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Review Article

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Trichogramma: a Promising Biocontrol Agent

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Abstract

Parasitoids that are able to remove the herbivore from the agroecosystem before larval eclosion are known as egg parasitoids. Mostly they belong to the Hymenopteran order which includes 15 families. Adult of *Trichogramma* spp. is 0.2-1.00 mm in size with body color pale yellow to brown color. Most of *Trichogramma* spp. finds their host through the direct host related cues and indirect host related cues. In general, eggs of all lepidopteran pests are parasitized by *Trichogramma* spp. The black layer inside the chorion of host egg and the exit hole are evidences of parasitism by *Trichogramma.* There are two ways to release *Trichogramma* in the field. One is Trichocard and another one is release as adults. *Trichogramma* species are the most widely exploited and used for pest management across the world among all the egg parasitoids. *T. chilonis*, *T. japonicum*, *T. pretiosum* and *T. achaeae* are the major species of the genus *Trichogramma* and are effective against different pests.

Keywords: Biological control, egg parasitoid, IPM, *Trichogramma*

1. Introduction

Biological control of insect pests is promising as an important component of Integrated Pest Management (IPM) globally, with the realization of environmental and human hazards associated with the use of chemical pesticides. Currently, world agriculture is transforming into a more professional approach, support to eco-friendly pest control techniques as key thrusts in promoting export horticulture and organic farming. Among other different bio-control techniques, a procedure that has shown efficient results in controlling pest outbreaks, mainly from the order Lepidoptera, is the use of egg parasitoids. An insect parasite of an arthropod; parasitic only in its immature stages, destroying its host in the process of its development and free living as an adult is known as parasitoid. Parasitoids that able to remove the herbivore from the agroecosystem before larval eclosion is known as egg parasitoids. So that the preventing hatching of the larvae which are the damaging stages for the crop to be protected. Mostly they belong to the Hymenopteran order (Table 1 and 2) which includes 15 families, among them major families are Trichogrammatidae, Mymaridae and Scelionidae. There were 230 recorded species of *Trichogramma* from USA, India, Brazil, China, and Russia, parasitizing eggs of over 200 insect species belonging to 70 different families (Jalali et al., 2016). In India, various *Trichogramma* spp. are reported, among them major were *T. chilonis*, *T. japonicum*, *T. achaeae* and *T. pretiosum* (Os and Varshney, 2018).

This distribution maps depict worldwide distribution of egg parasitoids, there are six major species of egg parasitoids belonging to three major families. Among them *Trichogramma* spp. is most dominantly spread all over entire world compare to rest of egg parasitoids (Figure 1).

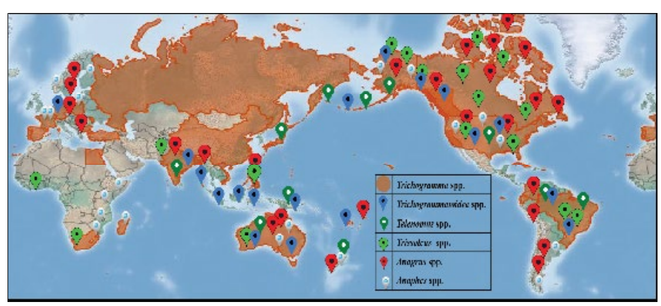

Figure 1: Distribution map of major species of egg parasitoid

2. Morphology of Trichogramma

Generally, in all *Trichogramma* spp., adults are 0.2 to 1 mm

Table 1: Different species of egg parasitoids used for parasitisation

Species of egg parasitoids	Used for parasitisation of host eggs
Trichogramma chilonis Ishii	Sugarcane borers (*Chilo infuscatellus, Chilo sacchariphagus* indicus, *Chilo auricilius, Acigona steniellus*); Cotton bollworms (*Helicoverpa armigera, Pectinophora gossypiella & Earias* Spp.); Maize stem borer (*Chilo partellus*); Diamond back moth (*Plutella xylostella*); Tomato fruit borer (*Helicoverpa armigera*)
Trichogramma japonicum Ashmead	Top shoot borer of sugarcane (*Scirpophaga excerptalis*), Paddy stem borer (*Scirpophaga incertulas*)
Trichogramma achaeae Nagaraja and Nagarkatti	Cotton bollworms and Okra fruit borer (*Helicoverpa armigera*)
Trichogramma pretiosum Riley	Tomato fruit borer (*Helicoverpa armigera*)
Trichogramma dendrolimi Matsumara	Lepidopteran pests on cruciferous crops
Trichogramma evanescens Westwood	*Lepidopteran pests (Agrotis ipsilon, Achaea Janata, Corcyra cephalonica, Etiella zinckenella, Helicoverpa armigera, Heliothis virescens, Spodoptera littoralis, Plutella xylostella* etc..)
Trichogramma mwanzai Schulten & Feijen	*Busseola fusca, Chilo partellus, Eldana saccharina, Ephestia kuehniella, Sitotroga cerealella*
Trichogrammatoidea armigera Nagaraja	Lepidopteran pests (*Achaea Janata, Corcyra cephalonica, Etiella zinckenella, Helicoverpa armigera, Heliothis virescens, Spodoptera littoralis, Plutella xylostella*)
Trichogrammatoidea bactrae Nagaraja	Lepidopteran pests (*Agrotis ipsilon, Achaea Janata, Corcyra cephalonica, Etiella zinckenella, Helicoverpa armigera, Heliothis virescens, Spodoptera littoralis, Plutella xylostella* etc.)
Trichogramma brassicae Bezdenko	Diamondback moth (*Plutella xylostella*) and Cabbage butterfly (*Pieris brassicae*) on cabbage and cauliflower
Trichogramma embryophagum Hartig	Apple Codling moth (*Cydia pomonella*)
Trissolcus basalis Wollaston	Green stink bug (*Nezara viridula*), Red banded stink bug (*Piezodorus guildinii*)
*Anagrus girault*i Crawford	Wheel bug (*Arilus cristatus*), Beet leafhopper (*Circulifer tenellus*)
Anagrus flaveolus Waterhouse	Brown plant hopper (*Nilaparvata lugens*), Maize leaf hopper (*Dalbulus maidis*)
Anaphes fuscipennis Haliday	Clover leaf weevil (*Hypera zoilus*), Alfalfa root weevil (*Sitona discoideus*)
Telenomus remus Nixon	Tobacco leaf eating caterpillar (*Spodoptera litura*)

