Parasitoids need the presence of suitable hosts for their feeding, survival, growth and reproduction; this agonistic interaction between parasitoid and its host is the result of a long co-evolutionary process over time. Hosts do not survive and thus parasitoids play an important role in regulating the population of their hosts through effective biological control [6]. Region wise inventories of different parasitoids in the vegetable ecosystem are scanty. Therefore, an attempt was made to collect and document the parasitoid fauna of major vegetable insect pests, along with their seasonal incidence, extent of parasitization, etc. under agro-climatic conditions of eastern Uttar Pradesh, India.

Materials and Methods

Periodical surveys were conducted in major vegetable groups, *viz*., solanaceous (brinjal, tomato), cruciferous (cabbage, cauliflower), cucurbitaceous (bottle gourd), malvaceous (okra) and leguminous (pea) in and around the experimental farm of ICAR-Indian Institute of Vegetable Research (82°52' E longitude and 25°12' N latitude), Varanasi, Uttar Pradesh, India and also from adjoining districts of Mirzapur, Sonebhadra and Deoria. The experimental sites at Varanasi are under the alluvial zone of Indo-Gangetic plains with soil which is silt loam in texture with low inorganic carbon (0.43%) and available nitrogen (185 kg ha^{-1}). Pest monitoring surveys were conducted throughout the year during 2009-2018.

Different stages of major insect pests of these crops along with its host plant(s) from various vegetable ecosystems were collected and brought to the biocontrol laboratory and reared on their natural food under laboratory conditions of 28±2°C temperature, 70-80% relative humidity and a photoperiod of 13:11 (L:D) hour. Regular observations were made for emergence of any parasitoid(s) from them, if any. After emergence of the parasitoids from their hosts they were assessed and preserved in 70% ethanol. Some specimens were sent to the National Pusa Collection, Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi for identification and deposition of voucher specimens. Seasonal incidences of these parasitoids were recorded by periodic collection of host insects from their respective crops and percent parasitization was computed by the following formula throughout the crop growth period.

$$\text{Percent parasitization} = \frac{\text{Number of parasitoids emerged}}{\text{Total number of host insects collected}} \times 100$$

Results and Discussion

During the present study, a total of seventeen parasitoid species were recorded from the major vegetable insect pests (Table 1.). They were identified as *Aenasius arizonensis* (Girault), *Diaeretiella rapae* (McIntosh), *Pediobius foveolatus* (Crawford), *Campoletes chloridae* (Uchida), *Apanteles paludicole* Cameron, *Trathala flavo-orbitalis* Cameron, *Cotesia plutellae* (Kurdjumov), *Chelonus blackburni* Cameron, *Agathis* spp., *Microplitis tuberculifer* (Wesmael), *Cotesia glomerata* (Linnaeus), *Neochrysocharis formosa* (Westwood), *Dinarmus basalis* (Rondani), *Apanteles obliuquae* (Wilkinson), *Meteorus* sp., *Brachymeria lasus* (Walker) and *Pristomerus euzopherae* Viereck. Perusal of the parasitoids *vis-à-vis* their host indicated highest affinity (70.59%) towards lepidopteran host insects (*Earias vittella* (Fabricius), *E. insulana* (Boisduval), *Helicoverpa armigera* (Hubner), *Diaphania indica* (Saunders), *Plutella xylostella* (Linnaeus), *Leucinodes orbonalis* Guněe, *Sphenarches caffer* (Zeller), *Spilosoma obliqua* (Walker), *Spodoptera litura* (Fabricius)) followed by coleopteran (*Henosepilachna vigintioctopunctata* (Fabricius), *Epilachna dodecastigma* (Wiedemann), *Callosobruchus chinensis* Linnaeus, *C. analis* (Fabricius), *C. maculatus* (Fabricius)) and hemipteran hosts (*Phenacoccus solenopsis* Tinsley, *Myzus persicae* (Sulzer), *Brevicoryne brassicae* (Linnaeus), *Lipaphis erysimi* (Kaltenbach)) (11.77% each). Only one parasitoid (5.88%) *viz*., *Neochrysocharis formosa* (Westwood) has a dipteran host *i.e., Liriomyza trifolii* (Burgress).

