IMPACT OF PARASITES, PREDATORS, AND DISEASES ON RICE PESTS[1]

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According to Walker (139), more than one thousand and four hundred species of injurious insects have been recorded as rice pests in the world. Among them, the groups including abundant species, belong to the orders Hemiptera, Coleoptera, Lepidoptera, Orthoptera, and Diptera. Most of the detailed studies of rice pests have been concentrated on the lepidopterous rice stem borers and hemipterous leafhoppers which are widely distributed in the temperate and tropical regions of Asia. In this connection, the role of natural enemies as a cause of population fluctuations of such pests has received much attention during the past fifty years, and many accounts are found in the literature relating either to fragmented records of their natural enemies or detailed ecological and biological studies of some certain parasites and predators. About 100 species of natural enemies, including parasites and predators, as well as diseases, have been recorded from the rice stem borers in Asia, e.g., 56 species from *Chilo suppressalis,* 40 species from *Tryporyza incertulas,* and 16 species from *Sesamia inferens* (8, 13, 16, 17, 26, 35, 39, 63, 65, 84, 89, 109, 111, 124, 130, 144, 146–148).

One of the difficult problems in reviewing the impact of parasites, predators, and diseases on rice pests is that there are many common parasitic species among the rice, sugarcane, and corn borers. But, the writers' policy is to review the more important literature which has a direct connection with the natural enemies of rice pests. As for the enumeration of an exhaustive list of natural enemies of rice pests, the readers may refer to the parasite and predator catalogue published by the Commonwealth Institute of Biological Control and to some other reports of the same nature written by the entomologists enumerated in the citations above.

RATE OF ATTACK BY NATURAL ENEMIES

The literature shows that in the case of natural control of rice pests by parasites, predators, and diseases, the percentage of parasitism or predatism and the infection rate vary a great deal with place, year, and many other factors, ranging from none to 100 per cent. Therefore, it is meaningless to enumerate all of the recorded cases. But, it is of practical value to choose from the past records examples of greatest attack by natural enemies and proceed to the discussion of the utilization of the natural enemies of rice pests. The following table is compiled from the literature to show the degree of attack by natural enemies.

[1] The survey of the literature pertaining to this review was concluded in March 1967.

TABLE I

SOME RECORDS OF HIGH RATES OF PARASITISM, PREDATISM OR INFECTION (MORE THAN 40%) AMONG RICE PESTS

Host	Stage attacked	Percentage attacked	Natural enemy	Country	Reference
Chilo auricilia	Egg	46.4	*Trichogramma minutum*	Malaya	Pagden (103)
Chilo suppressalis	Larva	76.22	*Amphimermis zuimushi*	Japan	Imamura (37)
Chilo suppressalis	Larva	100	*Isaria farinosa*	Japan	Tateishi, Murata (129)
Chilo suppressalis	Larva	50	*Bracon onukii*	Japan	Nawa (87)
Chilo suppressalis	Newly emerged adult	94.98 (♀) 91.83 (♂)	*Lyctocorus beneficus*	Japan	Oho (91, 92)
Chilo suppressalis	Egg	71.09	*Telenomus dignus*	Japan	Okada, Maki, Kuroda (95)
Chilo suppressalis	Egg	80.3 (Egg mass) 62.0 (Egg)	*Telenomus dignus*	Korea	Paik (104)
Chilo suppressalis	Egg	74.0 (1st gen.) 66.0 (2nd gen.)	*Trichogramma japonicum*	Japan	Iyatomi (52)
Chilo suppressalis	Egg	99.7 (1st gen.) 83.5 (2nd gen.)	*Trichogramma japonicum*	Japan	Hidaka (30)
Chilo suppressalis	Egg	49.5	*Trichogramma japonicum*	Korea	Paik (104)
Chilo suppressalis	Egg	70	*Trichogramma japonicum*	China	Tsai (132)
Chilo suppressalis	Egg	80	*Trichogramma minutum*	India	Chopra (14)
Chilo zonellus	Larva	50	*Apanteles chilonis*	Pakistan	Yasumatsu (143)
Chloriona cubana	Nymph Adult	60	*Sogatelenchus mexicana*	Mexico	Pierce (106)
Delphacodes striatellus	Nymph Adult	53.6	*Haplogonatopus atratus*	Japan	Santa, Nambu (113)
Eulema oryzae	Egg	96.67	*Anaphes nipponicus*	Japan	Kuwayama (67, 68)
Leafhoppers	Nymph Adult	70	*Agamermis unka*	Japan	Kobayashi (66)
Leafhoppers	Nymph Adult	80	Araneid spiders	Japan	Kobayashi (65, 66)
Leafhoppers	Egg	80	*Japania andoi*	Japan	Kobayashi (65, 66)
Naranga aenescens	Larva	80	*Apanteles ruficrus*	Japan	Minamikawa (73)
Nephotettix cincticeps	Nymph Adult	53.6	*Haplogonatopus atratus*	Japan	Santa, Nambu (113)

TABLE I—(*Continued*)

Host	Stage attacked	Percentage attacked	Natural enemy	Country	Reference
Nephotettix cincticeps	Egg	90	*Japania andoi*	Japan	Oho (93)
Nilaparvata lugens	Nymph Adult	41.3	*Agamermis unka*	Japan	Imamura (38)
Nezara viridula	Egg	93.8	*Telenomus nakagawai* *Trissolcus mitsukurii*	Japan	Kiritani (61)
Oebalus pugnax	Egg	100	*Telenomus podisi*	U.S.A.	Bowling (7)
Oxya yezoensis *Oxya velox*	Egg	45 (Egg mass) 60 (Egg)	*Scelio muraii* *Scelio tsuruokensis*	Japan	Murai (81)
Pachydiplosis oryzae	Larva	100	*Platygaster oryzae*	India	Khan, Murthy (59)
Pachydiplosis oryzae	Egg	75	*Platygaster oryzae* *Eurytoma* sp. *Neanastatus* sp.	India	Rao (110)
Pachydiplosis oryzae	Egg	76	*Polygnotus* sp. *Neanastatus* sp. Unknown sp.	India	Reddy (112)
Parnara guttata	Larva Pupa	67.1	Parasites	China	Liu (71)
	Larva	62.5	*Pleurotropis* sp.	China	Tsai, Chun (133)
Pelopidas mathias	Larva	60	*Argyrophylax nigrotibialis* *Halidaya luteicornis*	India	Rao (110)
	Larva	45	*Oncophanes hesperidis*	India	Rao (110)
Pseudaletia unipuncta	Larva Pupa	42	Larval and pupal parasites	Russia Far East	Engelhardt (19)
Scotinophara lurida	Egg	95	*Telenomus gifuensis*	Japan	Katsumata (57)
Sogatella furcifera	Nymph Adult	70.58	*Agamermis unka*	Japan	Imamura (38)
Solubea ornata	Egg	62.7 (Egg mass) 61.8 (Egg)	*Telenomus latifrons*	Dominica	Liang (70)
Tryporyza incertulas	Larva	55.5	*Tropobracon schoenobii*	India	Rao (110)
Tryporyza incertulas	Egg	70	*Trichogramma minutum*	China	Tsai (132)
Tryporyza incertulas	Egg	70	*Telenomus rowani* *Trichogramma minutum*	Malaya	Pagden (103)
Tryporyza incertulas	Egg	68.83	*Telenomus rowani*	Formosa	Sonan (122)
Tryporyza incertulas	Egg	50	*Telenomus rowani*	Formosa	Tao (127)

From the above table it becomes clear that the role played by the natural enemies of rice pests cannot be neglected, and many interesting and fruitful fields exist for the study of such beneficial insects and diseases.