(Source: Anonymous, 2019)

Table 2: Different species of egg parasitoids introduced in India

Species of egg parasitoids	Used for parasitisation of host eggs
Trichogramma brasiliensis Auctt	Pink boll worm, *Pectinophora gossypiella* (Saunders), *Earias* Spp.
Trichogramma cacaeciae Marchal, *Trichogramma embryophagum* Hartig	Codling moth, *Cydia pomonella* (L.)
Trichogrammatoidea nana Zehntner	Teak leaf skeletonizer, *Eutectona machaeralis* (Walker)
Telenomus nawai Ashmead	Castor semilooper, *Achaea janata* (L.)
Trichogramma brasiliense auctt., *Trichogramma pretiosum* Riley, *Trichogramma semifumatum* Perkins	Old World bollworm, *Helicoverpa armigera* (Habner)
Telenomus remus Nixon	*Spodoptera litura* (Fabricius), Castor semilooper, *Achaea janata* (L.)

Table 2: Continue...

Species of egg parasitoids	Used for parasitisation of host eggs
Telenomus alecto Crawford, *Telenomus nephele* Nixon, *Trichogramma australicum* Girault, *Trichogramma brasiliense* Auctt., *Trichogramma evanescens* Westwood, *Trichogramma dendrolimi* Matsumura, *Trichogramma fasciatum* Perkins, *Trichogramma japonicum* Ashmead, *Trichogramma minutum* Riley, *Trichogramma perkinsi* Girault, *Trichogramma semifumatum* Perkins, *Trichogrammatoidea bactrae* Nagaraja, *Trichogrammatoidea eldanae* Viggiani	Sugarcane borers (lepidopteran pests)

(Source: Anonymous, 2019)

mm in size with body color pale yellow to brown color. Head inclination hypognathous type with chewing type mouth parts. Forewings are wide, covered with small hairs, with longer hairs forming fringe on perimeter of wing. Hindwings are narrower than forewing. Hindwing bearing fringe of long setae along posterior margin. Legs are slender and ambulatorial type (walking type). Each leg consists of coxa, 2 segmented trochanter, femur, tibia, and 3 segmented tarsi it is the major morphological character for identification. Tibiae of legs apically bear well-developed branched spurs. Apical tarsomere bears two claws and well-developed arolium. In both male and female antennae geniculate type (elbo type) while in male hairs were more condensed and elongated than female hairs. Morphologically all *Trichogramma* spp. are more or less like each other. A major advance in the identification of *Trichogramma* was the discovery that characteristics of male genitalia can be used to identify species. This is the primary means of identification today, but body color, wing venation and features of the antennae serve as supporting characteristics. Females cannot be identified with the same level of confidence, so collections submitted for identification must include males (Querino and Zucchi, 2005).

3. Biology of Trichogramma

In all lepidopteran pests, larval hatching occur within 3-4 days but when it is parasitized by *Trichogramma* spp., in those cases after finding a egg, the female drills a hole through the chorion (egg shell) and inserts two to three eggs into the egg. The internal pressure of the bollworm egg forces a small drop of yolk out of the oviposition hole. Females feed on this yolk, which increases their longevity. A venom injected by the female at the time of oviposition is believed to cause this predigestion of the egg's contents. Eggs hatch in about 24 hours and the parasite larvae develop very quickly. There are three larval instars, all sacciform. At the beginning of the third larval instar (3 to 4 days after the host egg was parasitized), the host egg turns black due to the deposition of black granules at the inner surface of the chorion. These are followed by a prepupa, when the adult characters form, and a pupa. Fecundity varies between 20 and 120 eggs female^{-1} according to the species, the host, and the longevity of the adult. Longevity is related to food supply (sugar and water), availability of host eggs, temperature, humidity, and the activity of the female. Under laboratory conditions a female parasitizes from one to ten bollworm eggs day^{-1} or from 10 to 190 during her life span. Large females parasitize more eggs than smaller females. Females which are provided honey and young bollworm eggs to feed on live an average of 11 days, while females receiving only honey live only for three days. The black layer inside the chorion and the exit hole are evidence of parasitism by *Trichogramma* spp. (Samara, 2005).