Monthly distribution of parasitoids abundance revealed that highest diversity of parasitoid (15.25%) in terms of species number occurred during the month of September coinciding with the autumn seasons in Northern India particularly Indo-Gangetic plains followed by February, March and August (13.5% each). However, during the month of May only one parasitoid *i.e., P. euzopherae* was recorded from the vegetable ecosystem. Thereafter June (3.4% occurrence) onwards abundance of parasitoids gradually increased until September and again declined during the months of November (3.4%), December (5.1%) and January (8.5%) possibly due to severe winter condition in the region. Critical observations also unveiled the fact that generally maximum parasitoids were recovered during the second fortnight of January *i.e.,* with the receding winter. Since, highest parasitoid activity was recorded during February, March and September months so, precaution should be taken to select chemical insecticides which are safer/compatible to these important parasitoids and emphasis for use of biopesticides including botanicals should be given. Efforts should also be directed for *in-situ* conservation, mass rearing and periodical release of these bioagents. The details of the bionomics of the pests and the parasitoids are being discussed crop wise below.

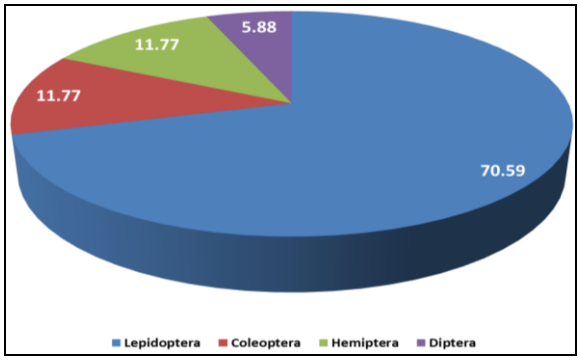

Fig 1: Occurrence (%) of different parasitoid orders in the vegetable ecosystem

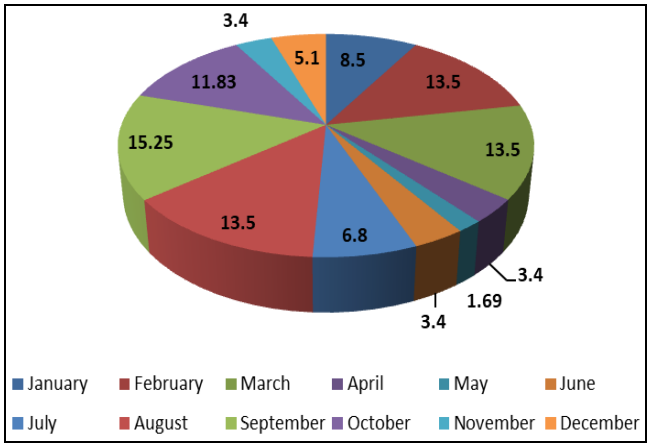

Fig 2: Monthly abundance (%) of different parasitoids in the vegetable ecosystem under eastern Uttar Pradesh condition

Solanaceous vegetables (Eggplant, Tomato)

Eggplant: Brinjal shoot and fruit borer, *Leucinodes orbonalis* (Pyralidae: Lepidoptera); brinjal stem borer, *Euzophera perticella* (Pyralidae: Lepidoptera); Hadda beetle or *Henosepilachna vigitioctopunctata* and *Epilachna dodecastigma* (Coccinellidae: Coleoptera) were recorded as major in this region. Apart from these, sporadic incidence of Bihar hairy caterpillar, *Spilosoma obliqua* (Noctuidae: Lepidoptera) which was also recorded causing serious damage as a sporadic foliage feeder. The important parasitoids parasitizing these major pests of brinjal were recorded as follows

***Trathala flavo orbitalis* Cameron (Ichneumonidae: Hymenoptera)**

Trathala flavo-orbitalis is one of the important parasitoid causing considerable larval parasitization of brinjal shoot and fruit borer, *Leucinodes orbonalis* [13, 37]. Being deuterototokous (uniparental) *i.e.*, produces maximum number of females (more than 90 percent) and few males; thus having a great biocontrol potential against *L. orbonalis*. Its incidence was noted 33rd standard meteorological week (SMW) (third week of August) onwards and continued till 8th SMW (last week of February). Highest parasitization (17.25%) was recorded during 42nd SMW (third week of October) whereas during second fortnight of December to first week of January its activity reduced possibly due to chilly winter in North India. Like many other endoparasitoids, it also pupates outside the host insect within whitish silken cocoons and pupal periods lasted for about 4-7 days depending upon the environmental conditions. Apart from India, its activity has also been reported from Sri Lanka where a high level of parasitism was reported [38] and Bangladesh.