BIONOMICS OF SOME NATURAL ENEMIES OF RICE PESTS

The following table (Table II) is compiled to acquaint the reader with the more important natural enemies whose bionomics have been more or less well investigated. Though it is impossible to review all of the bionomic factors of each owing to the limited space, the readers may refer easily to references for the respective natural enemies listed.

SPECIES PROBLEMS AND HOST-PARASITE RELATIONSHIPS

As pointed out by several workers, confusion exists with respect to the specific names and the host relationships of the egg parasites of rice stem borers. In his excellent study on some Asiatic Telenominae, Nixon (90) wrote that "all references to *Telenomus beneficiens* Z. having been bred from hosts other than *Diatraea striatalis* Sn. must be regarded as of doubtful value," and called attention to the important fact that "the name *beneficiens* be restricted to an insect known to be bred from *Diatraea striatalis* Sn," So, it was not until 1937 that the specific names of two species of *Telenomus* which are parasitic upon the eggs of the rice stem borers, were accurately identified as *Telenomus dignus* and *T. rowani*. In 1950, Yasumatsu (142) made a revision of the species, *Telenomus beneficiens* of Japanese authors, which occurs both in Japan and Formosa. All of the former records pertaining to the rearing of *Telenomus* or *Phanurus* species from the eggs of the two species of rice stem borers under the name *beneficiens* should read *dignus* or *rowani,* depending upon the host borers. Furthermore, as pointed out by Yasumatsu (144), *Telenomus dignoides* and *T. rowani* attack only the egg of *Tryporyza incertulas,* while *T. dignus* is specific to the species of the genera *Chilo* and *Chilotraea,* viz., *Chilo auricilia, C. suppressalis,* and *Chilotraea polychrysa*.

The records of *Tetrastichus schoenobii,* an important egg parasite, from the eggs of *Chilo suppressalis, C. zonellus,* and *Sesamia inferens* are also incorrect, because this species is specific to the species of the genus *Tryporyza,* viz., *Tryporyza incertulas* and *T. innotata* (144).

There are many southern Asian references of rearing records, mass production, and liberation experiments of *Trichogramma* species under the names of *T. evanescens, T. minutum,* or *Trichogrammatoidea nana.* The identification of such species in southern Asia is quite doubtful. Judging by the elaborate work on the taxonomy of the species of *Trichogramma* by Quednau (108), it would be desirable for all the records under these specific names to be re-examined. According to his work, the colour development and the length of life cycle of the species of *Trichogramma* with respect to temperature are so variable that it is highly desirable to rear the species under a constant temperature of 30° C and relative humidity 80 per cent, using the egges of *Anagasta kuehniella* as a standard host, if a correct identification is to be made.

TABLE II

SOME NATURAL ENEMIES OF RICE PESTS FOR WHICH THE BIONOMICS AND BREEDING TECHNIQUES HAVE BEEN MORE OR LESS OR WELL INVESTIGATED

Parasite, predator or disease	Host observed or used		Country	Reference
	Species	Stage attacked		
Amauromorpha schoenobii (Ichneumonidae)	*Chilo suppressalis*, *Tryporyza incertulas*	Larva	Formosa	Shiraki (120)
Amphimermis zuimushi (Mermithidae)	*Chilo suppressalis*	Larva	Japan	Kaburaki, Imamura (55)
Anaphes nipponicus (Mymaridae)	*Eulema oryzae*	Egg	Japan	Kuwayama (68)
Apanteles chilonis (Braconidae)	*Chilo suppressalis*	Larva	Japan	Tateishi (128); Mochida, Yoshimeki (76); Drake (18)
Apanteles flavipes (Braconidae)	*Chilo suppressalis*	Larva	Japan	Drake (18)
	Chilo zonellus	Larva	Ceylon	Vinson (138)
	Chilo zonellus	Larva	India	Chandy (9); Mohammad Ali, Prasad (77)
	Proceras sacchariphagus	Larva	Mauritius	Moutia, Courtois (80)
Bracon chinensis (Braconidae)	*Chilo zonellus*	Larva	India	Cherian, Narayanaswami (11); Subba; Rao (123); Rao (110)
	Chilo zonellus	Larva	Ceylon	Vinson (138)
	Tryporyza incertulas	Larva	Formosa	Shiraki (120)
Bracon hispae (Braconidae)	*Dicladispa armigera*	Larva	Pakistan	Alam (4)
Bracon onukii (Braconidae)	*Chilo suppressalis*	Larva	Japan	Nawa (87); Suenaga (125); Hidaka (30); Yasumatsu (145)
	Sesamia inferens	Larva	Japan	Watanabe, Miyatake (141)
Centeterus alternecoloratus (Ichneumonidae)	*Chilotraea polychrysa*	Pupa	India	Rao (110)
Chelonus munakatae (Braconidae)	*Chilo suppressalis*	Egg	Japan	Maki (72); Ishii (40); Hidaka (30); Fujimoto (20)
Chilo iridescent virus	*Chilo suppressalis*	Larva	Japan	Fukaya, Nasu (24); Mitsuhashi (74)
Goniozus indicus (Bethylidae)	*Scirpophaga nivella*	Larva	India	Cherian, Israel (10)
Lyctocoris beneficus (Anthocoridae)	*Chilo suppressalis*	Larva, newly emerged adult	Japan	Oho (91, 92); Hiura (31)
Microgaster russatus (Braconidae)	*Chilo suppressalis*	Larva	Japan	Hidaka (30)
Oospora destructor (Muscardine fungus)	*Chilo suppressalis*	Larva	Japan	Morimoto (78, 79)

TABLE II—(*Continued*)