4. Host Searching Abilities of Trichogramma

Colazza et al. (2009) stated that most of *Trichogramma* spp. finds their host through the direct host related cues and indirect host related cues. Former one is more specific and emitted in lower quantity because it is emitted from direct host egg like contact and volatile kairomones and synomones induced by egg deposition on plant. While letter one are emitted in more quantity but not much specific like host scales and adult traces, host pheromones and allomones from larva or adult and synomones induced by feeding activity of herbivore on plant. Lewis et al. (1982) studied on tri-trophic interaction between maize and natural enemies and reported that 9-heptanol chemical emitted from maize which attracts female adult of *Helicoverpa armigera* for oviposition. After oviposition Tricosane chemical emitted from host egg and scales which cover egg attract *Trichogramma evanescens* for parasitizing. On the basis of morphology and biology, *Trichogramma* spp. are tiny wasp and short life cycle but it's importance of effective against many crops' pest in agroecosystem.

5. Mass Rearing of Trichogramma

For mass rearing of *Trichogramma* spp., generally used host is rice moth (*Corcyra cephalonica*) because it is easy to rear in laboratory and high fecundity. For mass rearing first take half cc eggs (8000–9000) and mixed it with 2.5 kg broken sorghum grains (2–3 pieces) and added 100 g of groundnut kernel powder, 5 g dry yeast powder, 5 g wettable sulphur (for storage mites) and 10 ml streptomycin sulphate (for bacterial infection) and covered the bowl with muslin cloth and put it under controlled conditions. After 40–45 days adult moth emergence starts, collect the adult male and female, transfer it to oviposition cage after 4–5 days collect eggs of rice moth and spread and glued it on trichocard. For killing of host embryo put trichocard in UV sterilization chamber for 45 minutes. Then put 3–4 new trichocards with one nucleus trichocard inside plastic jar and put some honey droplets inside for feeding of adult after 24–48 hours remove the nucleus trichocard. After 3–4 days eggs are turn in black in color that indicate successful parasitization. After 6–7 days trichocard ready to used in field direct or we can store it for 10–15 days at 5–10°C and for month inside freezer (Anon., 2022).

5.1. *Release technique of trichogramma*

In order to release *Trichogramma* at the proper time, the field workers and the rearing facility need to work well together. In the beginning, there are two ways to apply in the field: release on Trichocard and release as adults.

5.1.1. *Release on trichocard*

The *Trichogramma* are carried within grain moth eggs in the pupal stage, ready to become adults. They may be adhered to perforated cards or left unfastened. 20,000 eggs fit into a cubic centimetre, thus loose eggs can be split into paper cups or other containers (ml). There are advantages and disadvantages to using moth eggs that are adhered to cards that contain 100,000 to 120,000 *Trichogramma* each. Each card is divided into 30 hangable pieces, each containing about 3,300 parasitized eggs that can be easily distributed, especially in vines and trees, by hanging them on twigs. Each card can contain up to 100,000 *Trichogramma* and be divided into 30 squares, each containing 4,000 parasites square inch^{-1}, allowing for even dispersion in fields and orchards. There are roughly 20,000 eggs cubic centimetre^{-1} when it comes to loose eggs, which can be separated into paper cups. Each tab on the card has a door hanger-style hook on one end and a nominal 3,300 eggs. The card is perforated to cut into 30 tabs, each measuring 3/4 by 2 inches. In two to five days, depending on the temperature, which should ideally be between 80° and 90°F, *Trichogramma* wasps emerge from cards. Wasps normally emerge in the morning, but it is possible to delay their appearance by keeping parasitized moth eggs at colder temperatures (not less than 40°F). Avoid delaying release once adult wasps emerge to extend the amount of time spent combating pests. Keep *Trichogramma* cards in the shade to avoid exposure to the scorching sun, and adjust *Trichogramma* spp treatment rates based on the height of the crop to identify the best species to use. (Hommay et al., 2002, Li et al., 2007)

5.1.2. *Release as adult*

Superior percentage emergence and survival in the field are benefits for individuals who want to think about utilising loose *Trichogramma* wasps. Depending on the temperature, which should ideally range from 80° to 90°F, the wasps emerge in two to five days. By storing parasitized moth eggs at colder (but not below 40° F) temperatures, the emergence can be postponed. After cold storage, there can be a slight loss of emergence or seeking ability. Typically, male emerging wasps are initially observed in the morning, followed by females and mating activities, and subsequently the males die. After adult wasps emerge, do not postpone releases, and maintain *Trichogramma* in the shade to avoid the intense sun. A variety of containers can be used to incubate loose parasitized eggs (preferably glass or paper over plastic). Loose eggs are sorted into nearly equal amounts and placed in jars, vials, bags, or cups. Where there has been a higher moth activity, large containers can be opened at randomly spaced rows or trees, releasing additional (Wang et al*.,* 2014).