***Pediobius foveolatus* (Crawford) (Eulophidae: Hymenoptera)**

Hadda beetle or *Henosepilachna vigitioctopunctata* and *Epilachna dodecastigma* (Coccinellidae: Coleoptera) are well-known pests of eggplant and potato while are minor pests of cowpea. Recently, its serious incidence was reported in cowpea as foliage feeder in many parts of the country particularly eastern Uttar Pradesh and Bihar [35]. More than 80 percent leaves were infested by the grubs and adults of this beetle on cowpea during summer season. A hymenopteran gregarious endo-parasitoid *Pediobius foveolatus* was recovered. This parasite was recorded as a larval pupal parasitoid of *Epilachna* beetle causing 36.6 percent mortality of the pest in the Varanasi region, Uttar Pradesh. Highest number of parasitized grubs were recorded during the last week of September (4.9 dead grubs/plant) followed by September second week (4.5). Thereafter the population decreased gradually. Parasitized grubs can be clearly identified by their sluggish movement, blackened abdomen which finally mummified with a hollow silt abdomen. A maximum of seventeen *Pediobius* adults (of which > 65% were female) could be recovered from the intersegmental portion on the ventral side of a single mummified grub with an average of 7.56 adults per grub.

***Pristomerus euzopherae* Viereck (Hymenoptera: Ichneumonidae)**

The Ichneumonid endoparasitoid, *Pristomerus euzopherae* was recorded associated with this brinjal stem borer, *Euzophera perticella* (Lepidoptera: Pyralidae) in and around Varanasi. The adult female is 7.5 to 8 mm long (excluding ovipositor). The body is pale yellow with mandibular apices, claws, antennal flagellum and bases of all gastral segments black, mesothorax with three black patches. Head and thorax punctuate, gastral segment I and II aciculate. Wings are hyaline, all veins and stigma are dark. Antenna was extending to almost apex of post petiole. Fore and mid legs are pale yellow, hind legs with black patches, hind femur with a distinct spine [15]. The parasitization by *P. euzopherae* was recorded first during the second fortnight of April when only 1.91% *E. perticella* larvae were parasitized. From April onwards, rate of parasitization gradually increased and the highest parasitization (12.48%) was recorded during July followed by June (7.73%). The adult female parasitoid began to oviposit from the first day onwards. In the act of oviposition, the female arched her abdomen to penetrate its ovipositor into the host larvae residing inside the stem for egg laying. The lifespan of *P. euzopherae* females ranged from 7.5-13.75 days with an average of 10.63 days under laboratory conditions.

***Apanteles obliquae* Wilkinson and *Meteorus* sp. (Braconidae: Hymenoptera)**

Two larval endoparasitoids recovered from Bihar hairy caterpillar, *Spilosoma obliqua* (Noctuidae: Lepidoptera) infesting field bean, cowpea, cabbage and summer squash were identified as *Apanteles obliquae* and *Meteorus* sp.. Gravid female of *A. oblique* lay eggs in batches (gregarious) on early instars (first, second and seldom third) larvae. Upon hatching, parasitoid larvae fed on the internal body contents of the host larvae and before pupation they came out and finally spun a spindle shaped whitish cocoon outside the host body. The highest cumulative parasitization (22.5%) by these endoparasitoids was recorded during the 10th SMW *i.e.*, second week of March, 2014 followed by 9th SMW (first week of March) with 13.5% parasitization. The percentage of parasitization of *Diacrisia* (=*Spilosoma*) *obliqua* by *A. obliquae* in the field was 5.27-19.5% [28]. *Meteorus* sp. is a solitary, koinobiont parasitizing on *S. obliqua.* Its cocoon, generally adhering on the host plants, is elongated and blackish brown in colour slightly tapering at both the ends. Adult parasitoids emerged after cutting a circular lid at one end of the cocoon. *Meteorus* sp. was recorded from *S. obliqua* affecting sunflower crops in Punjab [42] and on cultivated *Vigna mungo* and wild *Xanthium strumarium* in Jammu and Kashmir [8]. In another study it was also documented that *M. spilosomae* causes heavy mortality of *S. obliqua* caterpillars with an average mortality ranging from 3.7% to 33.5% [30].

