BIO-ECOLOGY AND MANAGEMENT OF *SCIRPOPHAGA FUSCIFLUA* HAMPSON

THESIS

By

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(A-2014-40-009)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled **"Bio-ecology and management of *Scirpophaga fusciflua* Hampson"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Entomology** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Vikas Tandon (A-2014-40-009)** son of **Smt. Rani Devi and Sh. Gian Chand** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Palampur
Dated: 18th June, 2018

(Ajai Srivastava)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **"Bio-ecology and management of *Scirpophaga fusciflua* Hampson"** submitted by **Mr. Vikas Tandon (A-2014-40-009)** son of **Sh. Gian Chand** to CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Entomology** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place: Palampur
Dated: 18th June, 2018

(Vikas Tandon)

TABLE OF CONTENTS

LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1.	%	Per cent
2.	/	Per
3.	-	Minus
4.	+	Plus
5.	<	Less than
6.	>	Greater than
7.	@	At the rate of
8.	^{o}C	Degree Celsius
9.	Rs.	Rupees
10.	1st	First
11.	2nd	Second
12.	3rd	Third
13.	4th	Fourth
14.	5th	Fifth
15.	a.i.	Active ingredient
16.	CD	Critical Difference
17.	cm	Centimeter
18.	DAS	Days after spray
19.	DAT	Days after transplanting
20.	DH	Dead hearts
21.	et al.	et alii (and others)
22.	etc	Et cetera
23.	Fig.	Figure(s)
24.	g	Gram
25.	g hill^{-1}	Gram per hill
26.	G	Generation
27.	ha	Hectare
28.	hr	Hour

Sr. No.	Abbreviation	Meaning
29.	*i.e.*	Id est (that is)
30.	kg ha^{-1}	Kilogram per hectare
31.	L	Litre
32.	m^2	Square meter
33.	Max	Maximum
34.	Min	Minimum
35.	ml	Millilitre
36.	mm	Millimeter
37.	No. or no.	Number
38.	NS	Non-significant
39.	q	Quintal
40.	q ha^{-1}	Quintal per hectare
41.	r	Correlation coefficient
42.	R	Coefficient of determination
43.	RBD	Randomized Block Design
44.	RH	Relative humidity
45.	Rs.	Rupees
46.	RWRC	Rice and Wheat Research Centre
47.	SC	Soluble concentrate
48.	SG	Soluble granules
49.	SL	Soluble liquid
50.	sp.	Species (singular)
51.	Spp.	Species (many)
52.	SW	Standard week
53.	T	Temperature
54.	*viz.,*	videlicet (namely)
55.	WE	White ears
56.	WSB	White stem borer
57.	YSB	Yellow stem borer

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

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ABSTRACT

Detailed studies on white stem borer, *Scirpophaga fusciflua* (Hampson) were undertaken at Rice and Wheat Research Centre of CSK Himachal Pradesh Krishi Vishvavidyalaya at Malan during *Kharif* season 2015-2017. The studies included white stem borer annual life cycle, its population build-up, assessment of yield losses inflicted and management with suitable insecticides and biopesticides. Three generations of white stem borer were recorded under laboratory conditions. Life history of white stem borer comprised of four well-defined stages *viz.,* egg, larvae, pupa and adult. At the end of the crop season, as the temperature decreased, the full grown larvae diapaused in rice stubbles, adult of which emerged during last week of April to first week of May under laboratory conditions. The female moths on an average laid 58.4 to 65.6 eggs in masses in different generations with pre-oviposition, oviposition and post-oviposition period of 23.8 to 24.1, 24.9 to 26.0 and 6.0 to 6.6 hours, respectively. The larva passed through five instars to complete the larval development and the head capsule width increased with each instar. Population build-up of *S. fusciflua* was undertaken at three locations *viz.*, Kohala, Jia and Malan. The pest appearance initiated during the month of July and the peak activity of pest was recorded during the month of August and September. The adult population had a positive relationship with minimum and maximum temperature and relative humidity whereas, rainfall influenced adult population negatively. However, the larval population was found to be negatively correlated with minimum temperature, rainfall, relative humidity (morning and evening). The plant infestation was found to have significant negative correlation with temperature (maximum and minimum), relative humidity (morning and evening) and rainfall. Stepwise regression analysis based on the data clubbed for three cropping seasons (2015-2017) revealed that minimum temperature, maximum temperature and rainfall influenced light trap and sweep net catch, significantly. Predators *viz.*, spiders, dragonflies and damselflies, were found associated with white stem borer in paddy ecosystem. Four species of parasitoids *viz.*, *Telenomus* sp. *Tetrastichus* sp. *Stenobracon* sp. and *Xanthopimpla punctata* were found to be associated with white stem borer. The plant infestation and losses inflicted to paddy due to different release levels of *S. fusciflua viz.,* 2, 4 and 6 larvae per hill released at tillering stage revealed that maximum infestation in terms of dead hearts and white ears was 11.6 per cent at highest release level (6 larvae per hill) and lowest (6.2%) at release level of 2 larvae per hill and per cent avoidable losses varied from 7.5 to 32.3 per cent. Application of various insecticides *viz.*, flubendiamide 48% SC @ 50 ml ha^{-1}, rynaxypyr 20 SC @ 150 ml ha^{-1}, dinotefuran 20 SG @ 200 g ha^{-1}, monocrotophos 36 SL @ 850 ml ha^{-1} and two biopesticides *viz.*, melia and eupatorium 5% extract @ 2.5 L ha^{-1} proved promising in checking white stem borer infestation, with flubendiamide being the most effective and more or less comparable with other insecticides. Among biopesticides, eupatorium application provided a significant check. However, maximum returns were obtained from monocrotophos and flubendiamide.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's leading sources of food among cereals and ranks first in acreage and its total production. It is widely grown in Asia, parts of Europe and America having most diverse ecosystems, such as irrigated, rainfed lowland, rainfed upland and flood prone (Panda 2010; Saini et al. 2015). It is a major source of employment and income for rural people, mostly living in developing countries. Almost 90 per cent of the rice is cultivated and consumed in Asia (Samanta et al. 2014).

India is the largest rice growing country, while China is the largest producer of rice. In India, rice is the most important and extensively grown food crop, occupying 43.38 million hectare area with production of 104.3 million tonnes (Anonymous 2016). In Himachal Pradesh it is one of the important cereal crops and covers an area of 75.0 thousand hectare with total rice production of 119.0 thousand tonnes (Anonymous 2016).

Rice crop has relatively a large number of insect-pests associated which limits its production. In recent years, there is a need to increase food production so as to meet the growing demands of fast increasing human population from limited land resources. This has necessitated the use of intensive farming systems, with the inputs like narrow genetic base varieties, application of high fertilizer dose, irrigation, multiple cropping etc. which favour abrupt pest multiplication (Reddy 2013). Insect-pests proved to be major constraints in enhancing the rice productivity, besides diseases and weeds (Behura et al. 2011). In India, approximately 100 insect pests have been reported as pests of rice and 20 of these are considered to be major pests causing upto 30 per cent yield loss from seedling to dough stage (Cramer 1967; Pathak and Dhaliwal 1981; Atwal and Dhaliwal 2005; Dhaliwal et al. 2010), amongst which, rice stem borers are a key group of insect-pests damaging rice crop (Dhaliwal and Arora 1996). Five species of stem borers namely, white stem borer, *Scirpophaga fusciflua* (Hampson), yellow stem borer, *S. incertulas* (Walker), dark headed borer, *Chilo polychrysus* (Meyrick), stripped stem borer, *C. suppressalis* (Walker) and pink stem borer, *Sesamia inferens* (Walker) have been reported from different parts of India

(Pasalu et al. 2005). Yellow stem borer is most widespread, dominant and destructive pest of rice (Bandong and Litsinger 2005). Whereas, white stem borer (Lepidoptera: Pyralidae) is also abundant both in lowland and upland rice and is a highly adapted tropical rainfed species (Dale 1994). White stem borer is the species of increasing significance in rice though its dominance has neither been consistent and widespread. But, in certain pockets such as the state of Kerala in southern India and Himachal Pradesh in the northern hills, it is continuously present (Katti et al. 2011).

The most common insect-pests on paddy occuring in Himachal Pradesh are *S. fusciflua*, *Cnaphalocrocis medinalis* (Guenee), *Nymphula depunctalis* (Guenee), *Dicladispa armigera* (Olivier), *Hydrillia philippina* (Ferino) and *Heteronychus lioderes* (Redtenbacher) etc (Srivastava et al. 2009; Sharma et al. 2012). White stem borer, *S. fusciflua* is the predominant borer species in Himachal Pradesh and distributed nearly in all the rice growing areas of the state. It causes damage to rice crop right from tillering to dough stage. Newly emerged larva enters into the stem for feeding on inner tissues at vegetative and reproductive stage of the crop. At tillering stage, larvae feed inner content of stem from the base to the apical part of plants causing drying of central shoot known as ‘dead heart’. Affected tillers do not bear panicles. White ears occur when the stem borer attack at reproductive stage (Kumar 1996; Chatterjee and Mondal 2014).

In northern India, with the popularization of long duration Basmati rice varieties, the problem of rice stem borers has aggravated (Yadav et. al. 1998). Yield loss estimate across India varied from 11.2 to 40.1 per cent due to dead heart and 27.6 to 71.7 per cent due to white ears, respectively (Krishnaiah and Varma 2012).

Natural enemies play a major role in maintaining several species of insect-pests of rice below economic threshold levels. Natural enemies of rice stem borer proved to be important biological agents. Reuolin et al. (2018) reported four egg parasitoids *viz.*, *Telenomus* sp., *Tetrastichus schoenobii, Trichogramma japonicum, Trichomalopsis* sp. associated with yellow stem borer. Inter-relationship of natural enemies and the stem borers have been reported by several workers. However, the parasitism/predation and efficacy of these natural enemies vary with place and year depending on several factors. In Kangra valley of Himachal Pradesh, Kumar et al.

(1997) and Chhavi (2017) observed several species of parasitoids and predators prevalent in rice ecosystem. However, the information available on natural enemies associated with white stem borer from Kangra valley of Himachal Pradesh is lacking.

Studies on assessment of yield losses and management of the white stem borer demands utmost attention. Synthetic insecticides are effective in controlling *S. fusciflua* but their indiscriminate use has given rise to many problems *viz.*, development of resistance to insecticides, pest resurgence, environmental pollution and ecological disturbance. Judicious use of insecticides is the need of hour to save the crop from toll of various insect-pests. Further, the changing resistance level of pest demands for new safer insecticides possessing novel insecticidal action. Hence, the present study entitled "Bio-ecology and management of *Scirpophaga fusciflua* Hampson" was undertaken during *Kharif* 2015 to 2017 with the following objectives:

i) To study the annual life cycle of white stem borer

ii) To study the population build-up of white stem borer and its associated natural enemies

iii) To assess the yield losses caused by white stem borer

iv) To evaluate chemical insecticide/botanicals for the management of white stem borer.

2. REVIEW OF LITERATURE

The existence of rice stem borers is universal, Hattori (1971) reported eight species of rice stem borers of significance in Asia. As many as five species of stem borer are found in India *viz., Scirpophaga fusciflua, S. incertulas, Chilo polychrysus, C. suppressalis* and *Sesamia inferens* (Pasalu et al. 2005) of which white stem borer (WSB), *S. fusciflua* (Hampson) Lepidoptera : Pyralidae is abundant both in lowland and upland rice.

In north and north-western region, Kaul (Haryana), WSB was prevalent as most abundant species at tillering stage (3.6%) during 2001-2006. At Kapurthala (Punjab), Sharma et al. (1996) observed the WSB population ranged from 27.3 to 32.67 per cent throughout the crop growth. During heading stage, 10 per cent WSB population was observed at Uttarakhand. Singh et al. (2005) recorded 9 per cent of WSB population at Ghaghraghat (Uttar Pradesh).

In southern region, Pattambi (Kerala), WSB composition was upto 20 per cent at dough stage. During the tillering and maximum tillering stages, WSB was prevalent with a mean of 43.3 per cent at Monocompu (Kerala). In the state of Karnataka, the mean population of WSB was recorded a 5 per cent. In eastern region, Coochbehar (West Bengal), 3 to 5 per cent WSB population was reported by Chakraborty and Deb (2010). In north-eastern region, Wangal (Manipur), WSB was observed throughout the crop growth stages. Pujari et al. (2008) reported WSB became more dominant accounting for 40 to 50 per cent of the population during tillering and maximum tillering stage at Titabar (Assam). In western region, Navsari (Gujarat), 3 to 6 per cent population of WSB was recorded at all stages of crop growth. In Malan (Himachal Pradesh), during 2001-2004, WSB populations dominated in maximum tillering and heading phases (59-61%) closely followed by pink stem borer (26.3-33.25%). But during 2006-2008 only complex of white stem borers belonging to genus *Scirpophaga viz., S. magnalla, S. innotata, S. novella, S. fusciflua* and *S. virginia* have been reported (Anonymous 2001-2008).

WSB is the species of increasing significance in rice though its dominance has neither been consistent and widespread. But, in certain pockets such as the state of Kerala in southern India and Himachal Pradesh in the northern hills, it is continuously present (Katti et al. 2011).

The available review of literature in relation to the investigation reported in the thesis has been grouped under the following heads:

2.1 Annual life cycle

2.2 Seasonality and population build-up

2.3 Assessment of yield losses

2.4 Management through insecticides and biopesticides

2.1 Annual life cycle

Study on biology helps to understand the life cycle of pest, which ultimately useful in determining the most susceptible stage of pest for applying the different control measures in order to manage the pest below economic injury level.

The biology of the rice stem borer has been studied by various workers under different agroclimatic conditions. Li (1961) reported that overwintering white rice stem borer larvae move in to the roots and build tunnels upto 10 cm deep. On the restoration of optimum condition, these larvae pupate at hibernating sites.

Israel et al. (1965) reported that on an average 6.8 per cent of the paddy stubbles harboured the immature stages of the stem borer. The larval populations of rice stem borers left over in stubbles are reported to be highly potential to cause considerable damage to rice crop in next season.

Kok and Varghese (1966) have reported from Malaya while working under laboratory conditions that *Scirpophaga innotata* laid eggs in batches of about 100 which were covered with silky greyish hair, incubation period being 4-9 days. The larvae became fully grown in 19-31 days. Pupa was soft bodied, pale, 12-15 mm long and changed to adult in 7-11 days. Life cycle was completed in 30-51 days.

According to Banerjee and Pramanik (1967) eggs of *S. innotata* are covered with pale orange hairs. The borer lay upto 160 eggs in clusters on lower surface towards the tip of leaves which hatched in 4-9 days (Ghrist and Lever 1969). Eggs measure 0.14 x 0.11 mm in size. Full grown larvae were milky white with a well developed prothoracic shield and measured 25 mm in length. Pupa was reported to be yellowish white, 12 mm long in case of male and 15 mm that of female. Wing span of adult male was 18-24 mm and that of female was 26-30 mm.

Rao and Kulshreshtha (1970) found that the movement and downward migration of the larvae depends upon the cultural practices and the climate. At Cuttack the larvae reached the final instar before the onset of cold weather, pupated and emerged as moths in October and November. But few larvae reached the basal nodes of the stems before the harvest to undergo a low temperature induced facultative diapause in December and January. The general rise in soil and air temperature to 20-21°C and above terminated the diapause and pupation and the emergence of moths followed. The pupal period ranged from 2-6 days at 27-32°C. There was no aestivation of mature larvae after harvesting the *Rabi* rice crop in May.

The adults of *S. incertulas* are nocturnal, positively phototrophic and strong fliers. The moths lay eggs in mass near the tip of leaf blade of rice usually containing 50-80 eggs. A single female is capable of laying 100-200 eggs. The eggs are covered with pale-orange brown hairs from the anal tufts of the female moths. The eggs laid on the leaf of rice within a field are generally randomly distributed (Pathak 1977).