6. Utilization of Different Trichogramma Spp. in Insect Pest Management

6.1. *Trichogramma chilonis ishii*

Introduction of *T. chillonis* @ 50,000 ha^{-1} release^{-1} in the greenhouse and after 10 days of release the lowest densities of diamond back moth larvae observed was 14.7 plant^{-1} in *trichogramma* released treatment while 55.9 plant^{-1} in control plot (Miura, 2003). Inundative releases of *T. chilonis* in sugarcane @ 75,000 ha^{-1} release^{-1}, 6 times from 30 days after planting of sugarcane and 2 times at node formation at weekly interval found significantly lower % dead heart (6.54) and internode borer damage (3.92) followed by release @ 75,000 ha^{-1} release^{-1}, 4 times from 30 days after planting and 2 times at node formation at weekly interval with % dead heart (7.62) and internode borer damage (4.21) and they concluded that inundative releases of *T. chilonis* in sugarcane revealed that the frequency and rate of *T. chillonis* release had played a significant role in the management of sugarcane shoot borers (Visalakshi and Bhavani, 2020). Impact of *T. chilonis* release @ 125000 ha^{-1} starting from 30 days after transplanting of rice and continuously release it 15 days interval for 3 months found that 30 days after transplanting reduction in dead heart % over control was 39 % while after 60 days after transplanting reduction in dead heart % over control was 54.9 % caused by white stem borer, *Scircophaga innotata* (Rahimoon et al. 2021). Minimum shoot infestation % caused by *Leucinodes orbonalis* in brinjal from 15 to 90 days after transplanting with highest reduction of shoot infestation over control 87.87% and minimum fruit infestation % caused by *Leucinodes orbonalis* from 50 to 140 days after transplanting with highest reduction of fruit infestation over control 68.44% when, *T. chilonis* release @ 1,00,000 ha^{-1} reared on *L. orbonalis* egg till 30 generations (Biswas et al., 2021).

6.2. *Trichogramma japonicum ashmead*

Parasitism performance of two *Trichogramma* Spp. on yellow stem borer egg mass in the cage test and found that mean parasitism rates of egg masses were 60.0%±9.1% for *T. japonicum* and 40.7%±7.1% for *T. chillonis*. In contrast, *T. japonicum* wasps showed a significantly higher egg parasitism rate on yellow stem borer eggs (15.8%±22.2%) than *T. chillonis* (2.8%±5.0%). While overall emergence rate for *T. japonicum* was 94.5%, which was not significantly different from that of *T. chillonis* (100%) and sex ratios (measured as proportion of females) were 71.2% for *T. japonicum* and 62.5% for *T. chillonis*, with no difference observed between the two spp. Egg parasitism rate was lower as compared to egg mass parasitism mainly due to yellow stem borer egg mass consist several layers of egg and also special hair cover struture present on it (Tang et al*.,* 2017). Suitability of *Corcyra cephalonica* eggs parasitized with *T. japonicum* as intermediate host against sugarcane borer (*Chilo auricilius*) and revealed that the 900 eggs of *C. cephalonica* parasitized with *T. japonicum* with 100 eggs of *C. auricilius* has highest % parasitized eggs of *C. auricilius* (95.33) and also lesser number of larvae C*. auricilius* emerged (3.00) (Subandi et al*.,* 2017). Higher parasitism % and longetivity of *T. japonicum* was observed when it was reared on floor moth (*Ephestia kuehniella*) due to large size and smooth surface of floor moth eggs it was most suitable for oviposition as compared to different factitious host after 24 h and 48 h and also % was also significantly higher in *T. japonicum* reared on floor moth as host eggs after 48 h. Also higher parasitism of yellow stem borer egg were observed, where *T. japonicum* reared on floor moth egg as compared to other host eggs under field conditions. (Pandi et al*.,* 2021).

6.3. Trichogramma pretiosum riley

Among three *T. pretiosum* strain the highest parasitism %, emergence % and maximum longevity of *T. pretiosum* was observed in TM strain compared to TMC and TLEM strain when reared on *H. armigera* eggs (Carvalho et al*.,* 2017). Highest parasitism efficacy of *T. pretiosum* and *T. embryophagum* against one-day old eggs of *L. orbonalis* compare to old age eggs of *L. orbonalis* and among this two-parasitism efficiency of *T. pretiosum* was greater than the *T. embryophagum* (Niranjana et al*.,* 2018).

6.4. Trichogramma bactrae nagaraja

Mohamed et al*.* (2016) recorded minimum infestation % of pink boll worm and spiny boll worm when inundative releases of *T. bactrae* @ 40000 to 48000 parasitoids feddan^{-1} (feddan=4200 m^2) 4 times at 10 days interval at flowering and boll formation stage of cotton. Highest discovery efficiency % of *T. bactrae* found at 0.35m. away from release point and discovery efficiency % was decreased as distance increased from release point. And more parasitism was observed on 0-2 days old eggs at all distance compared to old age egg of *Tuta absoluta* in tomato greenhouses (Cagnotti et al*.,* 2018). Inundative releases of *T. bactrae* @ 1,50,000 ha^{-1} at two specific crop stage viz., two-time release at flowering stage and three time releases at boll maturation stage at weekly interval recorded % rosette flower (16.96%) compared to control (22.06%) and green boll damage was observed (18.24%) and in control was (22.51%) and at the time of harvesting, open boll damage and locule damage was noticed 7.85% and 4.22%, respectively compared to control 11.03% and 5.32%, respectively (Variya et al*.*, 2021).