Tomato

Tomato crop was attacked by a large number of insect pests throughout its growth period and among them tomato fruit borer, *Helicoverpa armigera* (Noctuidae: Lepidoptera); tomato leaf miner, *Liriomyza trifolii* (Agromyzidae: Diptera); solenopsis mealybug, *Phenacoccus solenopsis* (Pseudococcidae: Hemiptera) were found to be important for this region. The following parasitoids were recorded parasitizing these major pests.

Campoletis chlorideae **(Uchida) (Ichneumonidae: Hymenoptera)**

Gram pod borer or *Helicoverpa armigera* is a well-known polyphagous pest collectively attacking a wide range of food, fibre, oil and fodder crops as well as many horticultural and ornamental crops [21, 23]. Amongst the vegetables, its seriousness was observed in crops like tomato, chilli, pea, cowpea, field bean, French bean etc. A solitary endoparasitoid *Campoletis chlorideae* was recorded during January to March in Varanasi, Uttar Pradesh from *H. armigera* when it fed on pea (*Pisum sativum*). After parasitization, the egg hatches in 1-1.5 days inside the host larvae, and parasitoid maggots feed on the content of the host larva and completes development on 6-8 days [40]. The parasitized larvae generally died before attaining the fourth instar stage and a whitish elongated silken cocoon was this is wrong visible from outside the body of the larva. Highest parasitization of *H. armigera* larvae (17.63%) by this endoparasitoid was recorded during 8th SMW *i.e.,* last week of February, 2012 followed by third week (14.68%) and second week (12.82%) of February. However second fortnight of March onwards with the gradual increase of atmospheric temperature its incidence decreased.

Neochrysocharis formosa **(Westwood) (Eulophidae: Hymenoptera)**

Neochrysocharis formosa is a solitary, arrhenotokous, synovigenic, idiobiont endoparasitoid attacks the eggs or larvae of serpentine leaf miner, *Liriomyza trifolii*, a polyphagous dipteran pest, and thereby prevent any further development of the host. This is a generalist parasitoid, known from a very wide range of hosts, including Agromyzidae (Diptera); Chrysomelidae, Curculionidae (Coleoptera); Cimbicidae, Diprionidae, Pamphiliidae, Tenthredinidae (Hymenoptera); Argyresthiidae, Coleophoridae, Elachistidae, Gelechiidae, Gracillariidae, Lyonetiidae, Nepticulidae (Lepidoptera) [33, 34]. In vegetable ecosystem its occurrence was recorded from December to March on tomato as well as marigold when the latter was grown as a trap crop for tomato fruit borer, *Helicoverpa armigera*. Host mediated variation was observed and higher parasitization (48.3%) was on *L. trifolii* feeding on marigold during January – March followed by tomato with 37.5 percent parasitization during December to March [1] at the experimental farm of IIVR, Varanasi.

Aenasius arizonensis **(Girault) (=*Aenasius bambawalei*** **Hayat) (Encyrtidae: Hymenoptera)**

During recent years, solenopsis mealy bug, *Phenacoccus solenopsis*, an invasive, emerging, polyphagous pest has been observed in serious proportion on a number of solanaceous, malvaceous and cucurbitaceous vegetables and other crops including many weeds [19, 36]. A solitary, nymphal endoparasitoid was identified as *Aenasius arizonensis* (=*Aenasius bambawalei*) from this mealy bug. Parasitized mealy bug could be identified easily by the presence of brownish oval-shaped cocoon on its body which later transformed into dark reddish-brown mummies. Efforts were also directed to study the host plant mediated interaction of this mealy bug and its parasitoid. Highest cumulative parasitization (35.67 percent) by *A. arizonensis* on *P. solenopsis* was on tomato followed by okra (30.45%) and chilli (20.67%) whereas lowest was on pointed gourd (13.33%) and brinjal (17.33%) [16]. Earlier, many workers [31] also documented *A. bambawalei* as a prominent parasitoid present all over India throughout year with parasitization potential from 5-100 percent, average 30 percent depending upon season and host on which mealybugs fed. Along with this endoparasitoid, its Aphelinid hyperparasitoid *Promuscidea unfasciativentris* Girault was also recovered and a tritrophic interaction *viz*., mealy bug – *Aenasius arizonensis* - *Promuscidea unfasciativentris* was recorded in the vegetable ecosystem. Presence of the hyperparasitoid could be reducing the parasitic activity of *A. arizonensis* under field conditions.