Korat and Patel (1988) reported that incubation, pre-ovipostion, oviposition and post ovipostion periods were 6 to 8, 1.13, 1.33 and 0.27 days, respectively. There were 5 instars of rice stem borer *S. incertulas* under laboratory conditions. The pupal period varied from 6 to 10 days and 6 to 8 days in the month of March-May and August- October, respectively.

Hendarsih and Soeyitno (1991) found that artificial rainfall and flooding terminated aestivation in prepupae collected 52 or 96 days after harvest. Adults emerged 18-21 days after watering in artificial flooding regime and 29-45 days after watering in the artificial rainfall regime. The larval populations of rice stem borers left over in stubbles are known to be highly potential to cause considerable damage to rice crop in next season.

Islam and Catling (1991) reported that the female laid an average of 197 eggs within 3 days of emergence. The larval and pupal stages and total life cycle lasted 25.4, 9.1 and 45.8 days, respectively.

Bora et al. (1994) showed that females laid an average of 24-133 eggs which hatched within 6-8 days. The larval stage lasted for 27-30 days with 5 larval instars and the male to female ratio was 1:1.75. The average longevity of adult females and males was 0.84-4.25 days and 0.49- 2.5 days, respectively.

Kumar (1996) studied the biology of WSB, *S. innotata* under laboratory conditions at RWRC, Malan (HP) and reported the average fecundity of 36.9 eggs per female. The pre-oviposition, oviposition and post oviposition period was 21.8, 7.9 and 5.2 hours, respectively. The average longevity of adult male and female was 48.2 and 50.1 hours, respectively.

Malhi and Brar (1998) revealed that the average fecundity of yellow stem borer (YSB) was 213.20 eggs, with a range of 127-308 eggs. Longevity of male and female was 2.50 and 2.78 days in August, while it was 2.50 and 2.85 days in September, respectively.

Cohen et al. (2000) studied larval dispersal behaviour of two rice stem borers, *S. incertulas* and *C. suppressalis* and observed the extensive movement of both the species among plants in plots of transplanted rice, during the course of larval development. In vegetative stage, almost all *S. incertulas* larvae dispersed on the day of eclosion. Whereas at booting stage, most of the *S. incertulas* bored into hills on which egg masses were placed. Almost all neonate *C. suppressalis* also bored into the released hill, at both vegetative and booting stages. At these two rice growth stages, most larvae of two species dispersed to new hills between 7 and 18 days after eclosion.

Hugar et al. (2009) studied comparative biology of YSB in aerobic and transplanted rice. It was found that the longevity (4-5 days), fecundity of the females (39.8-159 eggs) and total life cycle of the pest (42.8 ± 1.73 days) was higher on transplanted paddy as compared to aerobic paddy.

Jadhao and Khurad (2012) studied biology of YSB under laboratory conditions during *Kharif* season at prevailing room temperature (18-29°C) and relative humidity (57-70%). The results revealed that the pre-oviposition and oviposition period lasted on an average for 1.0 and 1.5 days, respectively. The fecundity was 150 eggs per female. The incubation period was 6.5 days. The larval and pupal duration recorded was 27.5 and 8.0 days, respectively. The mean adult longevity was 2.5 days.

Satpathi et al. (2012) reported that the larval instars of YSB varied in both size and shape. The relative length of 1st, 2nd, 3rd, 4th and 5th instar larvae was 17.01, 18.72, 19.13, 19.54 and 20.32 mm, respectively. The head capsule with varied corresponding instars was 0.25, 0.48, 0.78, 0.97 and 1.28 mm.

Manikandan et al. (2013) revealed that the number of eggs laid by YSB increased at higher temperatures while egg hatching was reduced. Egg hatching was higher (90.6%) at 30.6°C followed by 28.3°C. The development time taken by different stages of the YSB revealed that there was an inverse relationship between development time and incubation temperature.

2.2 Seasonality and population build-up

Understanding the factors that influence the distribution and abundance of an insect is a fundamental issue of insect ecology and is of practical concern with insects that cause economic damage (Baskauf 2003). In relation to several weather factors, regular light trap catches and adult catch per five sweeps not only found useful to determine the activity of insect pests but also helps to study the population dynamics of the insect during particular period. To plan the different suitable control measures for the pest, knowledge of population dynamics is very much essential. It is also useful in development of forecasting model for pest. Now-a-days, the studies on population build-up of insect-pests have become essential to know the effect of changing climate on the population build-up of insects. This is because the population build-up of insect-pests is very useful in taking decision for pest management (Xia et al. 1991).

2.2.2 Seasonal occurrence

According to the Koch (1963), adults of the borers were usually present during wet season (November-April). Four generations were observed during the rice season and the progeny of the last remained in the prepupal stage until the beginning of next wet season. Light trap operations indicated that adults attained peak during late February and early March.

At Kapurthala (Punjab), Chhabra et al. (1976) showed that daily light trap catches of *S. innotata* was most common and abundant during September-October. On the other hand, Zafar and Chaudhary (1979) showed that *S. innotata* occurred in large numbers when the weather became warm in April-May and that another peak occurred in August and early October.

Saroja and Raju (1981) recorded the fluctuation of YSB moths and found that first generation moths were abundant during April to May. The population decline in the month of June and first fortnight of July and from the second fortnight of July till of August and again increased. However, from September to November, emergence was reported to be low.

Isahaque and Rahman (1983) studied the seasonal abundance of *S. incertulas* through light trap at Titabar in Assam and reported that the adult activity occurred throughout the year, with one peak in April and a smaller one in August.

Roy et al. (1985) operated three light traps in a rice field to monitor populations of *S. incertulas*. Maximum and minimum temperatures and relative humidity were important factors influencing catches. Activity peaks occurred in late October and, to a lesser extent, in late April. The trap data were useful in determining the times of initial infestation, peak infestation and reductions in the population.

Pandya et al. (1989) examined the effect of lunar cycle on light trap catches of the *S. incertulas*. The highest catches were obtained during the new moon periods while full moon light interfered with trap efficiency.

Kumar (1996) revealed that the adults of white stem borer started appearing during the month of July at early stage of crop and its population increased considerably during the month of August-September.

Wagan et al. (1999) studied the seasonal history of YSB with light trap and larval population in a rice-wheat rotation predominant area in Sindh area of Pakistan. The first moth appeared during first week of March after the winter season and reached its peak activity during October, but declined drastically later recording no yellow stem borer moth catch during December. Maximum larval infestation was also recorded during October at heading stage.

Kumar (2003) observed that the infestation of rice stem borer started during 37th standard week and gradually increased up to 43rd standard week. It was also reported that total infestation caused by stem borers was negatively correlated with maximum temperature, minimum temperature, rainfall and evaporation.

Arif et al. (2005) revealed that the maximum infestations of YSB as 7.8 white ears per 5 hills were observed during the crop growth. Weather parameters accounted for 98 and 95 per cent of total variations in the YSB incidence.

Dogra and Choudhary (2005) observed that the major rice insect-pests were stem borer, leaf folder and rice hispa, and appeared during the first week of July, with initial mean populations of 11.33, 1.00 and 1.67, respectively. Mean maximum population of these pests were recorded as 42.66, 51.67 and 59.33 during August to September which coincided with the vegetative stage of the crop.

Lal (2006) recorded that the emergence of YSB adults was initiated in 2nd week of April. Its 1st peak was recorded on 1st week of May and 2nd peak in 2nd week of May. Very less number of YSB adults was emerged from 3rd week of June to 3rd week of August. 3rd peak of adult was recorded in 1st week of September. There was no adult emergence of YSB after 3rd week of September.

Adiroubane and Raja (2010) monitored the rice stem borer at Kariakal (Pondicherry) and observed high pest incidence during March, August-September and October-November. The favourable weather conditions for high stem borer incidence were 27.6ºC, 30.1ºC, 26.1ºC mean temperatures during *Navarai*, *Kuruvai* and *Samba* seasons, respectively.

Huang et al. (2008) reported YSB, *S. incertulas*, striped rice borer, *C. suppressalis* and pink stem borer (PSB), *S. inferens* are the common insect pests of rice in Taiwan. The result revealed that the PSB, which was considered as a secondary pest of rice in the past, has tended to becoming more important than striped borer in central Taiwan, especially in the second cropping season.

Shukla and Sharma (2008) concluded on the basis of light trap and pheromone trap studies for stem borer during October-November that most of moths thus collectively caught showed the peak population of stem borer adult moth was found during the months October and November.

Prabal (2009) studied on the prevalence and influence of paddy stem borer on deep water rice in North Bank Plain zone of Assam. Stem borers moth population decreased from May to mid-August and the population increased from mid-August to mid-October as reflected from the moth population of light trap catches at study site. This population in turn caused borer incidence in terms of white ear (WE) 68.9-89.1 per cent stem damage at crop maturity stage.

Hugar et al. (2010) studied the influence of weather factors on the infestation of YSB, *S. incertulas* Walker in aerobic rice at Bangalore. The results revealed that borer infestation attained its peak activity when the crop was 60 days old.

Mandal et al. (2011) reported that the catching of *S. incertulas* moth was commenced as early as 32nd standard week (2nd week of August) with its peak during 37th standard week, while incidence of dead heart (DH) started at 34th standard week and reached the peak at 38th standard week.

Sharma et al. (2011) studied the population build up of YSB, *S. incertulas* and recorded maximum population of *S. incertulas* Walker in the month of September. The incidence of rice pests in Himachal Pradesh was studied by Sharma et al. (2012) and revealed that rice stem borer was more prominent in Kangra district with higher incidence during 2003, 2004 and 2006.

Chavan et al. (2013) carried out experimental trial at Navsari Agricultural University, Gujarat and observed maximum infestation of rice stem borer in first week of September, whereas minimum infestation was noticed in second week of October. The maximum, 19.23 per cent white ears damage was recorded during third week of October.

Chakraborty and Rath (2013) were reported eight peaks in a year and showed one major, three moderate and four minor peaks. Initiation of the population occurred at the second standard meteorological week, which was immediately followed by the two moderate peaks, one (173.1-167.2) during the 4th week of January to early February, the second one (174.1-160.6) during mid May and the third one (147.1) in mid October. The first minor peak (82.2-68.2) at mid February to mid March, the second one (79.4) is in late April, the third one (95.61) during mid July and the fourth one (78.3) is in October. The only major peak (410.2-230.7) was occurred during early to middle of November after which the population steadily turned down.

Kakde and Patel (2014) carried out experiment with conventional (transplanting) and SRI method of paddy cultivation. Under conventional method, YSB infestation peak appeared during first week of September (5.58% DH) and 1st week of October (5.79% WE). In SRI method, the peak incidence was observed during first week of September (4.19% DH) and at last week of September (4.93% WE). The results of both methods indicated that the weather parameters had less influence on the activity of YSB damage.

Bhutto et al. (2015) observed the activity of YSB moth by using light trap. Moth activity of over-wintering generation started during the 4th week of March reaches to its first peak during the 2nd week of April and drastically decline up to the end of May. No moth was captured during June and July. Moth population again started during 2nd week of August to infest rice crop, reaches to its second peak during the 1st week of October. Moth population gradually decline from 2nd week of October to last week of November.

Chanu and Ray (2016) studied on the population dynamics of rice stem borer, *S. incertulas* in the *boro* season at Assam. The peak incidence of adults was during the 2nd week of February. The peak incidence of larva was in the middle of April.

Patel and Singh (2017) studied the seasonal incidence of rice stem borer, *S. incertulas* (Walker) on different varieties of paddy. Dead heart started from 32nd standard week and continued upto 38th standard week, while white ear was recorded on 35th standard week and it reached peak in 45th standard week.

Rana et al. (2017) studied the population dynamics of YSB, *S. incertulas* Walker in basmati rice. The peak period of pooled maximum dead hearts (9.46%) of both cropping seasons was recorded in 35th standard week. Thereafter, infestation declined gradually, but again increased at reproductive stage of crop and the pooled maximum white ears (8.48%) infestation was recorded during both the seasons at 40th standard week.

Reuolin et al. (2018) studied the population build up of YSB, *S. incertulas* at different stage of crop. The results revealed maximum dead heart damage (10.47%) at 60 days after transplanting (DAT) and minimum (3.98%) at 45 DAT.

2.2.3 Effect of weather factors on its abundance

Ramakrishna and Ananthanarayanan (1935) reported that weather conditions greatly influence the activity of rice stem borers and heaviest infestation occurs during wet weather. The abundance of rice stem borers depend on weather conditions and it was concluded that the insects require high degree of relative humidity for their normal breeding (Nagaraju Rao and Varadharajan 1961).

Isahaque and Rahman (1983) studied the seasonal abundance of *S. incertulas* through light trap at Titabar in Assam. They reported a positive correlation was found between moth abundance and temperature, rainfall and relative humidity, hours of sunshine appeared to have no significant effect on stem borer populations.

Bhatnagar and Saxena (1999) studied the effect of climate on the population build up of YSB by using light traps over four years (1994-97) at Jagdalpur and observed a significant negative correlation with minimum temperature, evening relative humidity and rainfall.

Rai et al. (2002) conducted study on the influence of various weather parameters on YSB population catches in light trap showed positive correlation as well as coefficient of determination was found 71 per cent. Rainfall showed the negative influence on the catches of YSB.

Rehman et al. (2002) indicated that during YSB hibernation period (November to March), high maximum temperature, low minimum temperature, low relative humidity and rainfall; during its survival period on rice nurseries, volunteer rice and sprouted rice stubbles (April to June), high temperature, high relative humidity and low rainfall and during its survival on rice crop (July-October), low temperature, high relative humidity and rainfall resulted in YSB outbreaks. Occurrence of rainfall at the appropriate time was essential for YSB multiplication. High rainfall during winter resulted in the decay of rice stubbles and thus lowered the survival of hibernating larvae in stubbles, whereas, high rainfall during September was essential for its mass multiplication.

Kumar (2003) reported that total infestation caused by stem borers was negatively correlated with maximum temperature, minimum temperature, rainfall and evaporation.

According to Padhi and Saha (2004) from Cuttack (Orissa), the maximum temperature, rainfall, relative humidity and wind velocity were negatively, while minimum temperature, evaporation rate and sunshine hours were positively correlated with the moth population of stem borer recorded through the light trap catches.

Mukherjee et al. (2005) studied the effects of various weather parameters such as bright sunshine, rain, air temperature, humidity, wind speed, and morning and daytime vapour pressure on the population build-up of rice stem borer (*S. incertulas*) in a field experiment conducted in West Bengal. The stem borer population was found highly significant and positive correlation with minimum air temperature, morning vapour pressure and negative correlation with wind velocity.

Sastri et al. (2008) investigated the relationship between the weather parameters and YSB incidence. They found significant relation of weather parameters like maximum temperature, minimum temperature, relative humidity I and relative humidity II with the YSB population.

Hugar et al. (2010) studied the influence of weather factors on the infestation of YSB, *S. incertulas* Walker in aerobic rice at Bangalore. Regression equations between the infestation of stem borer and weather parameters showed a significant negative correlation with minimum temperature and afternoon relative humidity but showed non-significant and negative correlation with maximum temperature, morning relative humidity and rainfall and had significant positive correlation with sunshine hours.

Chakraborty and Nanda (2011) made fortnight assessment on the dynamics of YSB, *S. incertulas* Walker by light trap in relation to climatic parameters. The adult catch number was significantly influenced by average temperature, temperature gradient maximum relative humidity, average relative humidity and sunshine hour at positive level while by minimum temperature at negative level.

Sharma et al. (2011) recorded maximum population of *S. incertulas* Walker in the month of September. The value of multiple correlations for the insect was 0.949. Meteorological factors were also responsible for the dynamics of the populations of insects.

Mishra et al. (2012a) monitored population of rice stem borer using light as well as pheromone traps at Masodha, Faizabad and observed that the moth population was positively correlated with minimum and maximum temperature, whereas it was negatively correlated with rainfall and relative humidity.