6.5. Trichogramma achaeae nagaraja and nagarkatti

Parasitization of tomato pin worm (*T. absoluta)* eggs *Trichogramma* strain^{-1} in laboratory screening tubes on tomato leaflets and among 29 *Trichogramma* strain the *T. euproctidis* 1 (strain), was significantly more efficient than *T. achaeae* (Check). Another relevant strain was T*. evanescens* 5 because of its thelytoky and it showed a similar level of parasitism to *T. achaeae*. Also mean no. of *Tuta absoluta* egg was parasitized by *T. evanescens 1, T. evanescens 2, T. pretiosum* was not significantly different from *T. achaeae.* Parasitization of tomato pin worm (*T. absoluta)* eggs *Trichogramma* strain^{-1} in cages in the greenhouse and among 29 *Trichogramma* strain three strain showed significant parasitization in laboratory condition and able to parasitize *T. absoluta* eggs but *T. achaeae* showed the highest efficiency: 65.967.77% (mean±SEM) as opposed to 19.462.73% (mean ±SEM) for *T. euproctidis*. And they revealed that differences between results under laboratory and greenhouse conditions may be due to both biotic and abiotic parameters (Chailleux et al*.*, 2012).

6.6. Trichogramma evanescens westwood

In the corn field, dispersal ability and parasitization performance of *T. evanescens* on flour moth egg card (each card consists 1200 eggs) was found higher the release point 10.04%, which decreased to 7.10%, 5.98%, 3.46%, 2.98%, and 0.46% at distances of 50, 75, 100, 150, 200 cm, respectively and also highest daily parasitism rate was observed on first day of release at all distances from the release point and daily parasitization rate also decreased, depending on parasitoids age at all distances. In the grapevine field, dispersal ability and parasitization performance of *T. evanescens* on flour moth egg card (each card consists 1200 eggs) was found higher the release point 34.67 %, which decreased as distance from release point increased. And also, highest daily parasitism rate was observed on first day of release at all distances from the release point and daily parasitization rate also decreased, depending on parasitoids age at all distances. *T. evanescens* demonstrated similar dispersal ability on grapevine and corn plants, but there was a 2 m space between the grape plants and many of the parasitoids stayed on the plants; therefore, more parasitization was observed on grapevines than on corn plants (Ayvaz et al*.,* 2007). For the control of the rice stem borer (*Chilo agamemnon*) T*. evanescens* release @ 30,000 wasps feddan^{-1} at two stages which was Max. tillering+ panicle initiation stages have lowest% of white head 2.18% and reduction of white head over control was 84.77% which was significantly not different from insecticides treatment and they revealed that when they calculated the ICBR ratio *T. evanescens* treatment was high ICBR than insecticides (Hendawy et al., 2018).

6.7. Trichogramma dendrolimi matsumara

All *Trichogramma* spp. mostly preferred to parasitize 0-day old eggs as compare to other egg ages while highest parasitizion was performed by *T. dendrolimi* on *M. separata* eggs, and parasitiziton was decreased as egg age increasing. While *T. japonicum* had the highest parasitic rate on 0-day-old eggs, followed by 1- and 2-day-old eggs, but did not parasitize 3-day-old eggs. In general, *T. dendrolimi* had the highest parasitic rate on all host egg ages whereas *T. japonicum* parasitized the least host eggs at all egg ages compared to the other *Trichogramma* species. So they said that *T. dendrolimi* is best for control of *Mythimna separata* among different *Trichogramma* spp. (Hou et al*.,* 2018).

7. Integration with Other IPM Components

Minimum damage by boll worms on bud, boll and on locule basis by *Earias vittella & Pectinophora gossypiella* with obtain highest yield in Biointensive IPM Module (Hand picking of pest stages and putting them in wire screen cage twice during peak incidence, Inter planting of maize Once release of C*. carnea* @ 14000 larvae (2–3 days old) ha^{-1} $week^{-1}$ synchronizing with appearance of the pests, Release of *T. chillonis* @ 1, 50,000 ha^{-1} as per pest incidence. Application of 1 kg ha^{-1} *Bt* when any one of bollworms is seen. If *Helicoverpa* is seen apply *Ha*NPV@ 3×10^{12} POB ha^{-1}. Apply systemic imsecticides spray if necessary for sucking pests) compared to control and insecticides treatment (Anonymous, 2003). Minimum number of *H. armigera* egg 5 $plants^{-1}$, larvae 5 $plants^{-1}$ and lowest tomato fruit damage % with highest % parasitism with obtain highest yield in treatment where *T. pretiosum* @ 50,000 adults ha^{-1} released five times at weekly intervals+*Ha*NPV @ 1.5×10^{12} ha^{-1} 3 sprays-first spray 5 days after release of parasitoids and subsequent sprays at weekly intervals compared to rest of treatments and control (Anon , 2003). Inundative release of *T. chillonis* @ 1,50,000 adults ha^{-1} $week^{-1}$ synchronized with appearance with the bollworms and *C. carnea* @ 14,000 ha^{-1} twice a week recorded minimum % damage by boll worms on bud, boll and on locule basis by *Earias vittella and Pectinophora gossypiella* with obtain highest yield compared to rest of treatments and control (Anon, 2003). Sagheer et al*.,* (2008) reported lowest% increase in infestations of rice leaf folder when treatment of *T. chillonis* integration with *Bt* and Neem found effective in rice compared to rest of treatment and control. Trichocard having 300 parasitized eggs in combination with 45 *Chrysoperla* 2^{nd} instar larvae and neem extract show lowest fruit infestation of *H. armigera* with highest yield and lowest% weight loss 11.04 compared to other treatments and control (Usman et al*.,* 2012).