Parasite, predator or disease	Host observed or used: Species	Stage attacked	Country	Reference
Phorocerosoma forte (Tachinidae)	*Oxya yezoensis*	Larva	Japan	Iwata, Nagatomi (46)
Scelio muraii *Scelio tsuruokensis* (Scelionidae)	*Oxya yezoensis*, *Oxya velox*	Egg	Japan	Murai (81)
Spathius helle (Brachonidae)	*Chilo suppressalis*	Larva	Philippines	Ishii (44)
Stenobracon deesae (Braconidae)	*Chilo zonellus* *Corcyra cephalonica*	Larva	India	Narayanan (85)
	Chilo suppressalis	Larva	India	Alam (3)
	Emmalocera depressella	Larva	India	Alam (3); Narayanan, Chaudhury (86)
Telenomus dignus (Scelionidae)	*Chilo suppressalis*	Egg	Japa	Okada, Maki (94); Otake (99–102)
Telenomus gifuensis (Scelionidae)	*Scotinophara lurida*	Egg	Japan	Katsumata (57); Kawase (58); Hidaka (29)
Telenomus nakagawai (Scelionidae)	*Nezara viridula*	Egg	Japan	Hokyo (33, 34)
Temelucha shirakii (Ichneumonidae)	*Chilo suppressalis* *Tryporyza incertulas*	Larva	Formosa	Shiraki (120)
Tetrastichus ayyari (Eulophidae)	*Chilo zonellus*	Pupa	India	Cherian, Subramaniam (12); Puttarudriah et Shivashankara Sastry (107)
	Chilotraea polychrysa, *Tryporyza incertulas*	Pupa	India	Rao (110)
Tetrastichus schoenobii (Eulophidae)	*Tryporyza incertulas*	Egg	Malaya	Pagden (103)
Trichogramma australicum (Trichogrammatidae)	No mention	Egg	Formosa	Iijima (36)
	Proceras sacchariphagus, etc.	Egg	Mauritius	Moutia, Courtois (80)
Trichogramma chilonis (Trichogrammatidae)	*Chilo suppressalis*	Egg	Japan	Shibuya, Yamashita (119)
Trichogramma japonicum (Trichogrammatidae)	*Chilo suppressalis*	Egg	Japan	Many references from Japan
Trichogramma minutum (Trichogrammatidae)	*Chilotraea polychrysa*, *Tryporyza incertulas*	Egg	Malaya	Pagden (103); Corbett (15)
Trissolcus mitsukurii (Scelionidae)	*Nezara viridula*	Egg	Japan	Kiritani, Hokyo, Kimura (62); Hokyo (32); Nakasuji, Hokyo, Kiritani (83); Hokyo et al. (33, 34)
Tropobracon schoenobii (Braconidae)	*Chilo suppressalis*, *Sesamia inferens*, *Tryporyza incertulas*	Larva	Formosa	Shiraki (120)
	Tryporyza incertulas	Larva	India	Rao (110)
Xanthopimpla stemmator (Ichneumonidae)	*Chilo zonellus*	Pupa	Ceylon	Vinson (138)
	Proceras sacchariphagus, etc.	Pupa	Mauritius	Moutia, Courtois (80)

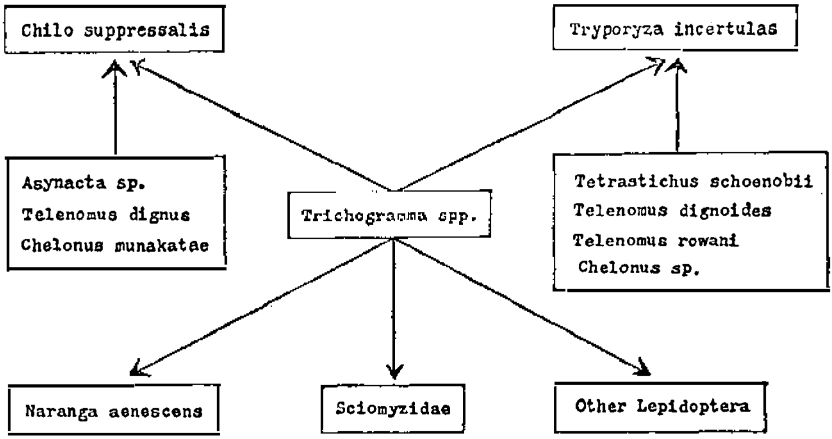

FIG. 1. Relationship between hymenopterous parasites and rice stem borers in the egg stage.

The diagrammatic representation of the relationships between the hymenopterous natural enemies and the rice stem borers (*Chilo suppressalis, Tryporyza incertulas, and Sesamia inferens*) in the egg, larval, and pupal stages is given in detail by Yasumatsu (144) (see Figures 1, 2, 3).

EFFECT OF INTRODUCED PARASITES

Only infrequently have attempts been made to introduce the natural enemies of rice pests from one country to another. In Hawaii, two egg parasites (*Trichogramma japonicum* and *Telenomus dignus*) and three larval parasites (*Bracon chinensis, Eriborus sinicus,* and *Apanteles* sp.) were introduced from Japan and China in 1928 for the control of *Chilo suppressalis* which had been earlier introduced in rice straw packing from Japan. Mass-reared *Trichogramma japonicum* and *Telenomus dignus,* together with the other parasites, were liberated in the paddy fields. All of these species became established and by the following year, the rice harvest returned to normal. It should be remembered, however, that factors other than parasites may have contributed to the reversal. In 1931, *Scelio pembertoni,* an egg parasite of *Oxya* spp. was introduced from Malaysia to help control of *Oxya chinensis.* This parasite has proved to be very effective on the islands (25, 89, 105, 111, 126, 137).

In Japan, *Spathius helle,* a larval parasite of *Chilo suppressalis,* was introduced from the Philippines in 1928, but this parasite failed to become established (45, 89, 111, 119, 140). In 1929, a species of *Trichogramma* was introduced from the Philippines. After being mass-produced, the parasite was released in the paddy field. But it became apparent that this parasite was not of much value as compared with the indigenous egg parasite, *Tri-*

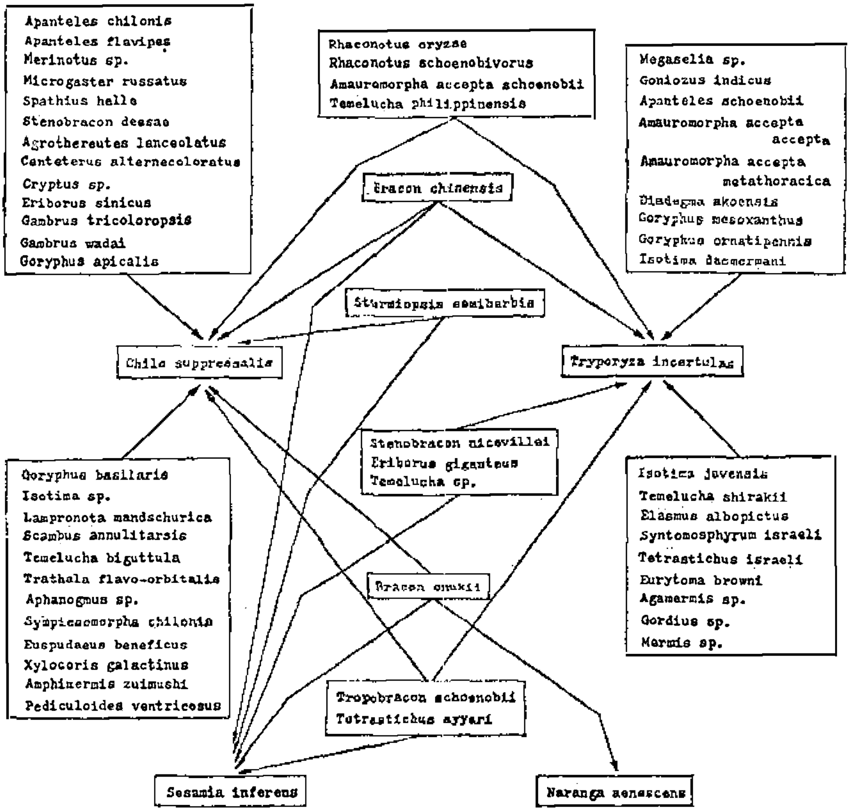

FIG. 2. Relationship between natural enemies and rice stem borers in the larval stage.

chogramma japonicum, as a control agent against *Chilo suppressalis.* Later, Watanabe (140) pointed out that the species in question was the same species as the indigenous egg parasite, *Trichogramma chilonis.*