Reji et al. (2014) studied the relationship between weather parameters such as maximum and minimum temperature, morning and afternoon relative humidity and the severity of stem borer damage and developed multiple linear regression model. The pest damage predicted using the model at three sites did not significantly differ from the observed damage. The range of weather parameters favourable for stem borer damage at each site were also predicted using the models. They prepared showing areas with high, medium and low risk of stem borer damage using geographical information system.

Kumar et al. (2015) revealed that maximum temperature (°C), minimum temperature (°C), relative humidity (%) at 7 hr, relative humidity (%) at 14 hr, rainfall (mm) and evaporation (mm) were positively correlated to the tune of 0.273, 0.453, 0.075, 0.478, 0.339 and 0.122, respectively with the population of male moth of YSB. Weather parameters were found to contribute about 34.60 per cent male moth population fluctuation of *S. incertulas* when acted together.

Somashekra and Javergowda (2015) studied the seasonal incidence and its relationship with weather parameters on peak emergence of *S. incertulas* in rice using light and pheromone traps. Result revealed that evening relative humidity and rainfall showed significant negative correlation with population in light. The minimum and maximum temperature and relative humidity had non-significant positive correlation with population in light.

Chanu and Ray (2016) studied the population dynamics of rice stem borer, *S. incertulas* in the *boro* season at Assam. In case of adults, a significant correlation with weather factors was observed, on the adults temperature and rainfall had an insignificant effect, while relative humidity had significant effect.

Rana et al. (2017) studied the effect of weather parameters on the infestation of YSB, *S. incertulas* Walker in basmati rice. Regression analysis of dead heart formation explained 60.20-61.60 per cent variability due to all tested environmental factors combined while in case of white ears the variability ranged from 63.90-73.50 per cent. Stepwise regression of pooled data of both the years revealed that incidence of YSB was depended on rainfall.

Zainab et al. (2017) observed the impact of temperature, rainfall and relative humidity on population build up of YSB. The results revealed that dead hearts and white ears incidence were negatively correlated with mean temperature, positively correlated with relative humidity and showed significant positive correlation with rainfall.

2.2.4 Associated natural enemies

Van der Goot (1948) reported that egg masses were parasitized by the *Telenomus beneficiens* (Telnbe), *Trichogramma japonicum* (Ashmead) and *Tetrastichus schoenobii* (Ferriere), where percent parasitism varied from 6-40, 0-28 and 0-2, respectively. However, total combined parasitism averaged 30 per cent. According to Van der Goot (1948), Delfinado (1959) is of the opinion that parasites of larvae are of little importance and *Bracon chinensis* could not be reared on *S. innotata* but could be reared from *C. suppressalis, S. inferens* and *S. bipunctifer.* The field release of this parasite in Java during the year 1930 yielded no results.

Delfinado (1959) reported three parasites, *viz., Shirakia schoenobii, Cremastus shirakii* and *Angitia lineata* from the larvae of *S. innotata.* On the other hand, Rothschild (1970) made observations on the parasites that attack eggs of *S. innotata.* The parasites reared from the eggs comprised *Telenomus rowani* (Gahan) from 40-80 per cent eggs and eulophid *T. schoenobii* from 30-35 per cent eggs.

Patnaik et al. (1983) studied egg parasitization of stem borer in the field by *Telenomus degncides* Nixon (Scelionidae), *T. japonicum* and *T. schoenobii*. Among the three, *Telenomus* was the most dominant and effective species. The parasitization varied from 73.6-96.9 per cent of egg masses, 16.8-31.6 per cent of eggs and 14.0-21.1 per cent of effective parasites emerged from each egg mass. The larval hatchability of parasitized egg masses was 32.2 per cent lower than those of unparasitized egg masses. The parasites population usually followed a linear trend with host egg number in the egg mass.

Predators of rice insect pests in Madhya Pradesh reported by Bhardwaj and Pawar (1987) included *Tetragnatha mandibulata* (Walckenaer), *Lycosa pseudoannulata* (Boes.et), *Conocephalus longipennis* (de Haan), *Agroicnemus pygmaea* (Rambur), *Ophionea nigrofasciata* (Schmidt-Gobel), *Casnoidae indica* (Thumberg), *Coccinella arcuata* (fabricius), *Menochilus sexmaculata* (fabricius), *Paederus fuscipes* (Curtis), *Cyrtorhinus lividipennis* (Reuter) and *Tropiconabis capsiformis* (Troica).

By using sweep net Chakravarthy (1987) recorded six spiders, two Odonata, one neuropteran, 16 spp. of *Cyrtorhinus* and 12 spp. of *Microvelia* per 10 clumps on main crop in hilly regions of Karnataka.

Wang and Wu (1988) reported two Katydids, *Conocephalus divergentus* and *Euconocephalus thunbergi* preying on eggs of *S. incertulas.* The rate of predation were 7.6, 3.0 and 36.8 to 69.1 per cent for second, third and fourth generation.

Islam (1991) evaluated the parasitic efficiencies of *T. rowani* and *T. schoenobii*, egg parasitoids of *S. incertulas*. About 41 per cent of the eggs were parasitized and about 16 per cent of the egg masses were jointly attacked by the 2 parasitoids. Interspecific competition was observed and *T. schoenobii* appeared to be the stronger competitor.

Joshi et al. (1991) observed two species of *Trichogramma*, three of *Telenomus* and two of *Tetrastichus* from 1, 18 and 12 per cent, respectively from the eggs of *S. innotata.* Kumar et al. (1997) recorded seven species of parasitoids and predators present on *S. innotata*, *S. incertulas* and *S. inferens* in Kangra valley of Himachal Pradesh.

Sigsgaard (2000) recorded relatively few insect pest problems in unsprayed, irrigated rice. Spiders were thought to play an important role in the suppression of insect pests such as plant and leafhoppers. Pest resurgence after insecticide spraying revealed negative impact of insecticides on spiders and other natural enemies.

Manju et al. (2002) studied the egg parasitism in YSB. Egg mass along with 3 cm long leaf bits were collected at random at 5-7 days interval from one square meter area at least from 5 places each time, transferred individually to cloth covered vials and maintained in a screen house at (34.71+ or -0.85 degrees C and 70.05+ or -0.92% RH) until parasitoids and host larvae emerged. Egg masses were more numerous at panicle initiation stage than at tillering and flowering stages. The parasitism was higher at panicle initiation stage (45%) than at flowering (29.86%) and tillering (21.23%) stages. Parasitism was due to both *T. dignus* and *T. schoenobii*. *T. dignus* occurred all the year round while the occurrence of *T. schoenobii* was seasonal. Parasitization was significantly higher due to the former (71.27) than due to the latter (28.72).

Kishore et al. (2003) evaluated the current status of natural enemies with special reference to parasitoids and predators of stem borers. They found that stem borers are most destructive insects in the world and seriously limits the production of cereal grains. They identified a large number of natural enemies of stem borers, including *Telenomus* sp. as an egg parasitoid and *Xanthopimpla* sp. as larval-pupal parasitoid, for their potential use in biological control programmes.

Litsinger et al. (2006) determined the role of egg parasitoids (*T. japonicum*, *T. rowani*, *T. dignus* and *T. schoenobii*) and general predators (spiders, coccinellids and orthopterans) in suppressing WSB numbers. Multiple parasitism occurred in 61 per cent egg masses.

Alagar et al. (2008) found the most common and dominant egg parasitoids was *T. schoenobii* among the two parasitoids *i.e*. *Telenomus* sp. and *Tetrastichus* sp. with mean egg parasitization from 45.0 to 95.8 per cent of the YSB eggs throughout the season.

Kumar et al. (2008) reported the most common and dominant predators of rice ecosystem as spiders, coccinellids, staphyllinids, mirids, damsel flies and dragon flies. The egg parasitoids had greater impact on the suppression of rice stem borer (*S. incertulas*) and the most important egg parasitoids observed were *Telenomus* sp. and *T. schoenobii i.e.* parasitizing up to 95.8 per cent egg mass in October, while the lowest egg parasitization was observed in the 1st week of August (6.4%), followed by 2nd week (7.5%).

In Pantnagar region, Varma and Khan (2009) studied upon the naturally occurring egg parasitoids of *S. incertulas*, they are *Telenomus* sp. and *Tetrastichus* sp. The mean per cent parasitization was low in the early stages (15.38%), which increased progressively and remained constant in the middle of the season but increased during the end of the season (73.56%). In the early phases of crop growth, *Telenomus* sp. was more prevalent and in the later period *Tetrastichus* sp. was dominant.

Lakshmi et al. (2010) revealed that egg parasitoids played an important role in population regulation of YSB by parasitizing 95 per cent of the egg masses. Ninety per cent of the egg masses were completely parasitized and the parasitoids species recorded were reported as *T. schoenobii, T. dignus* and *T. japonicum.* Among them *T. schoenobii* was the most dominant species by parasitizing 89 per cent of egg masses followed by *Telenomu*s which parasitized only 9 per cent egg masses. Among the parasitized egg masses, 23 per cent egg masses were parasitized by 2 or more species of parasitoids.

Chakraborty (2012) recorded activity of YSB egg parasitoids and observed egg mass of YSB was mostly parasitized either by single or by two parasitoid species. Presence of three parasitoids species in a single egg mass was uncommon. Incidence of parasitization by only *Trichogramma* sp., *Telenomus* sp. and *Tetrastichus* sp. was 6.12, 9.53 and 48.44 per cent, respectively. Parasitization by *Trichogramma* sp. + *Telenomus* sp., *Telenomus* sp. + *Tetrastichus* sp. and *Trichogramma* sp. + *Tetrastichus* sp. were 3.46, 21.06 and 2.35 per cent, respectively. *T. schoenobii* and *T. chilonis* were active almost throughout the year, while activity of *T. rowani* was recorded from late August to middle of October. Also Chakraborty (2013) studied that *T. rowani*, *T. schoenobii* (Eulophidae) and *T. chilonis* (Trichogrammatidae) were the three important YSB egg parasitoids. Activity of YSB egg parasitoids is seasonally allied; egg mass size dependent and paddy growth stage specific. In all cases, percentage of parasitization was found to be egg mass size dependent (r= 0.756) and was also befitting with the standing paddy growth stages; high in the early growth stages but low in late growth stages. High average parasitization at early vegetative stages (63.83%) decreased steadily and remained constant during mid-tillering stage (34.64%), and further declined during the ripening stage (14.65%).

Upamanya et al. (2013) evaluated the performance of *T. japonicum* in comparision to chlorpyriphos and azadirachtin against rice stem borer, and found significantly higher control in *T. japonicum* released plot and chlorpyriphos treated plot than the azadirachtin treated plots.

Reuolin et al. (2018) reported four egg parasitoids *viz.*, *Telenomus* sp., *T. schoenobii, T. japonicum, Trichomalopsis* sp. associated with YSB. The influence of crop stage on individual egg parasitization revealed highest parasitization of *T. schoenobii* (40.64%) followed by *Telenomus* sp. (19.69%) at 30 DAT while that of *T. japonicum* (1.65%) and *Trichomalopsis* sp. (0.87%) at 45 DAT. Total egg mass parasitization was also highest at 30 DAT (34.48%).

2.3 Assessment of yield losses

Catling et al. (1987) assessed yield loss due to damage by YSB, *S. incertulas* in deepwater rice in Bangladesh and Thailand using five different methods. Because of the long stems and special growing conditions of the crop only three methods proved reliable: pot experiments in metal containers, potted plants exposed in the field and floating exclusion cages in the field. Yields were reduced by 27-34 per cent and 1 per cent yield loss was associated with 2 per cent damaged stem at harvest. Yield loss was mainly due to a loss of bearing stems and lighter panicles borne by compensatory nodal tillers. A tentative damage threshold of 10 per cent damaged stems at booting/flowering stage and 20 per cent damaged stems at plant maturity is proposed.

Bakthavatsalam (1991) found that the relationship between damage (%) and loss in yield (%) was 1:1.5. With 5 per cent dead hearts the loss in yield was equivalent to 502 kg ha^{-1}. He also concluded that 5 per cent damage to the crop represents the economic threshold level above which control measures become necessary.

Islam and Karim (1997) studied relationship between white ears and yield loss. The results in boro rice revealed that grain yield at 1-10, 11-15, 16-20, 21-30 and 30 per cent white ears infestation recorded 22.7, 24.4, 21.8, 19.6 and 12.5 g hill^{-1}, respectively; and in aus rice the grain yield recorded as 15.9, 16.2, 12.9, 10.5 and 5.2 g hill^{-1}, respectively.

Afzal et al. (2002) determined new economic threshold level (ETL) on Super Basmati by artificially produced infestation levels (0-15%). They suggested the infestation level of 7.5 and 10 per cent to be the ETL. The extent of damage and yield loss due to six species of stem borers were studied on nine rice varieties, in vegetative, reproductive and mature phases of the plant. The hybrid variety (BR31) was found to be most susceptible against all the borers, and local varieties were resistant (Rahman et al. 2004). The percentage yield loss due to stem borers infestation was found highest (27.09, 24.54, 25.32, 36.26, 17.74 and 22.19 per cent by *C. polychrysus, C. suppressalis, C. partellus, S. incertulas, S. innotata* and *S. inferens,* respectively) on the variety, BR31 and lowest (11.17, 10.18, 10.54, 8.77, 8.10, and 7.07% by *C. polychrysus, C. suppressalis, C. partellus, S. incertulas, S. innotata* and *S. inferens,* respectively) on Bansphul. Yield loss was found to be correlated positively with dead hearts' and/or 'white ears' infestations at vegetative, reproductive and mature phases of the crop.

Daryaei (2005) revealed that at 5, 15, 30 and 60 per cent infestation the grain yield recorded as 5287, 4953, 4656 and 4440 kg ha^{-1} at vegetative stage; 5095, 4628, 3643 and 3155 kg ha^{-1} at panicle initiation stage; 5050, 4532, 3575 and 2326 kg ha^{-1} at grain filling stage.

Muralidharan and Pasalu (2005) reported losses over rice ecosystems due to 1 per cent dead hearts or white ears, or to both phases of stem borer damage as 2.5, 4.0 and 6.4 per cent yield loss, respectively and 108, 174 and 278 kg ha^{-1}, respectively in terms of grain production loss over ecosystems. In irrigated ecosystem, 1 per cent dead hearts resulted in 12 kg ha^{-1} loss whereas, 1 per cent white ears caused 183 kg ha^{-1} loss in grain yields; the loss due to 1 per cent infestation in both phases of stem borer damage was 201 kg ha^{-1}. In rainfed lowlands, for 1 per cent dead hearts and white ears caused 2.3 per cent or 76 kg ha^{-1} yield loss.

Panigrahi and Rajamani (2010) studied on yield contributing characters for 27 deep water rice cultivars indicated that the percent reduction in panicle length, number of grains per panicle, 1000 grain weight and increase in the chaffy grain per cent varied between 8.21-16.42, 7.83-16.99, 9.09-22.57 and 8.8-16.5 per cent, respectively in plants with stem borer damage over the healthy ones. The per cent yield loss due to 1 per cent damaged stem varied between 0.22-0.44 with an average of 0.31 as compared with 0.50 in the susceptible check Jalamagna.

Panigrahi (2011) stated that infestation took place at vegetative stage indicated per cent dead hearts varied from (7.8-16.4) and there was reduction in tillers in infested hills over control in all the test land races except Athagadia, where it was 1.6 per cent increase of tillers. The per cent reduction in all the yield contributing characters was negatively reduced in all the land races except Athagadia where the yield contributing characters increased positively. The per cent increase in panicle length, grains/panicle decrease of chaffy grain per cent, 1000 grain weight and panicle weight were 0.9, 1.4, 1.3, 1.2 and 1.5 Athagadia and accordingly there was increase/decrease in yield in the infested treatment over the control.