8. Factors Affecting to Efficacy of Trichogramma

Bueno et al*.* (2010) reported that developmental time of *T. pretiosum* RV reared on *S. frugiperda* eggs from egg to adult (days) were inversely correlated to temperature and were statically different among the treatments, except for 25ºC and 28°C temperatures. The emergence (%) of *T. pretiosum* progeny was also influenced by temperature. The lowest emergence rate was at 32ºC temperature and the highest ones at 18°C and 20°C temperatures. At 22°C, 25°C, 28°C, and 30°C temperatures, the emergence had an intermediate rate and had no statistically significant differences among them. Temperature has no effect either on the sex ratio of *T. pretiosum* and on the number of progenies emerging from each *S. frugiperda* egg. The highest number of parasitized eggs (avg. 30.1) $female^{-1}$ was obtained at 28^{o}C, whereas the lowest number (avg. 7.2) was obtained at 32^{o}C. Under laboratory conditions adult emergence was high in *T. exiguum* as compared to *T. atopovirilia*, *T. pretiosum.* While there are no significant differences in adult longetivity & sex ratio of three spp. Under greenhouse conditions adult emergence was also high in *T. exiguum* as compared to other two spp. And also, there is significant differences in adult longetivity of three spp. But no significant differences in sex ratio of three spp. Under field conditions adult emergence was also high in *T. exiguum* as compared to other two spp. While there are no significant differences in adult longetivity & sex ratio of three spp. (Diaz et al., 2012). Highest parasitization *Trichogramma* spp. on eggs of rice moth, (*C. cephalonica)* was recorded in cotton + sesame 1:1 (10.93%), followed by cotton+sesame 2:1 (6.13%), and cotton+sesame 3:1 (3.73%), activity of *Trichogramma* spp. were found to be greater in cotton intercropped with sesame. Provisioning the parasitoids with intercrops/border crops as sesame will help in sustaining their population in the agricultural habitats to enhance biological control of insect pests (Devi et al*.,* 2020). Interactions between natural enemies and insect pests affected by application of fertilizers, because changes in plant quality through the fertilizer application may therefore affect herbivore characteristics and suitability of them to parasitism (Mohamadi et al*.,* 2017). Safety of newer insecticides on % parasitization of *T. japonicum* as maximum % parasitisation was observed under flubendiamide with 75.33 % followed by azadirachtin > buprofezin > chlorantraniliprole > thiacloprid > thiamethoxam > dinotefuran with 70.00, 66.66, 64.66, 62.00, 60.66 and 59.33 % respectively. However lowest % parasitisation was observed under lambda cyhalothrin with 1.67%. As per the IOBC classification flubendiamide 20 WG, chlorantraniliprole 18.5 SC, buprofezin 25 SC and azadirachtin 5% w/w were categorized under class "harmless" whereas, thiamethoxam 25WG, thiacloprid 21.7 SC and dinotefuran 20 SG were categorized as "Slightly harmful". However, maximum reduction in parasitisation was recorded under lambda cyhalothrin 5 EC (98.20 %) hence categorized as "Moderately harmful" (Pawar et al*.,* 2020). Significant reduction in larval population of cotton bollworms in Multiple Insecticide and High Temperature Tolerant Strain (MIHTTS) of *T. chilonis* plots 0.5 $plant^{-1}$ compared to susceptible strain 0.8 $plant^{-1}$ and in farmer practices 1.2 $plant^{-1}$ also bad open boll $plant^{-1}$ was lesser and higher good open ball $plant^{-1}$, also High yield noticed in tolerant strain compared to susceptible strain and farmer practices. It indicated that tolerant *T. chilonis* survival in the sprayed cotton field and their ability to parasitize the eggs in greater numbers than the susceptible strain and farmer practices. As well as significant reduction in larval population of *H. armigera* on tomato in tolerant strain of *T. chilonis* plots @ 50,000 ha^{-1} $release^{-1}$ 1.5 $plant^{-1}$ compared to susceptible strain 4.8 $plant^{-1}$ and in farmer practices 3.7 $plant^{-1}$ also egg parasitism % was higher in tolerant strain and High yield noticed in tolerant strain compared to susceptible strain and farmer practices. Also, it found to control diamondback moth infesting cabbage when released @ 50,000 ha^{-1} $release^{-1}$ and significant reduction in larval population in tolerant *T. chilonis* plots 0.8 $plant^{-1}$ compared to susceptible strain 2.5 $plant^{-1}$ and in farmer practices 6.2 $plant^{-1}$ also egg parasitism % was higher in tolerant strain and High yield noticed in tolerant strain compared to susceptible strain and farmer practices. It indicated that higher parasitism by MIHTTS compared to susceptible strain could be due to its tolerance to various insecticides in sprayed situation in the field (Venkatesan and Jalali, 2015).

9. Conclusion

Trichogramma species are the most widely exploited and used for pest management across the world among all the egg parasitoids. *T. chilonis*, *T. japonicum*, *T. pretiosum* and *T. achaeae* are the major species of the genus *Trichogramma* and effective against different pests including yellow stem borer of rice, shoot and fruit borer of brinjal, early shoot borer and internode borer of sugarcane, cotton boll worm complex *etc*. There are many factors that affect the field release viz., weather, crop, host, predation, pesticide uses and parasitoid quality. It can be integrated with other IPM components for management of insect pests.