In the Philippines, the introduced parasites, *Trichogramma japonicum* from Japan, *Trichogramma australicum* from Taiwan, and *Trichogramma minutum* from the United States are considered to be established, but seem to be ineffective. A study of *Lixophaga diatraeae,* an introduced tachinid from Taiwan, against rice stem borers is now under way (5, 89). In Malaysia, the introduction and liberation of *Paratheresia claripalpis,* a tachinid fly of Trinidad origin, was attempted against *Chilotraea polychrysa,* but without success (69, 89). *Bracon chinensis* was introduced in Java from China in 1929–'30 against *Chilo suppressalis,* but was not successful (54, 111, 135). *Apanteles chilonis,* a larval parasite of *Chilo suppressalis,* was introduced in West Pakistan from Japan in 1962. It became established and

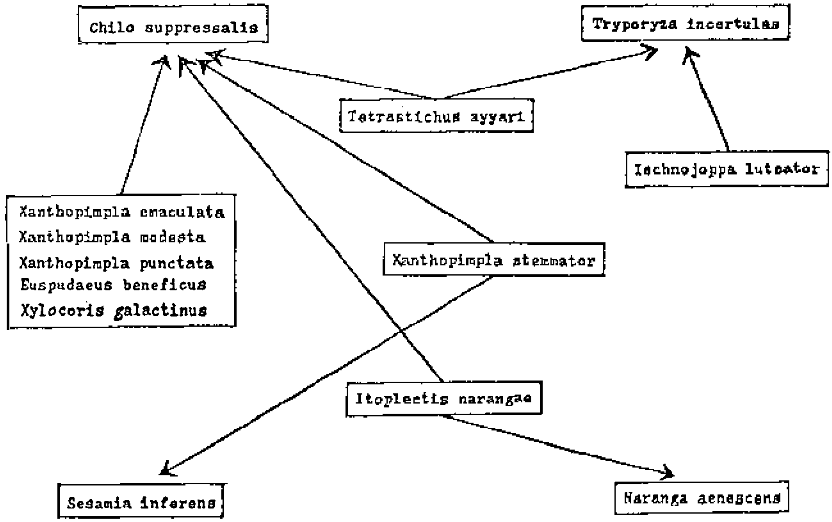

FIG. 3. Relationship between natural enemies and rice stem borers in the pupal stage.

spread rapidly as a larval parasite of *Chilo zonellus,* infesting maize and sorghum instead of *Chilo suppressalis* (89, 111, 143). In the Belgian Congo, tachinid parasites were introduced from Nigeria to control *Eldana sacchari* infesting rice, but these were rendered ineffective by epiparasitism by *Encyrtus* sp. (89). Thus, the review of the literature indicates that there is not a single case of successful control of the rice stem borers by introduced parasites alone.

BIONOMICS AND ECOLOGY OF SOME NATURAL ENEMIES OF SPECIAL IMPORTANCE

Although the literature relating to the studies of natural enemies of rice pests is voluminous, many reports are fragmental and some of them have become quite unreliable in accordance with the development of the taxonomy of natural enemies. Therefore, it is necessary to make a revision of the taxonomy, distribution, and host range of each species, together with a study of its biology and ecology. From the viewpoint mentioned above, the writers decided to review the limited number of specis which have been studied in detail.

TRICHOGRAMMA AND *TELENOMUS* SPECIES, EGG PARASITES OF RICE STEM BORERS

BIONOMICS

Trichogramma japonicum.—This egg parasite passes 15 or 16 generations a year in Yamaguchi Prefecture. The overwintering parasites appear about the end of April and pass one or two generations in the eggs of *Chilo suppressalis* and those of the other lepidopterous insects. From the beginning to the middle of May when *Chilo* moths lay their eggs abundantly, the females prefer to oviposit in *Chilo* eggs, and pass five or six generations in this state. Toward the middle to the end of July when *Chilo* eggs disappear, they resume parasitization of the eggs of the other lepidopterous insects, on which they pass one or two generations. In the interim, between the first and the second generation of the host, *Chilo suppressalis,* eggs of this species will disappear from the paddy field. The gap thus caused will be filled with the eggs of *Naranga aenescens,* which serve as an important host for maintaining the influence of *T. japonicum* (121).

If the seasonal prevalence of *T. japonicum* is expressed indirectly by the fluctuation of its percentage parasitism, it will be found that there is some correlation between this parasitization and the light trap catches of *Chilo* moths or the number of eggs laid by them. On the appearance of the eggs deposited by *Chilo* in its second generation, *T. japonicum* passes four or five generations in them. Some *T. japonicum* individuals pass the winter in the *Chilo* eggs, but others select the eggs laid by other lepidopterous insects and repeat one or two generations, finally overwintering therein as pupae (95, 118). The duration of parasitic life (viz., egg, larva, and pupa) varies with the season of the year. It lasts for about 16 to 17 days in April, but in later months, usually for 7 to 10 days, which is longer by one to three days than the length of the egg stage of *Chilo.* The longevity of the adult is about one week. Under laboratory conditions, the parasite can be reared for as many as 50 successive generations (60). According to Hidaka (30), the parasite repeated 10 generations a year under laboratory conditions from May to September, completing one generation in 10 days at 20° C, on an average. In the field, however, it seemed to have more than 10 generations a year. The sex ratio of this egg parasite approximates to ♀ : ♂ = 3 : 1, the number of females greatly surpassing the males in the field. As the degree of polyparasitism increases, however, the number of males increases as a result of a polyparasitic influence (50, 60). The average number of eggs per female is about 40 (95). There is a positive correlation between the fecundity of this female parasite and its body length. A female emerged from a polyparasitized host egg is small in body size, harbouring a small number of eggs. A female emerging from a monoparasitized host egg has 50.1 eggs on an average; the average number of eggs harboured by a female emerging from a diparasitized host egg decreases to 17.0; the number produced by a female emerging from a triparasitized host egg decreases to 6.5 (50). A similar relation was observed by Hama (28), who found that the female-to-male ratio of this parasite tends to increase at the period when the percentage of parasitism is low, and tends to decrease when the percentage of parasitism is high when this phenomenon takes place in the same year. The same relationship holds true between an area in which the parasitization of this parasite is high and one in which it is low. In the case of *T. japonicum* reared on the eggs of *Anagasta,* we find that the greater the ratio of this parasite to host eggs, the smaller will be the number of females.

Cold storage results in a marked reduction in the percentage pupating, exclusive of those larvae refrigerated on the day before pupation occurs. The percentage of emergence is normal on one week's storage, but is greatly reduced on storage of one month. There is little difference in fecundity between the normal parasite and the one refrigerated for a week on the third to sixth day of embryonic development, or the one refrigerated for a month on the second or the third day of embryonic development. However, fecundity is much reduced on other occasions, especially on one month's cold storage. The rate of infestation is much less among the liberated than among the resident species, probably because of the reduced fecundity of the liberated parasite (119).