Mishra and Sharma (2012) reported that incidence of YSB at the vegetative stage ranged from 2.65-5.63 and 2.43-5.70 per cent in IPM plots as compared to 3.19-11.63 and 3.12-13.07 per cent dead hearts in non-IPM plots. However at maturity stage, the damage ranged between 1.15-4.70 and 1.07-5.1 per cent in IPM plots against 3.05-10.15 and 3.73-11.01 per cent white ears in non-IPM plots. The yield data indicated that the validated modules gave 37.26 and 34.35 q ha^{-1} with an increase of 39.13 and 34.34 per cent over non-IPM plots, respectively and average yield of 35.805 q ha^{-1} with 36.77 per cent increase.

Sarwar (2012) studied the YSB incidence of insect-pests and yield performance of rice varieties. Early sowing date, the infestation (3.96% DH, 6.67% WE) was significantly low compared with medium (8.13% DH, 7.82% WE) and late sowing (14.45% DH, 12.46% WE). Among different varieties tested, Sharshar showed least pest infestation and increased grain yield followed by, IR8, Mehak and Basmati-370.

Selvaraj et al. (2012) determined multiple-pest economic injury levels on rice at different crop growth stages through field and pot experiments. The yield losses to damage functions were derived for two-pest combinations of stem borers, *S. incertulas* and *S. inferens*, at reproductive crop stage. Across experiments, single-species economic injury levels of stem borer ranged 1.9-3.0 per cent white ears, respectively.

Kumar and Ravi (2013) observed that in the maximum tillering, the proportions were equal (48.2 and 49.0%), while in heading stage, incidence of PSB was up to 13.6 per cent in *Kharif* 2008. In summer 2009 YSB proportion was more in the early and maximum tillering stages (77.6 and 68.6%, respectively). PSB became dominant as the crop reached reproductive phase (64.1%) and the share of YSB was 35.9 per cent. YSB composition in stem borer species complex ranged from 73.8 to 100 per cent in summer 2009 and 81.8 to 93.8 per cent during *Kharif* 2008-09.

Tripathi and Sexana (2013) evaluated local, improved and hybrid varieties of rice for insect pest complex in rewa region. The incidence of various pests 16 rice cultivars five were local cultivars namely Dehula, Newari, Bhataphool, Loachai & Lohindi & six were improved varieties *viz.*, Pusabasmati, IR-36, IR-64, Vandana, IR-20 & Pusa Sugandha and five were hybrid varieties *i.e.* PA-6201, KRH-2, PRH-10, JRH-4 & JRH-5. The observations were made regarding the incidence of insect pests, their spread, type and extent of damage.

Pradhan and Rath (2014) reported the reduction of panicle size, grain formation and grain weight at tillering stage *i.e.* 18 to 50 days from implantation. Number of panicles per plot at 75 DAT was found to be 291.2 and 230.4 in controlled and pest affected fields, respectively. Gradually it increased to 396.8 and 249.6 in controlled field and pest affected field, respectively at 120 DAT. In all observations the number of panicles has been reduced in the pest affected field. Reduction in panicle length has also seen in pest affected field than controlled field. A significant reduction in the weight of grains was observed which were 22 g in controlled field and 11 g in pest affected field.

Mondal et al. (2017) conducted field experiment on summer rice. There were two treatments, unprotected and protected which were replicated six times following pair plot technique design. The invading weed, insect and disease pests in the experimental plots were identified. Weed pest caused maximum loss in seed yield 37.02 per cent followed by insect pest 27.9 per cent and disease pest 15.6 per cent. In SRI productivity increase may be attributed to improvement in growth and yield parameters resulting from management of pests in the respective critical infestation period.

2.4 Management through insecticides and biopesticides

Dhivahar and Dhandapani (2003) studied the bio-efficacy of new molecules thiacloprid against rice stem borer, *S. incertulas* at Aliyar Nagar, Tamil Nadu. They noticed that treatments comprised of fenthion 50 EC @ 400 and 500 ml ha^{-1} was found superior whereas the straw (15574 kg ha^{-1}) and grain (3734 kg ha^{-1}) yield were recorded highest with thiacloprid EC @ 500 ml ha^{-1}.

Gowda (2005) reported that flubendiamide 20 WDG at 25 and 50 g a.i. ha^{-1} recorded low incidence of dead hearts (0.81 and 0.53 %) and white ears (1.26 and 1.20%) compared to other treatments.

The efficacy of four different insecticides against rice insect-pests *viz.*, stem borer, leaf folder and case worm was studied by Kalita et al. (2007). They noticed that all the insecticidal treatments reduced the insect population significantly over control and incurred significantly higher yield. Among the treatments, check insecticides monocrotophos 500 g a.i. ha^{-1} reduced maximum population of insect pests and gave highest yield (34.17 q ha^{-1}). Sekh et al. (2007) reported that flubendiamide 480 SC @ 24 and 30 g a.i. ha^{-1} provided effective control against YSB.

Sharma and Srivastava (2008) conducted field experiments to investigate the efficacy of insecticides against major insect pests of paddy and results revealed that monocrotophos @ 500 g a.i. ha^{-1} and acetamiprid 0.4% + chlorpyriphos 20 EC @ 510 g a.i. ha^{-1} were also found to be effective for the control of major insect-pests as compared to other insecticides.

Bhutto and Soomro (2010) conducted the experiment for efficacy of different emulsifiable concentration insecticides to control *S. incertulas*. They reported that karate 2.5 EC proved best among all the tested EC insecticides to reduced dead heart percentage as well as white ear head percentage and exhibited higher yield.

Rao et al. (2010) reported that takumi 20 WG (flubendiamide) @ 35 g a.i. ha^{-1} proved to be most effective treatments in reducing the stem borer population. The best treatments in order of their effectiveness were takumi 20 WG @ 35 g a.i. ha^{-1}, carbofuran 3 G @ 525 g a.i. ha^{-1}, cartap hydrochloride 50 SP @ 250 g a.i. ha^{-1}, phorate 10 G @ 1000 g a.i. ha^{-1}, and fipronil 5 SC @ 25 g a.i. ha^{-1}.

Suri (2011) evaluated efficacy of chlorantraniliprole @ 10, 20, 30 and 40 g a.i. ha^{-1} against YSB and found that chlorantraniliprole @ 40 g a.i. ha^{-1} provided an effective control of stem borers (1.62 per cent dead hearts and 2.00 per cent white ears) but, significantly better than its lower dosages of 10 and 20 g a.i. ha^{-1}.

Devi et al. (2012) revealed that acephate 95 SG @ 562 g ha^{-1}, acephate 50 WP @ 500 g ha^{-1}, and monocrotophos 36 SL @ 500 g ha^{-1} were found most effective against rice stem borer with per cent white ears of 6.69, 7.39 and 7.71 and 7635 kg ha^{-1}, 7398 kg ha^{-1} and 7024 kg ha^{-1} grain yield.

Karthikeyan et al. (2012) evaluated insecticides for the management of stem borer in rice and revealed that combination product flubendiamide 4 per cent + buprofezin 20 per cent was most effective against YSB and was significantly superior over all the treatment including check insecticides with 55.0 and 20.8 per cent reduction in dead heart and white ear respectively.

Mishra et al. (2012b) reported that the plot treated with fipronil 5 SC @ 50 g a.i. ha^{-1} proved their superiority over other insecticides, which resulted the lowest incidence of YSB with highest grain yield followed by cartap hydrochloride 50 SP @ 300 g a.i. ha^{-1} and cartap hydrochloride 4 G @ 750 g a.i. ha^{-1}. Dinotefuron 20% @ 200 ml ha^{-1} and Monocrotophos 36 % @ 1390 ml ha^{-1} were effective against rice stem borer.

Tanveer et al. (2012) evaluated the impact of insecticides against YSB in rice and revealed that the infestation of YSB was recorded more by using carbofuran (3G) *i.e.* 14.0 per cent as compared to cartap hydrochloride (4G) *i.e.* 6.0 per cent.

Abro et al. (2013) reported that application of insecticides significantly reduced the infestation of rice stem borer compared with control treatment. Second spray of cartap hydrochloride was found most effective insecticide with the minimum per cent infestation (4.37%) followed by carbofuran (7.08%), fipronil (8.68%) and control (38.53%). The maximum cost: benefit ratio of 1: 50.3 was obtained with cartap hydrochloride followed by carbofuran (1: 26.45) and fipronil (1: 24.24).

Islam et al. (2013) reported that botanicals and chemicals caused a significant difference in their effect against *S. incertulas*. After 21 days of spraying, fipronil treatment showed the reduction of 51.89 per cent dead hearts and 65.05 per cent white ears over control. Neem extracts reduced dead hearts and white ears by 38.38 per cent and 58.08 per cent respectively.

Singh et al. (2013) evaluated eleven insecticides *viz*., cartap hydrochloride 4 G @ 750 g a.i. ha^{-1}, cartap hydrochloride 75 SG @ 375 g a.i. ha^{-1}, fipronil 5 SC @ 75 g a.i. ha^{-1}, methomyl 40 SP @ 500 g a.i. ha^{-1}, monocrotophos 36 EC @ 500 g a.i. ha^{-1}, imidacloprid 17.8 SL @ 25 g a.i. ha^{-1} and spinosad 45 SP @ 100 g a.i. ha^{-1} against *S. incertulas*. Amongst these, cartap hydrochloride 4G @ 750 g a.i. ha^{-1} showed lowest infestation and higher grain yield of 28.20 q ha^{-1} followed by cartap hydrochloride 75 SG (25.43 q ha^{-1}) and fipronil 5 SC (24.61 q ha^{-1}).

In Kanyakumari district survey of rice growing blocks was carried out by (Justin and Preetha 2014) to establish the stem borer incidence and damage per cent in the farmer’s field. The data revealed that the *S. incertulas* to be dominant. The field experiments revealed that chlorantraniliprole 0.4 GR proved to be the best among all the tested insecticides with reduced stem borer infestation and recording higher yield.

Karthikeyan and Christy (2014) conducted pest management experiments at Regional Agricultural Research Station, Pattambi. The insecticide molecules tested during the periods were triazophos @ (750 ml ha^{-1} and 250 ml ha^{-1}), sulfoxyaflor (313 and 375 ml ha^{-1}), buprofezin (800 ml ha^{-1}), chlorantraniliprole (150 ml ha^{-1}), acephate (660 g ha^{-1}) and monocrotophos (1390 ml ha^{-1}) as check insecticide with an untreated control. Their result showed that chlorantraniliprole @ 150 ml ha^{-1} was the most effective treatment against *S. incertulas* and grain yield was also higher in chlorantraniliprole treated plot.

Kumar (2014) evaluated the new molecular insecticides and botanicals against stem borer of mid hill rainfed rice. Among nine treatments, flubendiamide, rynaxypyr and fipronil were significantly superior to other treatments with more than 95 per cent reduction in stem borer damage over untreated control. Triazophos, chlorpyriphos and quinalphos recorded more than 70 per cent reduction of stem borer damage over untreated control. Botanicals such as eupatorium *adenophorum* leaf extract @ 5 % and NSKE @ 5 % were less effective as compared to the insecticides.

Prasad et al. (2014) evaluated five new insecticides and two combination products along with treated check against *S. incertulas*. Among them, acephate 75 SP (667 g ha^{-1}) was found superior over flubendiamide (4%) + buprofezin (20%) SC (875 ml ha^{-1}) and flubendiamide 20 WDG (175 g ha^{-1}) and recorded 3.50, 4.15 and 4.40 per cent average infestation along with 18.00, 16.37 and 16.27 q ha^{-1} grain yield, respectively. Monocrotophos 36 SL (1390 g ha^{-1}), a treated check resulted in 5.54 per cent average infestation and 13.42 q ha^{-1} grain yield.

Eleven insecticides including check insecticide (monocrotophos) were evaluated in field conditions against YSB and gundhi bug (Rath et al. 2015). The grain yield of treatment imidacloprid 17.8% @ 300 ml ha^{-1} was highest (5.28 and 5.21 t ha^{-1}) and was significantly superior to check insecticide monocrotophos 36% @ 1390 ml ha^{-1} (4.65 and 4.62 t ha^{-1}) and at par with thiamethoxam 25% @ 100 g ha^{-1} (4.9 and 4.85 t ha^{-1}), triazophos 40% @ 625 ml ha^{-1} (4.78 and 4.8 t ha^{-1}) and Sulfoxaflor 24% @ 375 ml ha^{-1} (4.96 and 4.92 t ha^{-1}) during 2011 and 2012, respectively.

In Imphal, Devi and Singh (2016) evaluated the field efficacy of flubendiamide 39.35 SC @ 24 g a.i. ha^{-1}, fipronil 80 WG @ 40 g a.i. ha^{-1}, imidacloprid 17.8 SL @ 25 g a.i. ha^{-1}, thiamethoxam 25 WG @ 25 g a.i. ha^{-1} and spinosad 2.5 SC @ 50 g a.i. ha^{-1} against *S. incertulas*. Among these insecticides, flubendiamide was found very effective and recorded lowest dead hearts and white ears followed by fipronil and imidacloprid. The highest grain yield was also recorded with flubendiamide.

Mondal and chakraborty (2016) assessed the relative efficacy of three selected plant extracts *i.e.* neem, tobacco, akando and two selected chemical insecticides *i.e.* dursban 20 EC @ 3.2 L ha^{-1} and fipronil 0.3 G @ 4.5 kg ha^{-1} against YSB at murshidabad (West Bengal). Neem @ 1.5 L ha^{-1} significantly controls *S. incertulas* population that is comparable with chemical insecticides. Fipronil showed the reduction of 56.28 per cent (DH) and 65.27 per cent (WE) over control after 35 days of spraying. The result indicated that application of neem formulation effectively reduces *S. incertulas* infestation in consideration to chemical insecticides.

Prasad (2016) evaluated eleven new insecticides against *S. incertulas*. The infestation in terms of white ear head varied from 1.71 to 11.25 per cent. The lowest infestation (1.97%) and highest yield (32.03 q ha^{-1}) were recorded with sulfoxaflor 24 SC (375 ml ha^{-1}) followed by acephate 95 SG (592 g ha^{-1}). Monocrotophos 36 SL (1390 ml ha^{-1}) as check-insecticide was found superior over untreated check and recorded 5.13 per cent infestation and 24.53 q ha^{-1} grain yield.

Sandhu and Dhaliwal (2016) found out the effectiveness of different insecticides against rice stem borer at Krishi Vigyan Kendra, Sri Muktsar Sahib (Punjab). All the insecticidal treatments were significantly superior to untreated control. Fame 480 SC @ 50 ml ha^{-1} was found most promising with minimum dead heart and white ears. Considering the efficacy data and very low dose (ha^{-1}), Fame 480 SC proved to be better and economically viable option for management of rice stem borer.

Fakruddin et al. (2017) evaluated the impact of newer insecticides against YSB and found that cartap hydrochloride recorded a low overall mean (6.86% dead hearts and 6.85% white ears). The order of efficacy was cartap hydrochloride ≥ indoxacarb > carbosulfan > fipronil > phosphamidon > flubendiamide > emamectin benzoate > buprofezin. The grain yield (56 q ha^{-1}) and benefit cost ratio (1: 2.34) were higher in cartap hydrochloride compared to the untreated check (34 q ha^{-1}).

Jaiswal and kumar (2017) revealed that all the chemical treatments were significantly superior over control. Among all the treatments lowest YSB infestation was recorded in fipronil (1.02) followed by monocrotophos (1.37), spinosad (1.69), cartap hydrochloride (1.98), chlorpyriphos (2.15), imidacloprid (2.44) and acephate (3.02) as compared to control.

Omprakash et al. (2017) evaluated comparative efficacy of some insecticides against YSB. The infestation in terms of dead heats varied from 1.8 to 13.2 per cent and white ears from 0.4 to 25.6 per cent. Chlorantraniliprole 0.4 G @ 10 kg ha^{-1} followed by chorantraniliprole 18.5 SC @ 150 ml ha^{-1} with average 1.9 and 2.5 per cent dead hearts and 0.7 and 1.0 per cent white ears damage, respectively. Regarding the yield chlorantraniliprole 0.4 G recorded higher average yield (69.63 q ha^{-1}) and all other insecticidal treatments showed significantly superior over untreated control (47.21 q ha^{-1}).