Malvaceous vegetable (Okra)

Amongst the major insect pests of okra, okra shoot and fruit borers (*Earias vittella* and *E. insulana*) (Noctuidae: Lepidoptera) are of much significance and caused extensive damage to fruits resulting in 69% yield loss [2]. Their infestation started from the beginning of the crop growth and damage due to the borers varied from 21.33 to 43.99% in shoots and 21 to 51.3% in case of fruits. The following duo parasitoids were recorded causing significant natural control of the borer during *Kharif* season.

Chelonus blackburni **Cameron and *Agathis* sp. (Braconidae: Hymenoptera)**

A solitary, arrhenotokous, egg-larval parasitoid of okra shoot and fruit borer, *Earias vittella* and *E. insulana* (Noctuidae: Lepidoptera), a serious pest of okra [10] and cotton, *Chelonus blackburni* laid eggs on the sky blue coloured eggs of *Earias* and completed its egg and larval period inside the host insect's body and pupated outside its hosts. Its incidence was recorded during the August – October in and around Varanasi with maximum 19.58 percent parasitization during the second week of September. During early instars (first and second) of the host, larval parasitoids fed as an endoparasitoid within the developing host's larvae whereas during third–instar stage of its host it exits and starts to feed externally. The parasitoid pupates within a silken cocoon within the host's pupal cell after devouring the entire host except the exoskeleton and head capsule. Parasitized host larvae show sluggish movement, reduced feeding and retarded growth. Being uniparental and parthenogenetic, it has an added advantage as a potential biocontrol agent. Along with *C. blackburni* another braconid, larval endo-parasitoid *Agathis* sp. also occurred during August - September on okra shoot and fruit borer, *E. vittella* and *E. insulana.* However, its biocontrol potential is yet to be explored.

Cruciferous vegetables (Cabbage and cauliflower)

Cole crops *viz*., cabbage and cauliflower were attacked by a number of insect pests. Polyphgous insect pests like tobacco caterpillar, *Spodoptera litura* (Noctuidae: Lepidoptera); aphids, *Lipaphis erysimi*, *Myzus persicae* and *Brevicoryne brassicae* (Aphididae: Hemiptera) and oligophagous diamondback moth (DBM), *Plutella xylostella* (Plutellidae: Lepidoptera) were found to be important and caused serious

damage almost throughout the crop growth period. The following parasitoids were recorded during the course of study from Varanasi and its adjoining districts.

Cotesia plutellae **(Kurdjumov) (Braconidae: Hymenoptera)**

The diamondback moth (DBM), *Plutella xylostella*, is considered as one of the most serious pests of cruciferous crops such as cabbage, cauliflower, knolkhol, broccoli, Brussel's sprout, kale and oil seed crops like mustard and rapeseed in many parts of the world. Generally the incidence of *P. xylostella* on one or the other host crop occurs from the months of September to April at Varanasi. A prominent, solitary, larval endo-parasitoid *Cotesia plutellae* was recorded during January to April. A host-mediated interaction was observed as higher parasitization (25.75%) was noted on DBM collected from cauliflower followed by cabbage (22.35%). Our present findings are in accordance with earlier study [39] that field parasitization by *C. plutellae* on DBM was highest in cauliflower (56.3%) followed by cabbage (53.3%) whereas lowest was on Kale (23.4%). Parasitization rate was higher in late sown cauliflower and parasitoid activity increased second fortnight of February (7 and 8th SMW) onwards and continued till the first week of April (14th SMW) till the onset of spring. Critical observations also revealed that the koinobiont, *C. plutellae* mostly preferred the early instars of the DBM larvae (L1, L2 and L3) and they completed their egg and larval periods as endo-parasitoid before the host larvae reached fifth instar or the pre-pupal stage. Characteristic whitish silken oval cocoon attached to the plant surface or host body were recovered from the dead larvae. However, it was also [41] found that food consumption by *P. xylostella* increased after parasitism by *C. plutellae* and thereby caused more damage as expected.