10. Future Thrusts

Need to test safety of pesticides against *Trichogramma* spp. and further development of tolerant strain of *Trichogramma* spp. towards pesticides and climate changes also need of present century. Pre requisite of evaluating role of kairomones and tritrophic interaction in searching behavior of *Trichogramma* spp. Also, essential to understand the nutritional profile of *Trichogramma* spp. for mass rearing and release.

11. References

Ayvaz, A., Karasu, E., Karaborklu, S., Yilmaz, S., 2008. Dispersal ability and parasitization performance of egg parasitoid *Trichogramma evanescens* Westwood (Hymenoptera:trichogrammatidae) in field and storage conditions. Turkish Journal of Biology 32, 127–133.

Anonymous, 2003. Annual report of AICRP on biological control of crop pest and weeds, Anand.

Anonymous, 2019. Retrieved from: https://.nbair.res.in//Biocontrol_Agents/Insects/index.html

Anonymous, 2022. Retrieved from: http://ppqs.gov.in

Biswas, M., Mishra, I., Roy, S., 2021. Comparative efficacy of *Trichogramma chilonis* Bred on *Corcyra cephalonica* and *Leucinodes orbonalis* (Guenee) eggs in controlling shoot and fruit borer in brinjal. International Journal of Current Microbiology and Applied Science 10(02), 1524–1533.

Bueno, R.C.O.D.F., Bueno, A.D.F., Parra, J.R.P., Vieira, S.S., Oliveira, L.J.D., 2010. Biological characteristics and parasitism capacity of *Trichogramma pretiosum* Riley (Hymenoptera, Trichogrammatidae) on eggs of *Spodoptera frugiperda* (JE Smith) (Lepidoptera, noctuidae). Revista Brasileira de Entomologia 54, 322–327.

Cagnotti, C.L., Virgala, M.R., Botto, E.N., Lopez, S.N., 2018. Dispersion and persistence of *Trichogrammatoidea bactrae* (Nagaraja) over *Tuta absoluta* (Meyrick), in tomato greenhouses. Neotropical Entomology 47(4) 553–559.

Carvalho, G., Silva, L.B., Veras, M.S., dos Santos, E.C.B., dos Santos almeida, M.L., Reis, S.S., 2017. Biological parameters of three Trichogramma pretiosum strains on eggs Helicoverpa armigera. Biological Sciences 39(3) 349–355.

Chailleux, A., Desneux, N., Seguret, J., Do Thi Khanh, H., Maignet, P., Tabone, E., 2012. Assessing european egg parasitoids as a mean of controlling the invasive South american tomato pinworm *Tuta absoluta*. PloS One 7(10) 1–8.

Colazza, S., Peri, E., Salerno, G., Conti, E., 2009. Host searching by egg parasitoids: exploitation of host chemical cues. *In Egg parasitoids in agroecosystems with emphasis on Trichogramma.* Springer, Dordrecht 97–147 p.

Devi, S., Ram, P., Rolania, K., 2020. Effect of intercropping on the parasitoids, *Encarsia* spp. and *Trichogramma* spp. in cotton fields, India. Egyptian Journal of Biological Pest Control 30(1), 1–5.

Diaz, M.F., Ramirez, A., Poveda, K., 2012. Efficiency of different egg parasitoids and increased floral diversity for the biological control of noctuid pests. Biological Control 60(2), 182–191.

Hendawy, A.S., Sherif, M.R., El-Sayed, A.A., Omar, A. M., Taha, A.S., 2018. Role of the egg parasitoid, *Trichogramma evanescens* West., release and silica applications in controlling of the stem borer, *Chilo agamemnon* Bles. (Lepidoptera:Crambidae), in rice fields in egypt. Egyptian Journal of Biological Pest Control 28(1), 1–5.

Hommay, G., Gertz, C., Kienlen, J.C., Pizzol, J., Chavigny, P., 2002. Comparison between the control efficacy of *Trichogramma evanescens* westwood (Hymenoptera: trichogrammatidae) and two *Trichogramma cacoeciae* marchal strains against grapevine moth depending on their release density. Biocontrol science and technology 12, 569–581.

Hou, Y.Y., Yang, X., Zang, L.S., Zhang, C., Monticelli, L.S., Desneux, N., 2018. Effect of oriental armyworm *Mythimna separata* egg age on the parasitism and host suitability for five *Trichogramma* species. Journal of Pest Science 91(4), 1181–1189.

Jalali, S.K., Venkatesan, T., Murthy, K.S., Ojha, R., 2016.

Management of *Helicoverpa armigera* (Hübner) on tomato using insecticide resistance egg parasitoid, *Trichogramma chilonis* Ishii in farmers' field. Indian Journal of Horticulture 73(4), 611–614.

Lewis, W.J., Nordlund, D.A., Gueldner, R.C., Teal, P.E.A., Tumlinson, J.H., 1982. Kairomones and their use for management of entomophagous insects. Journal of Chemical Ecology 8(10) 1323–1331.