Pallavi et al. (2017) studied the effect of different treatments on crop loss due to YSB. The results revealed that the plots which was sprayed thrice at 15 days after sowing in nursery followed by 15 and 30 days after transplanting was considered as best treatment. The lowest yield loss compared to the best treatment was realized with 11.07 per cent in the treatment which was sprayed at 15 and 30 days after transplanting. Finally if there were no spray against stem borer, yield loss may expect up to 87.66 per cent.

Rana and Singh (2017) found chlorantraniliprole 18.5 SC most effective with minimum infestation of *S. incertulas* 2.73 per cent DH and 2.06 per cent WE after first and second spray, respectively. Whereas, among the insecticidal treatments the maximum DH (6.18%) and WE (7.47%) infestation were recorded from chlorpyriphos 50 + cypermethrin 5 EC. The untreated control was recorded with maximum dead hears (9.50%) DH after first spray and (8.67%) WE after second spray infestation. The maximum yield (44.58 q ha^{-1}) was recorded from chlorantraniliprole 18.5 SC, whereas the highest cost benefit ratio (1:12.56) was calculated in fipronil 5 SC.

Singh et al. (2017) studied the efficacy of different novel insecticides and bio-pesticides against stem borer. All the insecticidal treatments were found significantly effective in reducing the infestation and increasing the yield compared with control. Application of fipronil 5 SC was the most effective treatment in reducing the stem borer infestation. The maximum cost benefit ratio (1:2.43) was also obtained in the treatment of fipronil 5 SC.

Singh et al. (2018) evaluated the efficacy of some insecticides at different doses against the yellow stem borer in rice. They reported that among all the insecticides, profenofos 40% + cypermethrin 4% @ 880 g a.i. was most effective against the yellow stem borer, followed by profenofos 40% + cypermethrin 4% @ 440 g a.i. All the treatments were found effective and significantly superior over the control.

3. MATERIALS AND METHODS

The present studies on “Bio-ecology and management of *Scirpophaga fusciflua* Hampson” were carried out under laboratory as well as field conditions during *Kharif* 2015 to 2017 at Rice and Wheat Research Centre of CSK Himachal Pradesh Krishi Vishvavidyalaya at Malan (Kangra), Himachal Pradesh. The materials used and the methods employed during the course of the present study have been described in this chapter.

Experimental location

The experimental site lies in Kangra valley at 32°07.180 North latitude and 76° 25.065 East longitudes among Dhauladhar and Shivalik ranges of Himalayas at an elevation of 961 meters above mean sea level in Kangra district of Himachal Pradesh. The area represents the mid hills sub-humid zone of Himachal Pradesh.

Crop raising

Seedlings of Kasturi variety of paddy were transplanted during the second week of July during *Kharif* 2015-2017, followed by the recommended agronomic practices except the plant protection measures.

Mass rearing of white stem borer

For maintaining the culture of white stem borer (WSB), *S. fusciflua* in laboratory conditions, the field collected larvae were released on potted plants till the adult emergence. The emerged adults were sexed on the basis of abdomen and kept for oviposition in caged potted plants provided with 5 per cent honey solution as food. On alternate days, the potted plants with eggs were shifted to another cage for hatching and further development. After the completion of developmental stages, freshly emerged adults were collected daily, paired and kept for oviposition. The culture so obtained was used in various experiments from time to time. The culture of the test insect was maintained in the laboratory under prevailing conditions.

3.1 Annual life cycle studies

3.1.1 Morphometrics of different developmental stages

During the studies on biology of white stem borer under laboratory conditions on paddy hills, the observations on colour, shape and size (length and width) of different developmental stages *viz*., egg, larvae, pupa and adult were recorded. Measurements were taken under a stereo-zoom microscope fitted with imaging software (Nikon DSi). These observations were made on ten randomly selected individuals. The adults (males and females) were stretched and observations on body length and wing expanse were also recorded.

3.1.2 Number of generations

Separate experiment was also laid side by side under laboratory conditions where potted plants of rice were kept in 10 replications under cages. Newly emerged white stem borer adults were released in 5 pairs for egg laying. After successful egg-laying and hatching, larvae were allowed to grow till the cycle from egg to egg was completed and it was marked as one generation. Again 5 pairs of adults were taken from the first generation and released in a similar manner for second generation. The same process was continued throughout the year to record the number of generations of *S. fusciflua* in a year. Various parameters with respect to the annual life cycle of the pest were recorded.

3.1.3 Biology

Primary culture of adults to study the biology of the pest was collected from the mass culture. Egg laying capacity of the pest was studied by confining pairs of male and female in caged potted plants maintained for raising the laboratory culture. Paddy leaves with base dipped in water in a small tube were kept in the jar for the female to lay eggs on them. Honey solution (5%) in cotton swabs was provided as food to adults as per method suggested by Korat and Patel (1988).

3.1.3.1 Incubation period and hatching percentage

Ten freshly laid egg masses on the leaves were kept in the specimen tubes plugged with moist cotton wrapped in muslin cloth to study the incubation period and hatching percentage. The experiment was repeated ten times. The eggs were observed daily to record the number of eggs hatched on a particular day and to determine the developmental time. The period between date of oviposition and date of hatching was considered to be the incubation period. The hatching percentage was also calculated.

3.1.3.2 Number of larval instars and their duration

Larval period was studied by rearing the 100 newly hatched larvae on the tender pieces of paddy stems, the basis of stems were wrapped with cotton wool soaked in water. Such pieces of stems with larvae were kept in jars covered with muslin cloth. These stems were changed after two days interval. The duration of first instar was taken as the period lagging between larval emergence and first moulting characterized by change in colour of head capsule. The duration of second and third instar was determined by change in body colour at the time of moult. The duration of other instars was taken as the time period between two successive moults. Time gap between hatching of eggs and cessation of larval feeding was considered as the total larval period.

3.1.3.3 Pupal duration

The larvae which were used to record the number and duration of larval instars were also used to observe the pupal duration. After pupal formation each stem was split open from the top to facilitate easy emergence of the adults. Such stems with pupae were kept in jars covered with muslin cloth. The period between pupation and emergence of adult was considered as the pupal period. The moths so emerged were sexed to determine the sex ratio.

3.1.3.4 Adult fecundity, oviposition and longevity

Ten pairs of newly emerged moths were taken and each pair was released in caged potted plants covered with nylon net for mating and egg laying. Fecundity was determined on the basis of total number of eggs laid by a female during its life span. Visual observations were made to record the pre-oviposition, oviposition and post-oviposition period. The period between the emergence of adult female moth and the start of egg laying was recorded as the pre-oviposition period and the time taken from initiation of egg laying to the last egg laid by the female as the oviposition period. Post-oviposition period was considered as the time period between the last egg laying and death of the female. The adult longevity was recorded for both the sexes separately. Total number of days for which the adults survived was taken as adult longevity.

3.2 Population build-up of white stem borer

Population build-up of WSB was undertaken at nearby farmers' field (Kohala and Jia) of Kangra district besides the experimental field trial at RWRC, Malan. The crop was surveyed regularly for pest incidence starting from tillering to dough stage. For recording the observations, three plots of 250 m^2 (approximately) each were selected at each locality. The methodology used to determine the seasonal incidence and population fluctuation of white stem borer by different methods *viz.,* light trap, sweep net method catch, larval population count and plant infestation estimation is given as under:

3.2.1 Light trap (Ryrholm model)

The seasonal population fluctuation of WSB was monitored with the help of light trap and to achieve this objective a light trap provided with 200 watt mercury bulb was placed in paddy field, from early vegetative stage till the maturation stage of paddy throughout the *Kharif* crop season. The light trap was operated from 6:00 PM to 5:00 AM daily (Plate 3.1). The white stem borer adults trapped were collected and mean number of adults trapped per week was worked out.

3.2.2 Sweep net

The assessment of adult population under field conditions was made with the help of sweep net method at weekly intervals (Plate 3.1). The sweeps were made from one corner of the selected plot to the other corner diagonally, thus covering the whole field from four corners through the centre and a total of 5 sweeps were undertaken. The total adults per sweep and mean number of adults caught per sweep were worked out.

3.2.3 Larval population count

To assess the larval population in paddy fields during the crop season, random sampling of 10 hills was made from each block to observe the number of larvae and weekly mean was calculated. Individual tillers were dissected for the presence of larvae and pupae (Alam 1992).

3.2.4 Plant infestation

The per cent plant infestation was workout by counting number of dead hearts or white ears from 10 randomly selected hills per plot by using the formula:

At vegetative stage:

Plant infestation (%) = $\frac{\text{Total number of dead hearts}}{\text{Total number of tillers}} \times 100$

At booting stage:

Plant infestation (%) = $\frac{\text{Total number of white ears}}{\text{Total number of panicle bearing tillers}} \times 100$

Observations recorded on the larval population and plant infestation were utilized to work out the infestation index as follows:

Infestation Index = $\frac{\text{Larval population} \times \text{Per cent plant infestation}}{100}$

3.2.5 Influence of weather factors on population build-up of white stem borer

The population of WSB (both adults and larvae) and per cent plant infestation was correlated with various abiotic factors *viz.,* maximum and minimum temperature (°C), relative humidity (%) and total rainfall (mm). The data on population and prevailing abiotic factors were subjected to multiple linear regression analysis for evolving population forecast model. For this study, the weekly meteorological data were obtained from the meteorological observatory of RWRC, Malan.

3.3 Associated natural enemies

The fortnightly surveys of paddy fields of the experimental field trial at RWRC, Malan were made to study the abundance of natural enemies associated with WSB. Observations were made on predators and parasitoids of white stem borer by using following methods:

3.3.1 Predators associated with white stem borer

Observations on the associated predators were recorded on same day and from the same fields where sweepings were done for WSB. The data on predators were recorded and the total number of predators collected was worked out.

For estimating the diversity of predators following formula was used:

$$\text{Relative proportion of } i^{th} \text{ species} = \frac{\text{Total number of individuals of } i^{th} \text{ species}}{\text{Total number of individuals of all the species}} \times 100$$

i^{th} species = predator species associated with WSB

3.3.2 Parasitoids associated with white stem borer

Selected area was monitored at three crop stages *viz.,* tillering stage, maximum tillering stage and heading stage, during the crop season. At fortnightly intervals stem borer egg masses were collected from surveyed plots, based on availability ranging from 10-15 egg masses from unsprayed plot. Thereafter, stem borer egg masses were kept under observation for the emergence of adult parasitoids. Based on number of larvae emerging and parasitoid emergence the per cent egg parasitism was worked out.

On an average, 50 damaged tillers (dead heart/white ear) were collected at 15 days intervals from field and from these affected tillers, larvae of WSB were collected. Which were reared individually in collection vials on stem. To maintain the turgidity of stem, moistened cotton wool covered with filter paper was used. The stem was changed every 24 hours till the larvae pupated. The larvae and pupae were observed for the emergence of parasitoids. Observations on the parasitoids were made under laboratory conditions on the developing stages of the pest.

Based on the parasitoid emerged from eggs, larvae and pupae the per cent parasitization was calculated using following formula:

$$\text{Parasitization (\%)} = \frac{\text{Number of parasitized eggs or larvae or pupae}}{\text{Total number of eggs or larvae or pupae sampled}} \times 100$$

3.4 Assessment of yield losses

3.4.1 Experimental treatments and design

The experiments to assess the yield loss caused by WSB were conducted in RBD during 2016 and 2017. The trial was aimed to generate data on the extent of losses caused by WSB at different stages of crop growth. Varying levels of pest damage were created through the artificial release of larvae to know its impact on grain yield. The whole experimental area (400 m2) was divided into four equal plots (100 m2). Different levels *i.e.* 0, 2, 4, and 6 neonate larvae per hill were released at 32 DAT of paddy crop in each treatment.

The procedure followed by Indian institute of Rice Research, Hyderabad was used for yield loss estimation (Anonymous 2014). Four rice hills were selected and marked by bamboo sticks and these four hills served as one replication of a treatment. These hills were covered with nylon net supported with four bamboo sticks at the corners (Plate 3.3). Pre-treatment observations were recorded on total number of tillers and number of damaged tillers before enclosing the treatments. Each treatment was then infested with indicated release levels of WSB larvae obtained from a mass culture maintained in the laboratory. The net was removed after 10 days and data on damage caused by WSB larvae at various release levels were recorded by counting the total number of tillers and damaged tillers (dead hearts/white ears) on a day immediately after the removal of net followed by 30 days after the second observation *i.e.* at 42 and 72 DAT.

3.4.2 Yield components

The panicles from four hills of each replication were harvested at the maturity of the crop and placed in an envelope for recording yield data. These panicles were threshed, cleaned and weighed.

The avoidable yield losses were calculated using following formula outlined by Atwal and Singh (1990) given here under:

$$\text{Avoidable losses (\%)} = \frac{\text{Yield in uninfested rice hills} - \text{Yield in infested rice hills}}{\text{Yield in uninfested rice hills}} \times 100$$

3.5 Evaluation of insecticide/botanicals

Efficacy of six insecticides/botanicals *viz.*, flubendiamide, rynaxypyr, dinotefuran, monocrotophos, melia and eupatorium was evaluated against WSB. The experiment was conducted in RBD with 3 replications and 7 treatments (6+1 untreated check) on paddy at farmers' field (Kohala) in Kangra district, during *Kharif* 2015 and 2016 in the plot size of 9.6 m^2 with row to row and plant to plant spacing of 20 cm and 15 cm, respectively. The details of insecticides and biopesticides evaluated against the pest are given below in Table 3.1.

Table 3.1 Details of treatments used in the study

Treatment		Dosage (per ha)
T_1	Flubendiamide 48 % SC	50 ml
T_2	Rynaxypyr 20 SC	150 ml
T_3	Dinotefuran 20 % SG	200 g
T_4	Monocrotophos 36 % SL (standard check)	850 ml
T_5	Melia 5 % (*Melia azedarach* (L) extract)	2.5 L
T_6	Eupatorium 5 % (*Eupatorium adenophorum* Spreng extract)	2.5 L
T_7	Untreated check	-

Note: Manual spraying using knapsack sprayer was practiced; in untreated check no insecticide or biopesticides was sprayed.

The insecticides were applied 30 days after transplanting and were repeated at 15 days interval. Two consecutive applications were made. For recording the data with regard to the incidence, ten hills were marked in each plot and observations on white stem borer incidence were recorded one day before and at seven and fifteen days after spray. The grain yield per plot was recorded. The grain yield of all the treatments was recorded from all the three replications and converted to quintals per hectare. The economics of different insecticidal treatments was worked out on the basis of prevailing market price of insecticides and application cost and finally the incremental output input ratio was also worked out.

Statistical analysis

The data pertaining to the population of white stem borer and per cent infestation were correlated with various abiotic factors *viz.*, maximum, minimum temperature (^{0}C), morning, evening relative humidity (%) and rainfall (mm). The population and abiotic factor data were also subjected to multiple linear regression for evolving population forecast model. The data collected on different parameters were subjected to analysis with the help of various experimental designs (Randomized Block Design and Factorial Randomized Block Design) using the software CPCS-1 as per procedure suggested by Gomez and Gomez (1984).

(a) Light trap (Ryrholm model) **(b) Sweep net**

Plate 3.1 Monitoring of pest by using light trap and sweep net

Plate 3.2 Trial conducted at experimental farm RWRC, Malan

(a) General view of trial

(b) White stem borer larvae confined under nylon net

Plate 3.3 Yield loss estimation trial

Plate 3.4 Trial conducted at farmers' field

4. RESULTS AND DISCUSSION

The results obtained during the present investigation entitled “Bio-ecology and management of *Scirpophaga fusciflua* Hampson” are presented and discussed in this chapter under following heads:

4.1 Annual life cycle of white stem borer

4.1.1 Morphometrics of different developmental stages

The data pertaining to description and measurements of different developmental stages of white stem borer as carried out in laboratory conditions are presented in Tables 4.1-4.2 and Plate 4.1-4.2.