Microplitis tuberculifer **(Wesmael) (Braconidae: Hymenoptera)**

Spodoptera litura (Noctuidae: Lepidoptera) is a well-known polyphagous pests infesting vegetables like tomato, chilies, cabbage, cauliflower, French bean etc. A solitary, koinobiont, larval endoparasitoid *Microplitis tuberculifer* was recorded from the third instar larvae of *S. litura* infesting cauliflower during the month of October-November, 2014. Highest parasitization (7.55%) was recorded during 43rd SMW followed by 44th SMW (5.11%) [17]. The parasitoid has great potential as a biological control agent as they can parasitize host larvae early and mid in development, most preferably first or second instar, and allow them to grow and finally kill the larvae before reaching its pupation. However, unlike other koinobionts, *M. tuberculifer* allows the host to grow and continue feeding for some time and therefore plant damage may continue. Female *M. tuberculifer* showed a preference for second instar hosts of *Mythimna separata* (Noctuidae: Lepidoptera) exhibiting highest relative suitability, with first and third instars approximately of equivalent second choice [4]. Late fourth and fifth instar larvae were generally not preferred by the parasitoid as late instars even though providing more nutritional resources to the parasitoid but also offered higher level of physiological resistance [24, 29].

Diaeretiella rapae **(McIntosh) (Braconidae: Hymenoptera)**

Diaeretiella rapae is a common, solitary, cosmopolitan endoparasitoid of various aphids, a major sucking pest of vegetables. Being polyphagous, its host range includes almost all the vegetable aphids *viz*., *Lipaphis erysimi* infesting Indian mustard (*Brassica juncea* (L) Czern.), *Myzus persicae* feeding on cauliflower (*Brassica oleracea* var *botrytis* L), *Aphis craccivora* on field bean (*Lablab purpureus* (L.) Sweet), *Brevicoryne brassicae* on cabbage (*Brassica oleracea* var *capitata*), *Aphis spiraecola* Patch on eggplant (*Solanum melongena* L) [12, 22, 14, 9] during the month of January to April in the region. However, it preferred cruciferous aphids, *viz*., *Myzus persicae* (59% parasitization) followed by *Brevicoryne brassicae* (51%) and *Lipaphis erysimi* with 46 percent parasitization [20]. Our earlier study also revealed that, amongst the cruciferous aphids, highest parasitoid emergence was observed from *L. erysimi* (88%) followed by *B. brassicae* (81%) and *M. persicae* (80%) [20]. The parasitized aphids are easily recognizable from their bulging shiny abdomen. The aphids gradually become mummified and remain sticking to the leaf surface. The parasitoid adults emerge from small holes from the mummified bodies of their aphid hosts.

Cururbitaceous vegetable (Bottle gourd)

Bottle gourd is one of the most popular vegetable of this region and grown almost throughout the year. White plume moth, *Sphenarches caffer* (Pterophoridae: Lepidoptera) and cucumber moth, *Diaphania indica* (Crambidae: Lepidoptera) are among the very few insects that commonly attack this cucurbit crop. The parasitoids recovered from these pests are as follows-

Apanteles paludicole **Cameron (Braconidae: Hymenoptera)**

White plume moth or *Sphenarches caffer* is known as a pest of bottle gourd and many leguminous vegetables including lablab, beans etc. [3, 5, 32]. Larvae of plume moth, *S. caffer* damage the leaves and buds of bottle gourd by scraping the chlorophyll thereby reducing the photosynthetic activity of the plants. However, damage was more severe when they fed on the emerging buds resulting in restricted growth of the buds with characteristic black excreta inside it [18]. A prominent solitary larval endoparasitoid *Apanteles paludicole* was identified from this insect. Whitish oval-shaped silken cocoons adhering to the upper and sometimes on the lower side of the leaves indicated the presence of this braconid parasitoid. Number of parasitoids recovered during the 32nd SMW (second week of August) was 4.3 cocoons/plant and parasitization rate progressed from 33rd SMW onwards and peaked during the last week of August (40.91%) when it reached 8.8 larvae per plant [18].

Cotesia glomerata **(Linnaeus) (Braconidae: Hymenoptera)**

Being a polyphagous larval endoparasitoid, gravid *Cotesia glomerata* females oviposit in the early instar larvae (first and second) of cucumber moth, *Diaphania indica* (Crambidae: Lepidoptera) infesting cucumber and bitter gourd [11]. One host larva can be parasitized by more than one female wasp resulting in superparasitism. Parasitoid larvae continued to develop within the host till the host larvae attained its late fourth or fifth instar stage. Just before pupation the parasitoid larvae chew holes on the sides of their host body, crawl out, drop and spin whitish silken cocoons next to the dying host. Parasitoid activity was recorded during September – October in and around Varanasi with highest larval parasitization of 28.34 percent during the third week of September (38th SMW).