Yan, Li.J., Coudron, F., Pan, T.A., Zhang, W., Liu, X., 2007. Field release of the parasitoid *Microplitis mediator* (Hymenoptera:Braconidae) for control of *helicoverpa armigera* (Lepidoptera:noctuidae) in cotton fields in northwestern China's xinjiang province. Environmental Entomology 35, 694–699.

Miura, K., 2003. Suppressive effect of the egg parasitoid *trichogramma chilonis* ishii (Hymenoptera: trichogrammatidae) on the population density of the diamondback moth. Applied Entomology and Zoology 38(1), 79–85.

Mohamadi, P., Razmjou, J., Naseri, B., Hassanpour, M., 2017. Humic fertilizer and vermicompost applied to the soil can positively affect population growth parameters of *Trichogramma brassicae* (Hymenoptera: trichogrammatidae) on eggs of *tuta absoluta* (Lepidoptera:gelechiidae). Neotropical Entomology 46(6), 678–684.

Mohamed, H.O., El-Heneidy, A.H., Ali, A.E.G., Awad, A.A., 2016. Non-chemical control of the pink and spiny boll worms in cotton fields at assuit governorate, upper egypt, II-Utilization of the egg parasitoid, *Trichogrammatoidea bactrae* nagaraja. Egyptian Journal of Biological Pest Control 26(4) 807–813.

Niranjana, R.F., Devi, M., Sridhar, R.P., 2018. Comparative study on the efficacy of nine *Trichogramma* species (Hymenoptera:trichogrammatidae) on the eggs of *Leucinodes orbonalis* (Lepidoptera:crambidae). Journal of Entomology and Zoology Studies 6(2), 1051–1056.

Os, N., Varshney, R., 2018. Utilization of trichogrammatid egg parasitoids in pest management. Acta Scientific Agriculture 2, 49–53.

Pandi, G.G.P., Ullah, F., Patil, N.B., Sahu, M., Adak, T., Pokhare, S., Rath, P.C., 2021. Performance of *trichogramma japonicum* under field conditions as a function of the factitious host species used for mass rearing. *Plos one.* 16(8), 1–14.

Pawar, R.D., Sawai, H.R., Thakare, V.S., Wankhade, S.V., 2020. Evaluation of safety of some new insecticides to per cent parasitisation and survival of *trichogramma japonicum*. Journal of Entomology and Zoology Studies 8(3), 685–689.

Querino, R.B., Zucchi, R.A., 2005. An illustrated key to the species of *trichogramma* (Hymenoptera: trichogrammatidae) of brazil. Zootaxa 1073(1), 37–60.

Rahimoon, M.Y., Bukero, A., Chang, B.H., McNeill, M.R., Rajput, A., Lanjar, Z., 2021. *Trichogramma chilonis*, an effective egg parasitoid for control of white stem borer *scirpophaga innotata* (Walker), (Lepidoptera:pyralidae) in rice. Abasyn Journal of Life Sciences 4(1), 51–60.

Sagheer, M., Ashfaq, M., Rana, S.A., 2008. Integration of some biopesticides and *trichogramma chilonis* for the sustainable management of rice leaf folder, *cnaphalocrocis medinalis* (Guenee). (Lepidoptera: pyralidae). Pakistan Journal of Agricultural Sciences 45(1), 69–74.

Samara, R., 2005. Biology, behaviour and genetic diversity of *trichogramma aurosum* sugonjaev and sorokina (Hy menoptera:trichogrammatidae). Doctoral Dissertation Verlag Grauer, Stuttgart.

Subandi, M.U.H.A.M.M.A.D., Setiati, Y., Mutmainah, N.H., 2017. Suitability of *Corcyra cephalonica* eggs parasitized with *Trichogramma japonicum* as intermediate host against sugarcane borer *Chilo auricilius*. Bulgarian Journal of Agricultural Science 23(5), 779–786.

Tang, R., Babendreier, D., Zhang, F., Kang, M., Song, K., Hou, M.L., 2017. Assessment of *trichogramma japonicum* and *T. chilonis* as potential biological control agents of yellow stem borer in rice. Insects 8(1), 19–31.

Usman, M., Inayatullah, M., Usman, A., Sohail, K., Shah, S.F., 2012. Effect of egg parasitoid, *Trichogramma chilonis*, in combination with *chrysoperla carnea* and neem seed extract against tomato fruitworm, *Helicoverpa armigera*. Sarhad Journal of Agriculture 28(2) 253–257.

Variya, M.V., Bharadiya, A.M., Patel, D.R., Kaneriya, P.B., 2021. Inundative release of egg parasitoid *Trichogramma bactrae* in cotton. International Research Journal of Education and Technology 3(1), 31–34.

Venkatesan, T., Jalali, S.K., 2015. Development, characterization and field assessment of multiple insecticides and high temperature tolerant strain of an egg parasitoid, *Trichogramma chilonis* Ishii against crop pests. *In new horizons in insect Science:towards sustainable pest management*. Springer, New delhi, 327–345 p.

Visalakshi, M., Bhavani, B., 2020. Effect of inundative releases of *trichogramma chilonis* in sugarcane. Journal of Biological Control 34(1), 47–51.

Wang, Z.Y., He, K.L., Zhang, F., Lu, X., Babendreier, D., 2014. Mass rearing and release of *Trichogramma* for biological control of insect pests of corn in china. Biological Control 68, 136–144.