4.1.1.1 Egg

Eggs were laid in clusters on upper surface of the leaf tip near the mid rib and covered by yellowish hairs from the anal tuft of the female moth. The freshly laid eggs were oval, flattened and creamy white in colour, but later on changed to light brown colour and again to dark brown just before hatching. Egg on an average measured 0.60 mm in length and 0.52 mm in width.

4.1.1.2 Larvae

First instar: The newly hatched larva was black in colour and they moved rapidly on the leaves for one to two hours and then penetrate at the base of leaf sheath into the stem. The colour of the larvae changed during second instar from black to creamy white having a dark head and well developed prothoracic shield and measured on an average 1.95 and 0.25 mm with regard to its body length and body width, respectively. The average head capsule width of first instar was 0.19 mm.

Second instar: The body size on an average was observed to be 6.49 mm in length and 0.88 mm in width. The average head capsule width of second instar was 0.38 mm.

Third instar: It measured on an average 7.95 mm (body length) and 1.00 mm (body width). The average width of third instar head capsule was 0.54 mm.

Fourth instar: The body size on an average was observed to be 10.72 mm in length and 1.64 mm in width. The average head capsule width of fourth instar was 0.90 mm.

Fifth instar: The full grown larvae were smooth, pale yellowish white with the orange yellow colour heads and well developed prothoracic shield. All the larvae after hatching bored into the stem but only a few survived to reach the adult stage. Fifth instar larvae before pupation made emergence holes. The average size was (body length × width) 15.03 × 1.99 mm and head capsule width of fifth instar was 1.03 mm.

Table 4.1 Morphometerics of different developmental stages of *Scirpophaga fusciflua*

Stage	Length (mm)		Width (mm)	
	Range	**Mean±SE**	**Range**	**Mean±SE**
Egg mass	3.25-10.62	6.69±0.693	1.92-2.00	2.49±0.110
Egg	0.55-0.63	0.60±0.011	0.50=0.54	0.52±0.005
Larval Instar				
I	1.56-2.25	1.95±0.072	0.22-0.30	0.25±0.008
II	6.00-7.55	6.49±0.136	0.82-0.95	0.88±0.014
III	7.95-9.12	8.49±0.124	1.00-1.15	1.11±0.023
IV	9.87-11.78	10.72±0.223	1.56-1.71	1.64±0.018
V	12.58-16.45	15.03±0.544	1.92-2.06	1.99±0.150
Pupa	11.32-12.75	12.14±0.181	2.10-2.18	2.15±0.009
Adult				
Male	7.52-8.60	8.06±0.142	-	-
Female	9.48-14.52	11.87±0.576	-	-
Wing span				
Male	16.00-19.60	17.80±0.421	-	-
Female	22.00-26.70	24.47±0.535	-	-

*Mean of ten individuals

(a) Egg mass **(b) Pupa**

(c) Egg masses **(d) Adult**

Plate 4.1 Life stages of white stem borer

(a) I (b) II (c) III (d) IV (e) V

Plate 4.2 Different larval instars of white stem borer

4.1.1.3 Pupa

Pupation occurred within the rice stem. The newly formed pupae were yellowish white in colour with the greenish tinge. Later it turned to dark brown colour before the emergence of the adult. Length and width varied from 11.32 to 12.75 with an average of 12.14 mm and 2.10 to 2.18 with an average of 2.15 mm, respectively.

4.1.1.4 Adult

Both the male and female are white in colour. The female is larger than male with the tuft of yellowish hairs at the tip of abdomen. Females measured body length and wing expanse of 11.87 and 24.47 mm, respectively, as compared to 8.06 and 17.80 mm in case of males. The present findings are in agreement with Kumar (1996).

Table 4.2 Head capsule width of different larval instar

Stage	Head capsule Width (mm)	
	Range	Mean±SE
Larval Instar		
I	0.18-0.12	0.19±0.001
II	0.29-0.47	0.38±0.018
III	0.51-0.57	0.54±0.009
IV	0.85-0.94	0.90±0.009
V	0.96-1.12	1.03±0.020

*Mean of ten individuals

4.1.2 Number of generations

The number of generations of *S. fusciflua* was worked out to be a year thus recorded during emergences in the rearing cages under laboratory conditions during active crop season of study (Table 4.3). The first generation of adults emerged during the month of July caused first damage to the paddy plants at an early stage of plant growth. This low population of adults was followed by the second major population build up during the months of August and September causing maximum infestation. Adults thus collected from field during mid July, completed its first generation by first week of September with the average period of 48.9 days during 2015.

The second generation (first week of September - mid May) lasted for 256.8 days during the year 2015-2016 under laboratory condition, because at the end of the crop season, as the temperature decreased, the full grown larvae diapaused in rice stubbles, adult of which emerged during last week of April to first week of May under laboratory conditions.. Third generation started from mid May and completed in first week of July and its duration was 52 days. While under field conditions, two generations of white stem borer were observed. Because at the end of the crop season, as the temperature decreased, the full grown larvae of this generation or the pupal stage undergo diapause and remain in the stubbles which get burried in the soil at the time of field preparation for winter season. This stage continues from the month of November to June and July.

Table 4.3 Annual life cycle of *Scirpophaga fusciflua* under laboratory conditions (July 15, 2015 to July 7, 2016)

Developmental Stage/ Parameter		**G_I**	**G_{II}**	**G_{III}**
Egg	Incubation period (days)	7.9	7.7	8.2
	Hatchability (%)	67.2	71.2	69.8
Larval Instar				
I	Duration (days)	5.6	5.8	5.6
II	Duration (days)	5.4	5.6	5.3
III	Duration (days)	5.9	6.4	6.5
IV	Duration (days)	6.5	7.2	7.1
V	Duration (days)	7.6	211.2	7.9
Total Larval	Duration (days)	31.1	236.2	32.4
Pupa	Duration (days)	7.6	10.5	9.0

G_I : Mid July to 1st week of September
G_{II} : 1st week of September to mid May
G_{III} : Mid May to 1st week of July

The present results are strongly supporting the findings of Rehman et al. (2002), Li (1961), Israel et al. (1965) and Kumar (1996), they reported that larvae of the last generation hibernate in rice stubbles from November to the end of March and early April till pupation. In the present investigations larvae were found only in the stubbles and no tunnels were observed. Due to different agro-climatic conditions, moths were present only for the four months, largely during the active rice growing season, remaining abnormal in larval and pupal stages for eight months.

4.1.2.1 Incubation period

Observations recorded on the incubation period revealed that the average incubation period was 8.2 days in third generation followed by first and second generation with 7.9 and 7.7 days, respectively (Table 4.3). In the present study, the incubation period was approximately similar to earlier studies conducted by Kok and Varghese (1966), Banerjee and Pramanik (1967), Ghrist and Lever (1969), Korat and Patel (1988) and Bora et al. (1994) who recorded incubation period varied between 4 to 9 days. The per cent hatchability varied from 67.2 to 71.2 with an average of 69.8 percent during different generations. Almost similar findings made by Kumar (1996).

4.2.1.2 Larval period

The average duration of first larval instar was 5.6 days in first and third generation followed by second generation. The average duration of second instar varied between 5.3 to 5.6 days. The third instar average duration was maximum in second generation (6.4 days) followed by third and first instar with 6.5 and 5.9 days, respectively. The mean duration of fourth instar varied between 6.5 to 7.2 days with the lowest value corresponding to first generation and highest to second generation. The duration of fifth larval instar on an average 7.6, 211.2 and 7.9 days for first, second and third generation, respectively. According to the Kok and Varghese (1966), Bora et al. (1994), Jadhao and Khurad (2012) the larval stage lasted for 27- 30 days with 5 larval instars. These findings are very much in conformity with present findings.

4.1.2.3 Pupal period

The mean duration of pupa varied between 7.6 to 10.5 days with the lowest value corresponding to first generation and highest to second generation (Table 4.3). These findings are in agreement with those of Korat and Patel (1988), Islam and Catling (1991), Malhi and Brar (1998) and Jadhao and Khurad (2012) who reported pupal period lasted for 6 to 9 days.

4.1.2.4 Adult

In females, mean pre-oviposition period varied between 23.8 to 24.1 hours amongst different generations and higher oviposition period was recorded during second generation (26.0 hr) and minimum during third generation (24.9 hr). However, the average post-oviposition period was 6.6, 6.0 and 6.5 hours during first, second and third generation, respectively (Table 4.4). Present studies are much closer with findings of Malhi and Brar (1998), Korat and Patel (1988), Kumar (1996) and Jadhao and Khurad (2012) who reported the pre-oviposition, oviposition and post oviposition periods as (1.06, 0.92 and 0.85 days), (1.13, 1.33 and 0.27days), (21.8, 7.9 and 5.2 hours) and (1.0 and 1.5 days), respectively.

Table 4.4 Reproductive parameters of *Scirpophaga fusciflua*

Parameter	**G_I**	**G_{II}**	**G_{III}**
Pre-oviposition period (hr)	23.9	24.1	23.8
Oviposition period (hr)	25.2	26.0	24.9
Post oviposition period (hr)	6.6	6.0	6.5
Adult longevity (hr)			
Male	43.2	46.4	47.1
Female	55.7	56.1	55.2
Fecundity (Number of eggs/ female)	58.4	65.6	60.3

It was recorded that the females lived longer than the males and maximum average female longevity of 56.1 hours was recorded during second generation followed by first and third generation with average longevity of 55.7 and 55.2 hours, respectively. However, average longevity of male varied between 43.2 to 47.1 hours. These results are in line with those of Kok and Varghese (1966), Kumar (1996), Malhi and Brar (1998) and Jadhao and Khurad (2012) who also reported longer longevity of female as compared to male.

The average fecundity varied from 58.4 to 65.6 eggs per female in different generations (Table 4.4). Maximum fecundity was observed in second generation (65.6 eggs), whereas, the minimum fecundity corresponded to first generation (58.4 eggs). According to Jadhao and Khurad (2012), Hugar et al. (2009), Bora et al. (1994) and Kumar (1996) the fecundity of the females varied from 24-150 eggs which more or less support our present findings. There were no much reports on various characteristics of white stem borer.

4.2 Population build-up of white stem borer

Population build-up of white stem borer was estimated in terms of adult catches (light trap and number per sweeps), larvae (per 10 DH/WE) and per cent plant infestation at locations *viz.,* Kohala and Malan during two seasons (2015 and 2016), whereas a third location Jia was included during 2016 and 2017 for survey.

4.2.1 Monitoring of white stem borer by using light trap and sweep net

The data contained in Table 4.5 and 4.6 represented the monitoring of pest during the year 2015-2017 and are discussed below:

The results on monitoring of white stem borer using light trap and adults per five sweeps revealed that the moths were found to be active from 29th to 40th SW and 31st to 40th SW, respectively. It is further inferred that pest population reached its peak through light trap catches and adults per five sweeps in first week of September *i.e.* 36th SW during 2015-2016. The highest number of adults (78 and 82) in light trap and 38 and 42 adults/ 5 sweeps were caught during first week of September *i.e.* 36th SW, respectively. Whereas, during 2017, peak activity of pest was noticed in second week of September *i.e.* 37th SW with population level of (78 adults light trap) and (55 adults/ 5 sweeps) and thereafter population started declining.

Table 4.5 Monitoring of *Scirpophaga fusciflua* during *kharif* 2015-2017 using light trap (Ryrholm model)

Month	**SW**	**Weekly trap catches**		
		2015	**2016**	**2017**
July	27	0	0	0
	28	0	0	0
	29	7	4	4
	30	12	7	9
August	31	18	20	9
	32	26	25	18
	33	38	48	37
	34	35	45	45
	35	48	72	49
September	36	78	82	70
	37	55	50	78
	38	32	38	56
	39	14	15	35
October	40	6	5	25
	41	0	0	0
	42	0	0	0
	43	0	0	0
	44	0	0	0

SW: Standard week

The preceding observations with respect to monitoring of white stem borer are corroborated by the findings of several others workers. Kumar (1996) and Dogra and Choudhary (2005), who also observed peak activity during the month of August-September. Similar observations were also reported by Saroja and Raju (1981), Lal

(2006), Mandal et al. (2011) and Sharma et al. (2011) as stem borer adult exhibiting their peak activity in the month of September.

Table 4.6 **Monitoring of *Scirpophaga fusciflua* during *kharif* 2015-2017 using sweep net**

Month	**SW**	**Adult catch/ 5 sweeps**		
		2015	**2016**	**2017**
July	27	0	0	0
	28	0	0	0
	29	0	0	0
	30	0	0	0
August	31	6	5	4
	32	15	8	6
	33	22	17	16
	34	19	19	26
	35	24	27	25
September	36	38	42	36
	37	25	29	55
	38	14	16	37
	39	6	6	14
October	40	3	0	6
	41	0	0	0
	42	0	0	0
	43	0	0	0
	44	0	0	0

SW: Standard week

4.2.2 Population build-up of white stem borer in terms of larval population and plant infestation

Kohala: The perusal of data presented in Table 4.7 on population build-up of white stem borer in terms of larval population and per cent plant infestation during 2015 at Kohala revealed that the larval population was first recorded at 32nd SW which was 0.25 larvae and maximum of 6.85 larvae were observed during 37th SW and thereafter it started declining. The last larvae incidence was recorded during 42nd SW. The plant infestation due to white stem borer was observed during the 31st SW with dead hearts incidence (4.95%) and it increased progressively with maximum (16.39%) white ears incidence recorded during 38th SW. However, during 2016, the larvae first appeared to infest paddy crop during 31st SW. The larval peak of 7.60 was recorded during 38th SW and followed a declining trend afterwards till the 40th SW. The damage symptoms due to white stem borer were visible from the (30th SW) with 4.13 per cent dead hearts incidence in the paddy fields. The peak infestation was recorded at (39th SW) with 16.66 per cent white ears incidence.

The pooled data based on two cropping seasons presented in Table 4.7 revealed that maximum larval population and per cent plant infestation were observed during 38th and 44th SW with 6.43 larvae and 16.53 per cent plant infestation, respectively.

Jia: Data contained in Table 4.8 on larval population and plant infestation at Jia during 2016 showed that the larvae incidence started appearing 0.70 larvae at 32nd SW. A maximum of 6.10 larvae was observed at 39th SW and afterwards it declined. The plant infestation 5.27 per cent dead hearts started appearing during 32nd SW. The plant infestation varied between 5.27 to 18.11 per cent with the peak plant infestation (18.11%) WE was recorded during 39th SW. Whereas, during 2017, the first appearance of larvae incidence was noticed at 30th SW which was 0.40 larvae and increased progressively with maximum of 6.70 larvae at 38th SW, thereafter the larvae incidence started declining. The last larvae incidence was recorded at 41st SW. The infestation in the paddy fields due to white stem borer varied between 4.85 to 19.07 per cent plant infestations. The peak infestation was recorded at (39th SW) with 19.07 per cent white ears incidence.

The pooled data based on two cropping seasons presented in Table 4.8 revealed that maximum larval population and per cent plant infestation were observed in 39th SW with 6.10 larvae and 18.59 per cent plant infestation, respectively.

Malan: The data presented in Table 4.9 on larval population and per cent plant infestation at Malan during 2015 revealed that larvae started appearing as early as during 31st SW and increased progressively with maximum of 5.66 larvae recorded during 39th SW, thereafter population started declining. The maximum of 15.45 per cent infestation was observed at 40th SW during 2015. However, during 2016, the peak incidence of larvae was observed during 39th SW and 38th SW with 7.00 and 5.60 larvae. Last incidence of larvae was recorded at 42nd SW and no more larvae population was recorded during 43rd and 44th SW. The plant infestation was initiated during the 32nd SW with dead hearts incidence of 4.26 per cent and infestation reached its peak of 18.78 percent white ears incidence recorded during 40th SW. Whereas, during, 2017, the first appearance of larvae incidence was observed in second week of August *i.e.* 32nd SW with a maximum of 6.29 larvae observed at 39th SW and followed a declining trend afterwards. The initial plant infestation due to white stem borer was during 32nd SW with 4.44 per cent dead hearts incidence and it increased progressively with maximum of 17.90 per cent white ears incidence recorded during 39th SW.