***Brachymeria lasus* (Walker) (Chalcididae: Hymenoptera)**
A solitary, koinobiont, pupal endoparasitoid *Brachymeria lasus* was recovered from *Diaphania indica* (Crambidae: Lepidoptera) infesting bitter gourd and cucumber at Varanasi [11].Its parasitization started from August onwards with maximum of 19.2% parasitization during the third week of October. The parasitoid parasitizes host larvae in their early and mid-developmental phase, most preferably third or fourth instar, and finally kills the pupae before reaching adulthood [2].

Leguminous vegetable (Pea)
Being polyphagous, the pulse beetles, *Callosobruchus chinensis*, *C. analis* and *C. maculatus* (Bruchidae: Coleoptera) attack a number of leguminous crops including pea during storage. A promising parasitoid *Dinarmus basalis* was recorded.

***Dinarmus basalis* (Rondani) (Pteromalidae: Hymenoptera)**
Pulse beetles, *Callosobruchus chinensis*, *C. analis* and *C. maculatus* (Bruchidae: Coleoptera) are serious pests of garden pea and French bean during storage as they develop within the seeds. *Dinarmus basalis* has been identified as an endemic, solitary, larval-pupal ectoparasitoid of these beetles. Its natural occurrence was noted from July to October with highest parasitization of 33.33 percent during first fortnight of September (36 and 37th SMW). This parasitoid preferred *C. chinensis* and the instar preference was recorded as fourth instar larva < pre-pupa < third instar larva < pupa. However the parasitoid did not parasitize both the first and second instar host larvae [25]. The parasitism and suppressive efficiency of the parasitoid was consequently changed with the change of the density of the parasitoid. Potential of *D. basalis* as a biocontrol agent earlier was documented by several workers [7, 26]. So there is a great scope for exploitation of this native biocontrol agent against this serious store grain pest by artificial mass rearing and release.

Table 1: List of important hymenopterous parasitoids along with their hosts recorded from the vegetable ecosystems

Parasitoid	Host insect	Crop(s)	Major activity	Highest Incidence (%)
Aenasius arizonensis (=*Aenasius bambawalei*)	*Phenacoccus solenopsis*	Tomato, Chilli, Okra, Brinjal	August - March	22.35
Diaeretiella rapae	*Myzus persicae, B. brassicae, L. erysimi*	Cabbage, Cauliflower	January – April	21.60
Pediobius foveolatus	*Epilachna vigintioctopunctata*	Cowpea, Brinjal	August – October	36.60
Campoletis chloridae	*Helicoverpa armigera*	Tomato, Pea	January – March	17.63
Apanteles paludicole	*Sphenerches caffer*	Bottle gourd	June - September	48.33
Trathala flavo orbitalis	*Leucinodes orbonalis*	Brinjal	August – March	17.25
Cotesia plutellae	*Plutella xylostella*	Cabbage, Cauliflower	February – April	22.35 25.75
Chelonus blackburni, Agathis sp.	*Earias vittella, E. insulana*	Okra	August – October	19.58
Microplitis tuberculifer	*Spodoptera litura*	Cauliflower	October – November	7.55
Cotesia glomerata	*Diaphania indica*	Cucumber	September – October	28.34
Neochrysocharis formosa	*Liriomyza trifolii*	Tomato, Marigold	December – March and January – March	37.50 48.30
Dinarmus basalis	*Callosobruchus chinensis, C. analis, C. maculatus*	Pea, French bean	July - October	33.33
Apanteles obliquae, Meteorus sp.	*Spilosoma obliqua*	Cowpea, Field bean, Brinjal	March – April	22.86
Brachymeria lasus	*Diaphania indica*	Bitter gourd, Cucumber	August – October	19.20
Pristomerus euzopherae	*Euzophera perticella*	Brinjal	May- July	12.48

Conclusion
From the above study it is clear that these parasitoids can play an important role in biological control of the major vegetable pests and can be incorporated in integrated pest management programme of them. But before that is done their host-range, bio-ecology, seasonal incidence etc. need to be considered while selecting other management practices particularly synthetic chemical insecticides. Efforts must be directed for their on-farm conservation as well as to develop suitable low-cost mass rearing technology for off-season artificial releases. Compatibility of these bioagents with different microbial insecticides and plant origin insecticides also needs to be tested.

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