The fecundity of *T. japonicum* is affected by cold storage in two ways: (*a*) the effect on healthy host eggs before the parasitic eggs are laid; (*b*) the effect on host eggs already parasitized by *T. japonicum.* This egg parasite is able to parasitize the eggs of *Anagasta,* even when they are under cold storage of 8° C for 30 days, as long as the egg laying occurs within the period optimum for cold storage, that is, within 20 hours after oviposition. The higher the relative humidity, the higher becomes the percentage of parasitism. However, the host eggs must be kept under cold storage conditions around 9° C. The fecundity of the female is gradually reduced as the period of host egg storage is prolonged (*27*). It is very interesting that *T. japonicum* is able to oviposit in a host egg which was kept under cold storage conditions for a fairly long time. When the parasitized host eggs are cold-stored at 3° C, the embryonic development of *T. japonicum* is affected adversely, its fecundity as well as percentage of emergence being reduced considerably (*27*). It was ascertained that the fecundity of this parasite mounts to its maximum when the temperature ranges from 20 to 25° C with a relative humidity higher than 70 per cent. This is an indication that this egg parasite is well-adapted to such a wet environment as a paddy field (*21*). Parthenogenetic reproduction of this species is arrhenotokous, all of the emergents being male.

Trichogramma chilonis.—Reared in the eggs of *Anagasta,* this species passed through a yearly total of 16 generations from June to the beginning of December, 1930, and through 20 generations from March 3 to late October, 1931. None was found to overwinter in host eggs kept in an open insectary, where the minimum temperature was −4.8° C in 1930–31 and −4.4° C in 1931–32, respectively (119). The length of parasitic life in the egg of *Anagasta* varies with the average temperatures of the environment, ranging from 5.5 to 84.5 days. The duration of parasitic life in the egg, though scarcely different in *Anagasta* and the rice stem borer, is found to be prolonged three to five days in *Papilio* and *Dendrolimus,* which have large eggs. The longevity of the adult when deprived of food is usually two days, but it averages five or six days in the female and three or four days in the male when supplied with sugar solution. In the Tohoku district, the first emergence of the adult of *Trichogramma chilonis* was found to range from the beginning of September to November, although its annual generation could not be determined in the field as a result of its very rare occurrence in this district (30). Sexual reproduction in this species produces two or three times as many females as males, but parthenogenesis is arrhenotokous, producing male parasites only. The mated female produces 21.2 offspring on an average, when eggs of *Anagasta* are used as host.

The fecundity of *T. chilonis* is scarcely dependent on the food supply. However, under unfed conditions, more than 80 per cent of oviposition takes place within two hours after emergence, whereas under fed conditions it occurs usually on the first day, though covering two days or more. It was revealed experimentally that the size and fecundity of the mature parasite depends largely on the size of the host egg. The larger the host egg, the larger will be the parasite and the greater its fecundity. When allowed to oviposit in eggs of the rice stem borer, 60 to 70 per cent of *T. chilonis* are sterile, fertile parasites amounting merely to one third of those emerging from the eggs of *Anagasta*. Consequently, the progeny from eggs of the rice stem borer is no more than one tenth of that from the eggs of *Anagasta* (119).

Trichogramma australicum.—The female, when abundantly supplied with host eggs, begins oviposition in the first 24 hours after emergence and continues for two or three days. The total number of eggs laid by a fertilized female is about 40, while a maximum of 65 has been observed. Dissections of fertilized females showed that, within 48 hours after emergence, at least 65 per cent of the eggs are mature. Females that emerged from polyparasitized host eggs are inferior in fecundity as compared with those from monoparasitized host eggs. Females lay their eggs easily on unfertilized host eggs, and although the parasites can develop into adults, their fecundity is much inferior to that of adults which emerge from fertilized host eggs. Parasitized *Proceras* eggs collected in the field usually yielded three adults each, while from eggs of *Olethreutes schistaceana* two were usually obtained. The number of parasites capable of developing within a single host egg seems to depend upon its size, for in the laboratory as many as 17 parasite eggs have been laid in a single *Proceras* egg and, while nearly all hatched, the number of parasites that completed their development was always about three.

The duration of life of the adults, when confined in tubes without host eggs, varies with the temperature and humidity. At 24° C and 80 per cent relative humidity, it is about three days in the absence of food, and five to eight days when raisins are provided. At 32° C and 70 per cent relative humidity, adults live only two days without food and a maximum of four days when fed.

Oviposition occurs only in host eggs that are less than three or four days old. The larvae move actively after hatching and the contents of a host egg are completely consumed after three to four days in summer, regardless of the degree of polyparasitism. The duration of various stages at 23.4° C in *Proceras* eggs is as follows: egg—1 day; 1st to 3rd larval stages —3 days; prepupal stage—1 day; pupal stage—4 days; egg to adult—9 days.

Parthenogenetic reproduction is arrhenotokous, but the fecundity of unfertilized females seems to be reduced, for with 12 virgin females the average number of eggs laid was 8, whereas with mated females under the same conditions it was 40 (36, 80).

Telenomus dignus.—According to Okada et al. (95), this parasite passes eight or nine generations a year in Yamaguchi Prefecture and appears most abundantly from late spring to early summer. The duration of the pre-embryonic period from egg to adult varies with the season of the year, the longest being 24 days, the shortest, 10 days in spring to summer, and in autumn it lasts for about two weeks. The longevity of the adult is generally 15 or 16 days in summer, with a maximum of one month or a little more. This species hibernates as an adult and appears to live among withered grasses. The proportion of males to females is about 1:2. Males appear to emerge most abundantly from eggs laid both at the beginning and at the end of the period of oviposition. The number of eggs laid by one female averages usually about 143, with a maximum of 275 and a minimum of 45. The temperature optimum for the development of this egg parasite ranges from 25 to 30° C; development is retarded at temperatures over 35° C and below 15° C. The moisture requirement for development is as high as 75 to 80 per cent R.H. When immersed in water at about 20° C and 30° C, the parasite was found to survive for five and three days, respectively, in the course of embryonic development (95).

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Rate of parasitism.—The rate of parasitism by an egg parasite can be classified under the following two categories, as far as the egg mass of *Chilo suppressalis* is concerned: namely, the percentage of parasitism of egg masses and the percentage of parasitism of the eggs themselves. These percentages can be calculated as follows (114, 115):

The percentage parasitism, R, of egg masses:

$$R = \frac{\text{Number of parasitized egg masses}}{\text{Total number of egg masses}} \times 100$$

The percentage parasitism, r, of eggs:

$$r = \frac{\text{Number of parasitized eggs}}{\text{Total number of eggs}} \times 100$$

Concerning the relation between R and r, the following formula was derived by Utida (134):

$$\log (1 - R) = - n/m\ r$$

where m is the number of egg masses, and n the number of eggs. According to him, some data pertaining to the parasitism of *T. japonicum* against *Chilo suppressalis* and that of *Telenomus dignus* against *Chilo suppressalis* showed good accordance to this formula. The calculated values of n/m were 2.18 for *T. japonicum* and 1.45 for *Telenomus dignus*, while their theoretical value was 56.2. With respect to the wide discrepancy between these values, he postulated that it originates from the simplified assumption that the egg parasite deposits its eggs quite at random and that no polyparasitism occurs at all. He concluded that the parasites in question do not search their host eggs at random, but do host egg-masses with 2.18 or 1.45 egg-masses as unit. At the advanced stage of embryonic development of trichogrammatid eggs, the parasitized host egg always changes in color, remarkably enough, into black. This metachromic phenomenon in a parasitized host egg can be used as an important clue in discriminating between parasitized eggs and healthy ones.