The pooled data based on three cropping seasons presented in Table 4.9 showed that maximum larval population and per cent plant infestation were recorded in 39th and 44th SW with 6.32 larvae and 17.38 per cent plant infestation, respectively.

Infestation index was also worked out between larval population and per cent plant infestation of different locations and showed that the maximum infestation index was observed in Jia followed by Kohala and Malan (Fig 4.1).

Our observations are strongly supported the findings of Wagan et al. (1999) who observed that the maximum larval infestation of borer was recorded during August and October in terms of dead heart and white ear, respectively. Additionally, Adiroubane and Raja (2010), Chavan et al. (2013), Kakde and Patel (2014) and Rana et al. (2017) recorded the higher incidence of borer during August-September.

Table 4.7 Population build-up of *Scirpophaga fusciflua* on paddy during 2015-16 (Kohala)

Month	SW	2015		2016		Pooled	
		Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *
July	27	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.00	0.00	0.00	4.13	0.00	2.07
August	31	0.00	4.95	0.80	6.49	0.40	5.72
	32	0.25	6.25	1.76	7.69	1.01	6.97
	33	1.00	8.68	2.75	8.27	1.88	8.48
	34	1.60	10.25	3.65	8.78	2.63	9.52
	35	2.35	12.12	4.40	19.78	3.38	15.95
September	36	4.15	13.28	5.75	11.78	4.95	12.53
	37	6.85	15.10	4.10	13.49	5.48	14.30
	38	5.25	16.39	7.60	15.67	6.43	16.03
	39	5.10	16.10	6.25	16.66	5.68	16.38
October	40	3.70	16.39	5.00	16.55	4.35	16.47
	41	1.33	16.02	0.00	16.45	0.67	16.24
	42	0.55	16.25	0.00	16.66	0.28	16.46
	43	0.00	16.39	0.00	16.48	0.00	16.44
	44	0.00	16.39	0.00	16.66	0.00	16.53

SW: Standard week *Mean per cent plant infestation per ten hills

Table 4.8 Population build-up of *Scirpophaga fusciflua* on paddy during 2016-17 (Jia)

Month	SW	2016		2017		Pooled	
		Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *
July	27	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.00	0.00	0.40	4.85	0.20	2.43
August	31	0.00	0.00	0.90	6.08	0.45	3.04
	32	0.70	5.27	1.50	6.52	1.10	5.90
	33	1.00	6.39	2.88	8.17	1.94	7.28
	34	1.30	8.93	3.70	10.45	2.50	9.69
	35	2.90	10.16	4.50	11.53	3.70	10.85
September	36	3.70	11.90	4.60	13.86	4.15	12.88
	37	4.00	14.28	5.80	15.12	4.90	14.70
	38	4.40	15.63	6.70	17.37	5.55	16.50
	39	6.10	18.11	6.10	19.07	6.10	18.59
October	40	4.30	18.02	4.70	18.98	4.50	18.50
	41	2.00	18.11	1.90	19.07	1.95	18.59
	42	0.00	18.05	0.00	19.02	0.00	18.54
	43	0.00	18.09	0.00	19.05	0.00	18.57
	44	0.00	18.11	0.00	19.07	0.00	18.59

SW: Standard week *Mean per cent plant infestation per ten hills

Table 4.9 **Population build-up of *Scirpophaga fusciflua* on paddy during 2015-17 (Malan)**

Month	SW	2015		2016		2017		Pooled	
		Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *	Number of larvae per ten dead hearts or white ears	Plant infestation (%) *
July	27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	31	0.75	3.49	0.00	0.00	0.00	0.00	0.25	1.16
	32	1.32	6.30	0.60	4.26	0.30	4.44	0.74	5.00
	33	0.90	7.62	1.20	5.54	0.80	5.15	0.97	6.10
	34	1.75	8.06	2.00	6.32	1.20	6.25	1.65	6.88
	35	2.10	9.85	2.60	7.82	1.80	8.11	2.17	8.59
September	36	2.80	8.10	3.10	9.05	3.10	9.05	3.00	8.73
	37	4.25	10.89	4.30	10.41	5.70	12.04	4.75	11.11
	38	3.75	11.11	5.60	12.42	5.80	14.70	5.05	12.74
	39	5.66	13.42	7.00	15.42	6.29	17.90	6.32	15.58
October	40	4.00	15.45	5.20	18.78	5.90	17.87	5.03	17.37
	41	1.85	15.35	3.40	18.65	3.20	17.85	2.82	17.28
	42	0.00	15.42	1.50	18.78	1.30	17.82	0.93	17.34
	43	0.00	15.4	0.00	18.75	0.00	17.89	0.00	17.35
	44	0.00	15.45	0.00	18.78	0.00	17.90	0.00	17.38

SW: Standard week *Mean per cent plant infestation per ten hills

Dead hearts **White ears**

Plate 4.3 Formation of dead hearts and white ears by larval instar

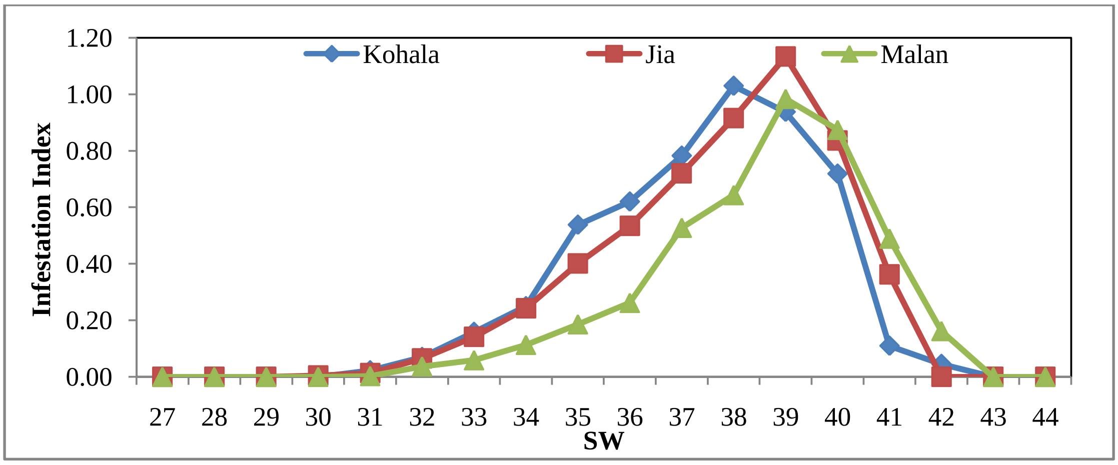


Fig. 4.1 **Infestation index of different locations**

4.3 Effects of abiotic factors on population build-up of white stem borer

The relationship between mean white stem borer population (adults, larvae and per cent plant infestation) of Malan with mean weekly meteorological parameters was worked out during 2015-2017 and data are presented in Table 4.10 and Fig 4.2-4.4.

4.3.1 Season I (2015)

The data revealed that maximum and minimum temperature had a positive and significant correlation with light trap catches (r= 0.599 and 0.512). However, negative and non-significant relationship was recorded with rainfall (r= -0.113) while morning and evening relative humidity (RH) were positively non-significant correlated (r= 0.161 and 0.216) to light trap catches. Similarly, adults per five sweeps were also found to be positively significant correlated (r= 0.533) to maximum temperature. However, RH (morning and evening) had positive non-significant correlation while rainfall showed negative non-significant correlation (r= -0.133). Whereas, correlation studies on larval population showed negative non-significant correlation with rainfall and RH (morning and evening) (r= -0.413, -0.195 and -0.108), respectively while maximum and minimum temperature showed positive non-significant correlation with larval population up to the tune of 0.173 and 0.149. Per cent plant infestation showed negative significant correlation with temperature (maximum and minimum), rainfall and RH (Morning and evening) r= -0.694, -0.736, -0.730, -0.742 and -0.797, respectively.

Table 4.10 Correlation (r) between various abiotic factors and population parameters of *Scirpophaga fusciflua* on paddy at Malan

Factor	Correlation (r)				
	Year	Trap catch	Adult Catch (Sweep net)	Larval population	(%) plant infestation
Max. temperature (°C)	2015	0.599*	0.533*	0.173	-0.694*
	2016	0.304	0.247	-0.128	-0.860*
	2017	0.081	0.088	0.208	-0.324
	Pooled	0.249	0.166	0.080	-0.462*
Min. temperature (°C)	2015	0.512*	0.458	0.149	-0.736*
	2016	-0.075	-0.097	-0.470	-0.811
	2017	0.299	0.223	-0.008	-0.546*
	Pooled	0.178	0.206	-0.048	-0.372*
Rainfall (mm)	2015	-0.113	-0.133	-0.413	-0.730*
	2016	-0.159	-0.231	-0.493*	-0.710*
	2017	-0.222	-0.253	-0.485*	-0.711*
	Pooled	-0.165	-0.212	-0.459*	-0.706*
Morning RH (%)	2015	0.161	0.171	-0.195	-0.742*
	2016	0.114	0.021	-0.152	-0.805*
	2017	-0.375	-0.428	-0.476*	-0.828*
	Pooled	-0.003	-0.065	-0.247	-0.730*
Evening RH (%)	2015	0.216	0.215	-0.108	-0.797*
	2016	0.083	-0.007	-0.171	-0.779*
	2017	-0.380	-0.435	-0.501*	-0.847*
	Pooled	0.018	-0.041	-0.216	-0.730*

* Significant at 5% level, n= 18, n= 54 (pooled)

4.3.2 Season II (2016)

The correlation analysis revealed that the light trap catches had a positive but non-significant correlation with maximum temperature and RH (morning and evening) and values of ‘r’ obtained were 0.304, 0.114 and 0.083, respectively; though it was non-significant negatively correlated with minimum temperature and rainfall (r= -0.075 and -0.159). Similarly, the adults per five sweeps also showed positive but non-significant correlation with maximum temperature and RH morning (r= 0.247 and 0.021), respectively. However, minimum temperature and rainfall were found to be non-significant negatively correlated (r= -0.097 and -0.231). On the other hand, larval population had non-significant negative correlation with temperature (maximum and minimum) and RH (morning and evening) (r= -0.128, -0.470, -0.152 and -0.171), respectively. However, negative significant relationship was recorded with rainfall (r= -0.493). The relationship of per cent plant infestation also showed significant negative correlation with temperature (maximum and minimum), rainfall and RH (morning and evening) (r= -0.860, -0.811, -0.710, -0.805 and -0.779), respectively.

4.3.3 Season III (2017)

During this year, it is evident from the data that maximum and minimum temperature showed positive correlation with light trap catches (r= 0.081 and 0.299), respectively. While rainfall and RH (morning and evening) were non-significant negatively correlated. Similarly, adults per five sweeps also showed positive correlation (r= 0.088 and 0.223) with maximum and minimum temperature. Whereas, correlation studies on larval population showed negative significant correlation with rainfall and RH (morning and evening) (r= -0.485, -0.476 and -0.501), respectively. However, maximum temperature was found to be positively correlated (r= 0.208). Per cent plant infestation also showed negative significant correlation with minimum temperature, rainfall and RH (morning and evening) (r= -0.546, -0.711, -0.828 and -0.847), respectively.

The pooled data based on three cropping seasons (2015-17) revealed that maximum and minimum temperature had a positive non-significant correlation through light trap catches with correlation 0.249 and 0.178, respectively. However, negative and non-significant relationship was recorded with rainfall and morning relative humidity (r = -0.165 and -0.03) while evening relative humidity (RH) was positively non-significant correlated to light trap catches. Similarly, adults per five sweeps were also found to be positively non-significant correlated to maximum and minimum temperature. However, RH (morning and evening) and rainfall had negative non-significant correlation. Whereas, correlation studies on larval population showed negative non-significant correlation with minimum temperature and RH (morning and evening), while rainfall showed negative significant correlation (r= 0.459) with larval population. Per cent plant infestation showed also negative significant correlation with temperature (maximum and minimum), rainfall and RH (Morning and evening) (r= -0.462, -0.372, -0.706, -0.730 and -0.730), respectively.

The findings of present investigation are supported by Mishra et al. (2012a) and Somashekara and Javaregowda (2015) who observed the adult population was positively correlated with minimum and maximum temperature, whereas it was negatively correlated with rainfall and relative humidity. Similarly, Isahaque and Rahman (1983) from Assam reported the positive correlation between maximum temperature and adult population. Bhatnagar and Saxena (1999) at Jagdalpur observed a significant negative correlation with minimum temperature, evening relative humidity and rainfall. Oo et al. (2003) concluded that the weather conditions including temperature and rainfall were considered important factors for light trap catches of stem borer.

According to Kumar et al. (2015) maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity and rainfall were positively correlated with the light trap. Zainab et al. (2017) reported that dead hearts and white ears incidence were negatively correlated with mean temperature, positively correlated with relative humidity and showed significant positive correlation with rainfall. Such differences could be due to the difference in agro-climatic conditions under which population build-up were studied.