Local and seasonal variation in rate of parasitism of Trichogramma japonicum.—The average percentage of parasitism of this egg parasite is 33 per cent in the nursery and 83 per cent in the transplanted rice field, in the first generation of *Chilo suppressalis*, 34 per cent in the rice field in the second generation of the rice stem borer, and increases to an average of 50 per cent throughout the year. This percentage is always low at the beginning of both the first and the second generation of *Chilo*. The low rate in the second generation of *Chilo* may be ascribed to the lack of intermediate hosts. The rate at which this wasp parasitizes the first generation tends to increase when the air temperature is high (41, 42). The seasonal fluctuation of the percentage parasitism of this wasp seems to be strongly correlated with that of abundance of *Chilo* (53). According to Ishii (43), however, both the abundance of this hibernating parasite and the air temperature during the period of parasitization are chiefly responsible for such a seasonal fluctuation. It was revealed by four-year observations that the percentage of parasitism on both an egg mass and an egg base tends to increase gradually as *Chilo* approaches later stages in the first generation, while the sex ratio continues to be substantially constant although the values of parasitism vary with the year (43).

Shibuya (116) made an extensive survey over three years of the rate of parasitism of this wasp over 19 Japanese prefectures on the mainland, Shikoku, and Kyushu, and came to the conclusion that the total average percentage of parasitism is 47.3 per cent on an egg mass base, and 19.7 per cent on an egg base, the relation between localities and the rate of parasitism on an egg base being summarized as follows.

The value was less than 10 per cent in areas of the mainland facing the Pacific Ocean as well as the Japan Sea; in localities extending from the middle part of the Kinki district and the southern coast of the Inland Sea of Seto to the southern part of Kyushu, it ranged from 10 to 20 per cent; in Kanagawa, Nagano, Shizuoka, Aichi, and Mie Prefectures it was 20 to 30 per cent; and a value over 30 per cent was recorded in some prefectures facing the Strait of Korea such as Yamaguchi and Nagasaki Prefectures, and Kochi Prefecture in Shikoku Island. It was observed that there seems to be a significantly high correlation between the yearly average temperature in combination with the yearly average moisture in each prefecture, and the percentage of parasitism in each prefecture.

Usually, the level at which *Chilo* is parasitized by *T. japonicum* is low at the beginning of the nursery stage, rises gradually afterward, and finally amounts to more than 40 per cent toward the end of the nursery stage of cultivation (22).

Quantitative relation between parasite and host.—By changing the numbers of eggs of *Anagasta* on which *T. japonicum* oviposits, Fukaya (21) determined the favorable density, to range from 50 to 100 host eggs for inducing the maximum parasitism. Iyatomi (47) also pointed out that the rate of parasitism of this wasp does not increase proportionately to an increase in density of its host, but rather decreases gradually, the relation between the two being governed by the degree of polyparasitism. Examining the ratio between the number of host eggs and that of parasites and the rate of parasitism, Fukaya (22) determined that when the maximum number of eggs parasitized by the wasp is 20, the ratio, 1:30, of the number of parasites to that of host eggs will produce nearly the maximal efficiency in parasitization.

The frequency distribution of the number of eggs parasitized by *T. japonicum* against its host eggs, *Chilo suppressalis,* was analyzed statistically by Iyatomi (48, 49). According to this analysis, either the concentrating distribution or the random distribution resulted when the parasite is low in density, and the intermediate distribution when the number of parasites amounted to more than half of the host. Moreover, it was shown that the quantitative relation between the number of *T. japonicum* and its rate of parasitism can be expressed in two formulae following the Bliss dosage-mortality curve. In polyparasitism, the same relation can be expressed in another two formulae. In both cases, the percentage parasitism must be converted into a Probit value. Based upon these statistical analyses, Iyatomi clarified the quantitative relation between the density of host eggs and the percentage parasitism inclusive of monoparasitism and polyparasitism, and further estimated the number of host eggs necessary for obtaining a certain desired percentage parasitism. From this, it was made clear that a vast number of parasitic wasps must be liberated to increase artificially the rate of parasitism beyond the natural one when the parasitization is kept at a comparatively high level in the field. If this should be done, however, polyparasitism will frequently result and lead to reduction in both fecundity and vitality or to the death of parasites as a natural consequence of intraspecific population pressure. By such liberation, therefore, we cannot expect success in biological control of *Chilo,* but probably merely aid the reduction of the parasite in its next generation. The maximal value of monoparasitism is about 80 to 85 per cent. If the percentage of parasitism increases over this range, monoparasitism decreases in proportion, and polyparasitism increases remarkably in proportion. Therefore, if the percentage of parasitism is increased beyond 85 per cent by the field liberation, the likelihood exists that the percentage parasitism of *T. japonicum* in the field will be lowered in its succeeding generation, contrary to our expectation. On this basis, it may be said that by field liberation we may expect successful biological control of *Chilo* only when the rate of parasitism of this wasp is lower than 80 per cent in the field (49–52).

With the conclusion drawn by Iyatomi (48) as a turning point, the program concerning the utilization of *T. japonicum* was suspended in its entirety. On the basis of modern theory of biological control, however, the problem appears to need re-examination in terms of the possible use of *Trichogramma* as a biotic insecticide.

Population phenomena concerning Trichogramma japonicum *and* Telenomus dignus.—The population phenomena concerning the *Trichogramma japonicum* and *Telenomus dignus* in the rice field were investigated by Otake (96–100, 102) toward the end of the 1950's. Interspecific competition, direct or indirect, was studied at the rice field where these two species coexisted (96). The conclusion was not decisive, but a certain direct interspecific competition was inferred from the fact that both species often parasitize the same egg mass of *Chilo suppressalis,* but seldom coexist in it in a state of high parasitization. On the statistical analysis of other results added soon afterward, however, this inference was denied, as it seemed that both species have no ability to discriminate between healthy host eggs and parasitized ones and, further, that *Telenomus dignus* is killed by *Trichogramma japonicum* when polyparasitism occurs between them. Polyparasitism does not occur frequently, because the number of host eggs parasitized by *T. japonicum* in each egg mass is usually small as compared with the total number of eggs comprising an egg mass, and therefore the majority remains available for parasitization. For this reason both parasites can coexist in the same habitat in the same season, despite the fact that the population of *Telenomus dignus* is checked substantially by that of *T. japonicum* (99).

When there was much variation in density of *Chilo* egg masses in the nurseries under survey, the percentage of parasitism of these two species of coexisting egg parasites did not vary proportionately with the densities of *Chilo* eggs, but varied inversely. Such a phenomenon may be explained on the assumption that the number of adult parasites is substantially constant regardless of the density of *Chilo* egg masses in a rice nursery (98).

In Shimane Prefecture, it seems that these two egg parasites do not appear in rice fields until the end of May, but *T. japonicum* is often observed to parasitize in large numbers of *Chilo* eggs near the end of the first generation. When no *Chilo* eggs are available the eggs of *Naranga aenescens* seem to be of special importance for the perpetuation of *T. japonicum;* probably more so than the eggs of other lepidopterous insects. *Telenomus dignus* disappears almost entirely from rice fields after the middle of June, and is not seen again until the second generation of *Chilo* is established (100).

Further observations were made by Otake (102) on the parasitization by these two egg parasites during the succeeding three years, and the conclusion as mentioned above was confirmed in principle.

Importance of the occurrence of the Sciomyzidae in the paddy field.—Sciomyzid flies are very common in almost all paddy fields of Asia and serve as the important alternate hosts of *Trichogramma* species, when the eggs of the rice stem borer moths are scarce or absent (143, 144). It was ascertained by Otake (101) and Nagatomi & Kushigemachi (82) that the egg of *Sepedon sauteri* is an alternate host of *Trichogramma japonicum* in Japan. Nagatomi & Kushigemachi (82) studied the life history of this fly. According to the study of one of the author's co-workers, the commonest species of *Sepedon* are *sauteri* and *plumbellus.* The former species is widely distributed in Japan, the Ryukyus, Taiwan, Hong Kong, the Philippines, Thailand, Nepal, India, and East and West Pakistan, and *plumbellus* occurs in China, Hong Kong, Thailand, the Philippines, Sumatra, Java, Borneo, Celebes, New Guinea, Burma, and India.

Two Scelionid Egg Parasites of *Nezara viridula*

Telenomus nakagawai and *Trissolcus mitsukurii* have been the most effective biological control agent of *Nezara viridula* in Japan. *Telenomus makagawai* is oligophagous and prefers the large egg masses of pentatomids such as *N. viridula* and *N. antennata. Trissolcus mitsukurii* is polyphagous and prefers the pentatomids which deposit eggs in small egg masses. *T. nakagawai* is unisexual, producing female progeny by parthenogenesis (females constituting 96 to 100 per cent of the population), while *T. mitsukurii* is bisexual (60 to 80 per cent being females) and the first egg deposited by a mated female is always a male. In *T. mitsukurii,* both sexes display aggressive behaviour, but such behaviour does not occur in *T. nakagawai.* The developmental period of the female *T. mitsukurii* at 25° C was shorter by about three days than that of *T. nakaqawai,* which was more prolific and lived longer than *T. mitsukurii.* Both species are endowed with a pronounced ability to evade hyperparasitism (34).

When both species laid their eggs on the same egg mass of *Nezara viri-*

dula in its first generation, the number of *Trissolcus* emerging was always significantly large as compared with that of *Telenomus* (62). From this finding it was concluded that an interspecific competition for the same host egg exists between the two species, and the oviposition behaviour on the part of *Telenomus* was disturbed by the aggressive behaviour of the female *Trissolcus*. The correctness of this conclusion was verified experimentally. It was found that as soon as the female *Trissolcus* occupies the host egg mass, it prevents the female *Telenomus* from approaching by displaying aggressive behaviour, and the oviposition behaviour of the female *Trissolcus* cannot be induced until the female *Telenomus* has disappeared (32).

In order to assess the efficiency of the two egg parasites, *Trissolcus mitsukurii* and *Telenomus nakagawai*, a large number of host eggs were artificially placed in a paddy field and exposed to parasites for a week (83). As mentioned above, these two species compete with each other for the eggs of *Nezara viridula*. The host-searching ability of *Telenomus* was found to be superior to that of *Trissolcus*, and the duration of residence on the host was shorter by the former than by the latter. The percentage of parasitism on an egg mass basis increased more noticeably in *Telenomus* than *Trissolcus* with the increase in their densities. The female *Telenomus* was able to parasitize the host egg masses more efficiently than *Trissolcus* during the limited exposure to the host eggs. From these findings it was concluded that *Telenomus* would be a superior parasite, if no competition with *Trissolcus* existed (32, 61, 83).

TELENOMUS GIFUENSIS, AN EGG PARASITE OF *SCOTINOPHARA LURIDA*

In Japan, *Telenomus gifuensis* passes six generations in southern Kyushu and three generations in central Honshu. The adults overwinter in clumps of dry grasses or in other sheltered places. The length of the life cycle of this species is between 10 and 17 days in Kyushu and between 12 and 19 days in Honshu. The female produces parthenogenetically 75 progeny on an average, all of them males. The average number of eggs laid by the parasite of central Honshu was 82; the average for the unfed and fed parasite of southern Kyushu was 43 and 107, respectively. The ratio of male to female was 1:4.6 in the population brought from central Honshu and 1:3.6 in that from southern Kyushu. The earlier stages of parasitic development are greatly affected by the degree of development of the host embryo, that is, the embryo of the parasite can complete the development on a one- to four-day-old host embryo. If the eggs of the parasite are laid in the egg of a five-day-old host, some can develop but many others may die during embryogenesis. The six-day-old host egg is unable to support the development of the embryo of the parasite.

The eggs of *Scotinophara lurida* were reported to be parasitized by *T. gifuensis* from early June in central Honshu where, during the middle of the month, 55.5 per cent of the host eggs were injured by the parasite, and the percentage of parasitism reached 88.2 per cent at the end of July. On the other hand, in southern Kyushu, the host eggs are parasitized from the end of July, but the percentage of parasitism attains 100 per cent by the end of August.

The central Honshu parasite emerges earlier than that from southern Kyushu. The former was brought to Miyazaki Prefecture and liberated for the study of its effectiveness in the paddy field. The results indicate clearly that the parasite thus liberated is effective in controlling the bugs in southern Kyushu (29, 57).

ANAPHES NIPPONICUS, AN EGG PARASITE OF *EULEMA ORYZAE*

Studies on the biology and liberation of *Anaphes nipponicus,* an egg parasite of *Eulema oryzae,* were carried out by Kuwayama (68). This parasite appears to pass through five or six generations per year in the northern part of Japan. The adults appear in the paddy fields early in July when the oviposition of the rice leaf-beetle has begun, and may always be seen until the middle of August when the oviposition of the beetle ends. Usually the percentage of parasitism is low during the first half of June, then increases gradually until the maximum is reached at the end of July and in early August. The duration of one generation varies from 8 to 13 days. It survives 11 days at 20.3° C of daily mean temperature, and 9 days at 20.7° C. Among 1,608 adults reared in 1934, 70 per cent were females and 30 per cent were males. Thirty-three females were dissected to determine the number of eggs that may be deposited, and 26.3 eggs on an average were found in the ovaries of each. The female attacks only the eggs of the rice leaf-beetle, preferring relatively fresh eggs deposited one to three days previously. Experiments on the introduction of this parasite to unaffected localities were attempted and parasitized egg masses of *Eulema oryzae* collected in paddy fields were transported and protected by the use of an egg parasite-protecting apparatus. It was found that parasitism was higher in the vicinity of the apparatus, the maximum percentage being 25.64. Kuwayama concluded that this method is desirable as one of the most effective measures of control.

SPIDERS AS PREDATORS OF LEAFHOPPERS IN THE PADDY FIELD

A detailed survey of the araneid spiders as natural enemies of leafhoppers was carried out by Kobayashi (66) in Tokushima Prefecture, Japan. About 70 species of spiders belonging to 13 families were found to live in the field under investigation. Approximately one to seven spiders per rice plant hill inhabit the field, and preys upon about two leafhoppers per day during the period July to October. Thus, their predaceous capacity is nearly equivalent to more than the total number of leafhoppers occurring in the paddy field during this period. It was inferred from the rearing experiment that *Oedothorax insecticeps,* which represents 50 to 80 per cent of the spider population, is able to control about 81 per cent of the leafhoppers in the paddy field from the middle of July to the first of August. Furthermore, it was inferred that another spider, *Lycosa pseudoannulata,* has the ability to control about 9 per cent of the leafhoppers during the same period. These relations were demonstrated statistically in the paddy field. Therefore, if chemical control is applied against the *Chilo* population in its first generation, then an abnormal increase in population density of leafhoppers always results, for which the reduction in biotic environmental resistance deriving mainly from the decrease in araneid population density, seems to be responsible.

The role played by the araneid population in the paddy field is not constant throughout the whole period, but its predatory rate decreases gradually from 80 per cent to 40 per cent toward October, decreasing to the point where it is no longer able to control the leafhopper population at the autumn season. When the leafhopper population is reduced in density in autumn as a result of efficient insecticidal application against the *Chilo* population in its second generation, the role of the araneid population as a biological control agent will be restored and will be sufficient to depress the leafhopper density until harvest time.

Diseases

With respect to the pathogens which cause diseases among rice pests, our present knowledge is quite limited, and most of the past studies of these diseases are of little more than academic interest except those observed in *Chilo suppressalis* and *Scotinophara lurida* in Japan (1, 2, 23, 24, 56, 74, 78, 79, 89, 111, 129–131, 143).

The overwintering larvae of *Chilo suppressalis* are often heavily infected with *Isaria farinosa* during the spring season through early summer. This entomogenous fungus infects the larvae before hibernation and causes sclerosis in the larvae which are hibernating within the stems of rice in the field. The conditions which contribute to the high population of spores, and the chances by which the spores contact the larval body, are important in the induction of infection of *Isaria.* It should be noted that little difference in degree of infestation by *Isaria* could be observed with regard to the physiological stage of the hibernating larva or the localities where the materials were collected.

Two kinds of virus diseases have been found in *Chilo suppressalis,* viz., a granulosis virus (BGC) and a *Chilo* iridescent virus (CIV). These are not pathogenic for the silkworm but are quite infectious for the larvae of the rice stem borer.

Recently, the experimental selection and breeding of a *Bacillus thuringiensis* strain which is low in toxicity to the silkworm while remaining high in toxicity to the rice stem borer, has been instituted. This strain possesses weak chitinase, and such a strain will invade through the surface of the insect, as do the fungi, causing septicemia.

Oospora destructor is an efficient muscardine fungus, infective against

Scotinophara lurida, and the field experiments indicate that the effect of this fungus continues until harvest season by natural infection of spores from the mummified bugs. It is of interest that BHC and parathion have no effect upon the activity of this fungus.

ADVERSE EFFECT OF INSECTICIDAL APPLICATIONS UPON THE NATURAL ENEMIES OF RICE PESTS

The adverse effects of synthetic organic chemicals such as BHC, Diazinon®, parathion, and toxaphene against *Trichogramma japonicum, Telenomus dignus,* and *Tetrastichus schoenobii,* the efficient egg parasites of rice stem borers; *Lyctocoris beneficus,* an effective anthocorid predator of *Chilo suppressalis,* spiders, and other natural enemies of leafhoppers (viz., *Japania andoi,* an effective egg parasite, and *Microvelia douglasi,* an interesting and efficient predator), have been reported by several authors in Asia since 1939 (66, 75, 93, 117, 136). In the United States, Bowling (7) reported on his experiments to determine the effect of spray applications on *Oebalus pugnax* in Texas and found that dieldrin gave poor initial control of the bug and apparently interfered with the natural control of parasites.

Yasumatsu (143) discussed the experiments of his co-workers on the effect of insecticides on the rice stem borer, *Chilo suppressalis,* and emphasized the interesting result that a high percentage of parasitism by *Trichogramma japonicum* was gained in paddy fields which had received soil applications of insecticides. This work clearly indicates that certain insecticides selected in accordance with their method of application, allowed the egg parasite to increase to a very high degree and, at the same time, might have reduced the population of *Chilo* larvae within the rice plant by systemic action. Yasumatsu writes that "this data strongly indicates that our future study on the control of rice borers should be focused on the integration of both biological and chemical control."

FUTURE PROSPECT FOR THE UTILIZATION OF NATURAL ENEMIES OF RICE PESTS

Yasumatsu (143) gave the following suggestion for the control of rice stem borers:

> The considerations and reviews mentioned above seem to offer a good possibility of utilizing integration of chemical and biological control. Our present knowledge reveals that the method of application of some insecticides could be used successfully in the paddy field without destroying the natural enemies of rice borers. But, despite the enormous amount of the past research on the rice borer problems, there are still considerable gaps in our knowledge of their natural enemies and much should be done on the artificial use of biotic agents or the positive protection of natural enemies for the purpose of establishing a more ideal method of control of rice borers in the rice cultivated areas.

Nickel (88) published the following opinion on the control of rice stem borers:

Quick or sensational results should not be expected in a biological control effort. Although drastic borer reductions are possible, results may be subtle and will require detailed surveys and ecological studies.

As biological agents will probably not provide complete economic control of rice pests, other control methods must be sought which will be compatible with this approach. Recent development with varietal resistance and systemic insecticides offer hope that an integrated program for rice stem borers is possible.

Bess (6) derived the following conclusion from his study on the feasibility of chemical and biological control of rice stem borers:

It appears that parasites of eggs and predators of newly hatched larvae are the most effective and promising natural enemies to use in biological control programs. There is ample justification for further concerted efforts in the investigation of natural enemies of rice stem borers and the introduction of the more promising ones into those areas where stem borers occur in damaging numbers. The possibilities for integrated control are sufficiently promising to warrant studies on how to encourage the natural enemies and to use insecticides with the least damage to them.

Further, Yasumatsu (144) called attention to the characteristic of the mortality of rice stem borers and the role played by their natural enemies as follows:

According to a number of elaborate studies on the rice stem borer, *Chilo suppressalis*, in Japan, only one per cent of the hatched larvae of the rice stem borer can usually grow to the adult moth. If five to ten per cent larvae became adults, the infestation should take the state of an outbreak causing severe damage to rice cultivation. About 50 to 90% of the eggs of the first emergence moths are parasitized by *Trichogramma* or *Telenomus* species and about 24% of the larvae are killed by some environmental factors including high temperature in the summer time, shortage of nutrient in the younger plant and pupal or larval parasites, etc. Many of the overwintering larvae are destroyed by *Isaria farinosa, Apanteles chilonis* and Anthocorid bugs in the rice straw.

Thus, the extreme abundance of the various parasites and predators in the paddy field is unnecessary. If they are too abundant, the natural enemies cannot survive. These phenomenon would affect the maintenance of the offsprings of natural enemies in the paddy field and suggest that each parasite or predator has an efficient capacity of host finding in the paddy field. It is also our opinion that in the case of natural control of rice stem borers, it is highly desirable to enrich the parasite or predator fauna of the paddy field to some extent by artificial means. It probably would require the combined action of many species of natural enemies of rice stem borers for satisfactory control instead of what is often obtained with only one or two natural enemies in the case of fruit insect pests.

The data derived from our four years of study strongly indicate that the role played by the natural enemies of rice stem borers is extremely important and our future study on the control of rice stem borers should be focused on the integration of both biological and chemical control through the judicious use of insecticides and the augmentation and conservation of natural enemies. But, as indicated by the list of natural enemies of rice stem borers in Asia, the species of natural enemies are too abundant and the relationship between natural enemies and rice stem borers is too much complicated to study within any short time.

As the literature reveals that none of the rice pests has ever been controlled constantly by the aid of natural enemies, the above statements may also be applicable to all the injurious insect pests of rice cultivation other than the rice stem borers.

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