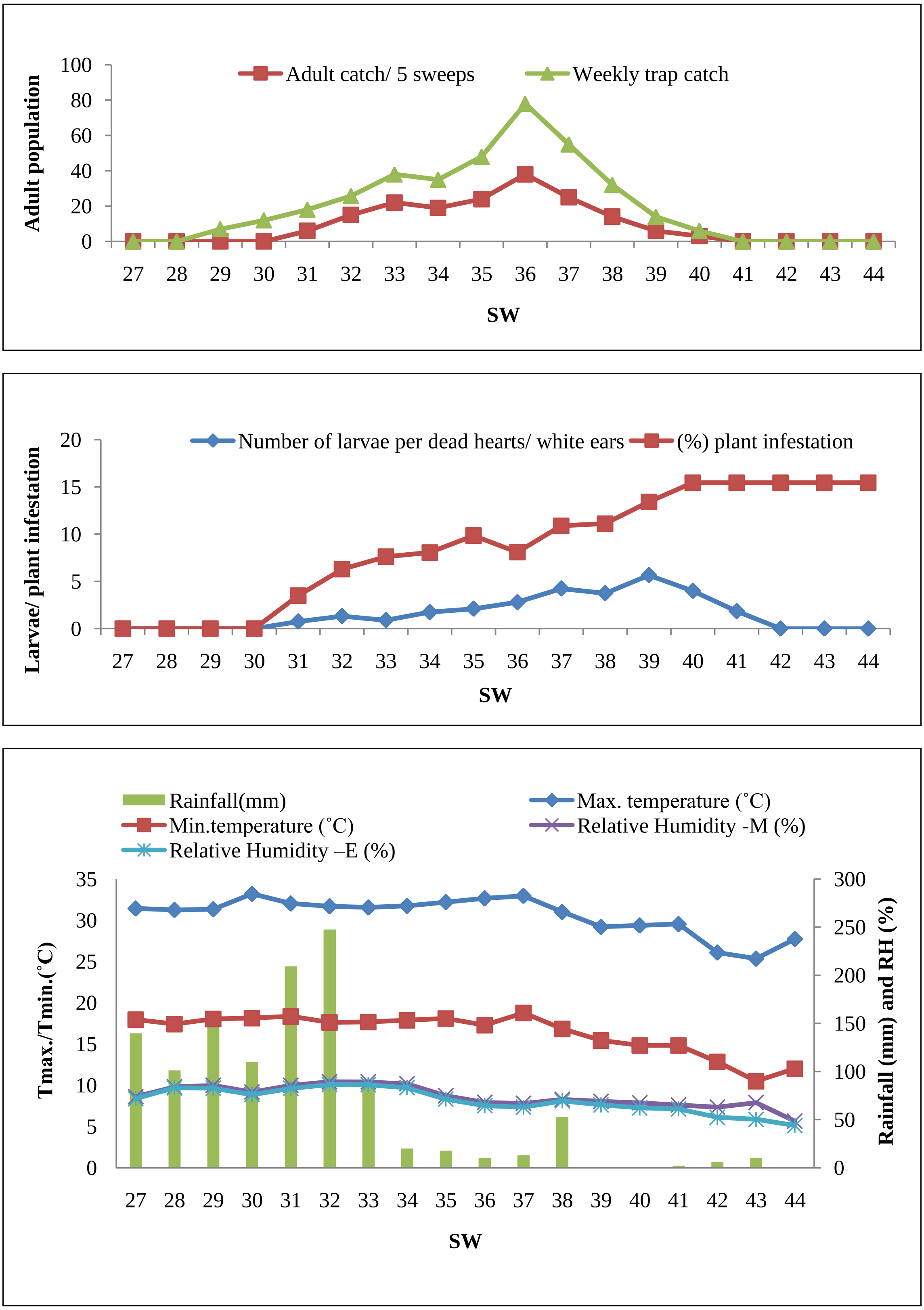
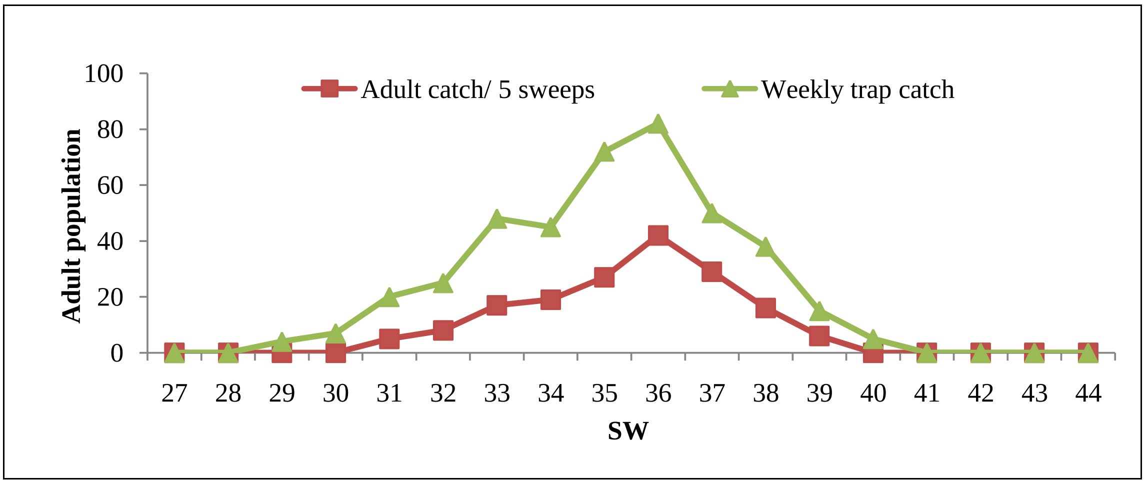
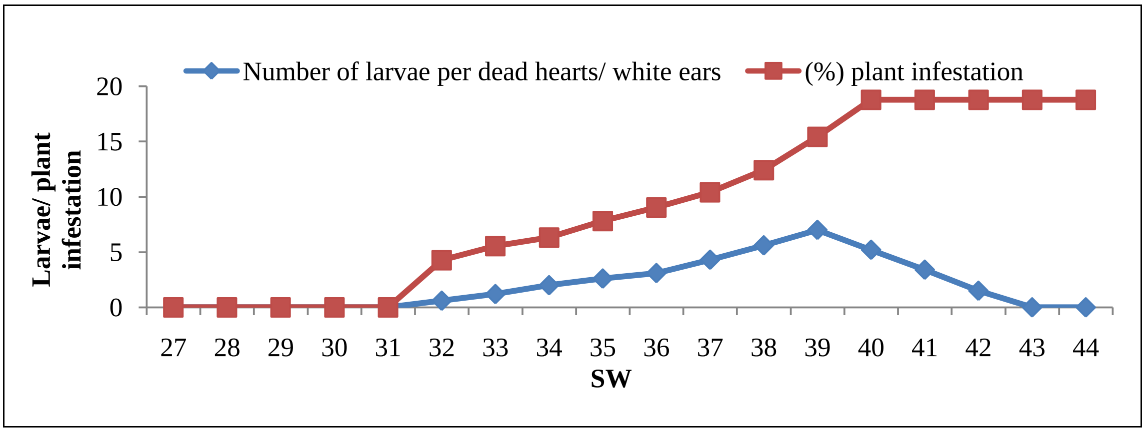


Fig. 4.2 **Effect of abiotic factors on average incidence of *Scirpophaga fusciflua* during 2015 (Malan)**





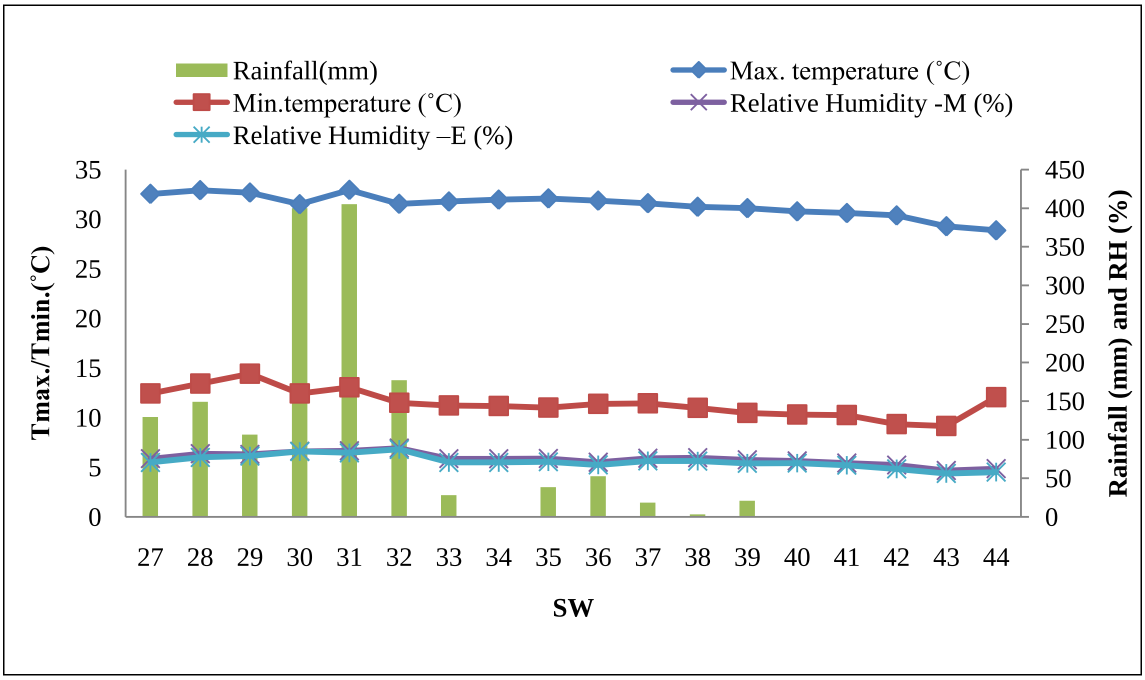


Fig. 4.3 **Effect of abiotic factors on average incidence of *Scirpophaga fusciflua* during 2016 (Malan)**

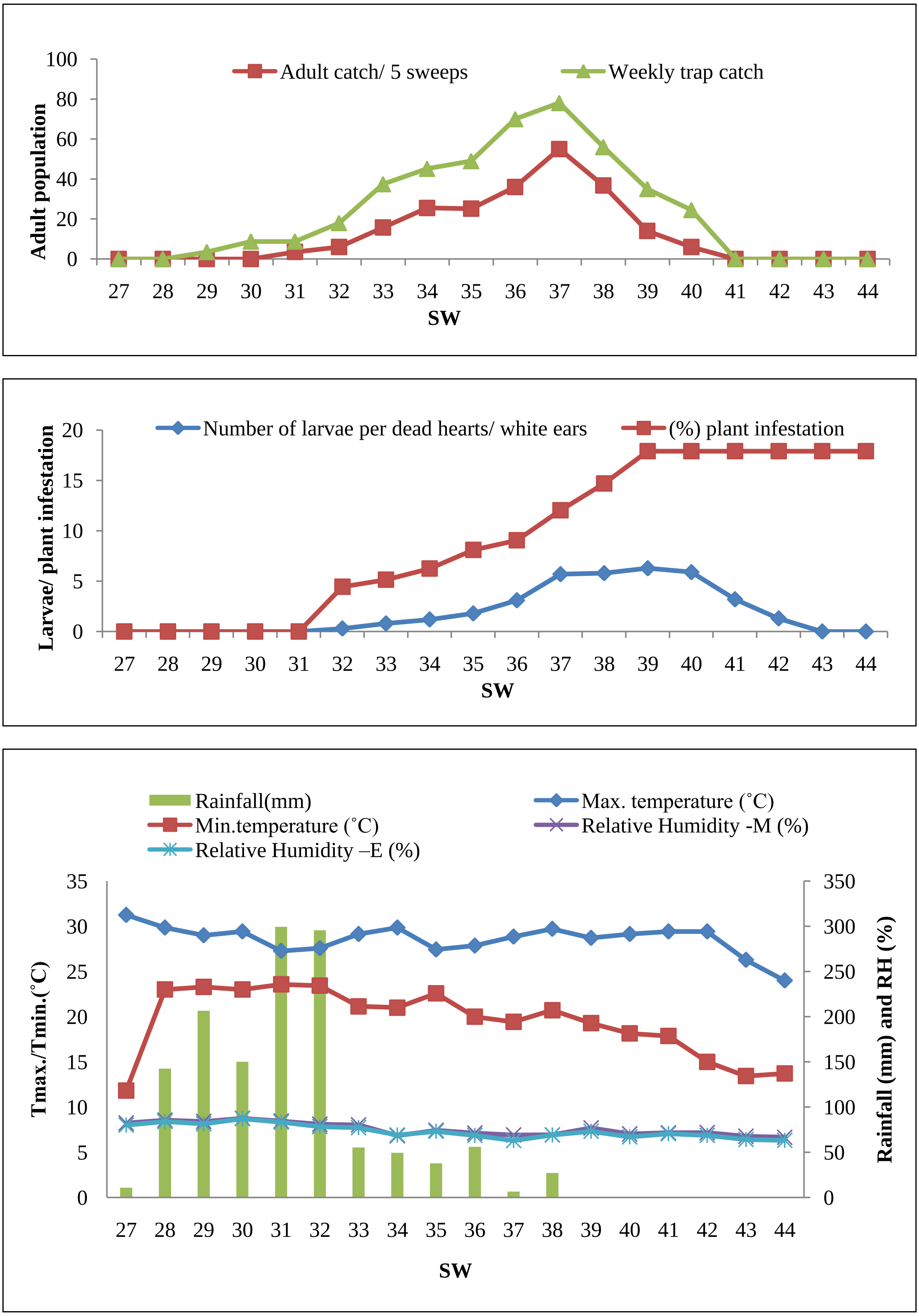


Fig. 4.4 **Effect of abiotic factors on average incidence of *Scirpophaga fusciflua* during 2017 (Malan)**

4.4 Relationship based upon step wise regression analysis

Step wise regression model evolved for predicting population build-up of white stem borer based upon relationship between abundance of adult catches, larval population and per cent plant infestation data of three consecutive years of Malan as dependent variable (Y) and abiotic factors *viz.*, temperature, rainfall and relative humidity as independent variable (X) presented in Table 4.11-4.14.

It was evident from data contained in Table 4.11 during 2015 stepwise multiple regression equations revealed that maximum temperature and rainfall were found to be influencing trap catch population significantly. Amongst them, maximum temperature alone contributed to the extent of 35 per cent for variation in trap catch population. Both maximum temperature and rainfall, jointly contributed to about 53 per cent trap catch. While in case of adult catch by using sweep net regression analysis revealed that maximum temperature was the most important factor affecting the adult catch population which alone contributed to 28 per cent. Furthermore, rainfall alone contributed about 17 per cent. The joint contribution of both the factors was up to 45 per cent of adult catch.

Table 4.11 Regression model for white stem borer population build-up during 2015

Regression equation	**R^2**
Light trap	
$Y = -165.39 + \mathbf{0.59\ T_{max}}$	0.35
$Y = -218.37 + \mathbf{0.79\ T_{max} - 0.46\ Rainfall}$	0.53
Adult catch	
$Y = -75.18 + \mathbf{0.53\ T_{max}}$	0.28
$Y = -101.67 + \mathbf{0.73\ T_{max}} - 0.45\ Rainfall$	0.45
Larval population	
$Y = -3.38 \mathbf{- 0.67\ Rainfall} + 0.492\ T_{min}$	0.35
Plant infestation	
$Y = 33.01 \mathbf{- 0.76\ RH_e}$	0.58
$Y = 25.94 \mathbf{- 0.48\ RH_e} - 0.39\ Rainfall$	0.65
$Y = 30.69 - 0.10\ RH_e \mathbf{- 0.45\ Rainfall} - 0.41\ T_{min}$	0.71

Values in bold are significant
RH: Relative humidity; T: Temperature
Subscript: max= maximum: min= minimum: m= morning; e= evening

However, rainfall and minimum temperature were observed to be the major factors influencing the larval population and contributed to the extent of 35 per cent. In case of plant infestation, the equation obtained by stepwise multiple regression depicted that evening relative humidity, rainfall and minimum temperature resulted in 71 per cent variation out of which the evening relative humidity alone contributed to the extent of 58 per cent.

A perusal of data presented in Table 4.12 during 2016 depicted that maximum and minimum temperature contributed about 23 per cent in trap catch population. In case of adult catch by using sweep net the maximum temperature and rainfall were found to influence the adult catch. The joint contribution of both the factors was up to 23 per cent of the adult catch population. Whereas, in case of larval population regression analysis revealed that rainfall was found to influence larval population significantly and alone contributed about 24 per cent. Further stepwise regression analysis revealed that other environmental factors *viz.,* evening relative humidity and minimum temperature contributed only 21 per cent variability in larval population.

Table 4.12 Regression model for white stem borer population build-up during 2016

Regression equation	**R^2**
Light trap	
Y = - 334.3 + 0.63 T_{max} - 0.49 T_{min}	0.23
Adult catch	
Y = - 78.3 + 0.47 T_{max} - 0.46 Rainfall	0.23
Larval population	
Y = 2.76 - **0.49 Rainfall**	0.24
Y = - 0.92 - **0.72 Rainfall** + 0.65 RH_e - 0.45 T_{min}	0.45
Y = - 5.77 - **0.85 Rainfall** + 0.47 RH_e	0.33
Plant infestation	
Y = 190.36 - **0.86 T_{max}**	0.74
Y = 153.09 - **0.67 T_{max}** - **0.38 Rainfall**	0.85
Y = 140.32 - **0.52 T_{max}** - **0.30 T_{min}** - **0.27 Rainfall**	0.89

Values in bold are significant
RH: Relative humidity; T: Temperature
Subscript: max= maximum: min= minimum: m= morning; e= evening

However, maximum temperature contributed to the extent of 74 per cent in plant infestation. Further inclusion of minimum temperature and rainfall in stepwise regression analysis improved the predictability of plant infestation considerably to the extent of 89 per cent. Though, the minimum temperature and rainfall impact was significant.

The data on stepwise multiple regression analysis during 2017 are presented in Table 4.13 revealed that evening relative humidity and minimum temperature were found to influence the trap catch significantly. The joint contribution of both the factors was up to 52 per cent of trap catch. Further inclusion of maximum temperature improved the predictability of trap catch to the extent of 60 per cent. Though, the factor's (maximum temperature) impact was non-significant. However, in case of adult catch by using sweep net, evening relative humidity and minimum temperature were observed to be major factors influencing adult catch and significantly joint contribution of both the factors was to the extent of 49 per cent. Further stepwise regression analysis revealed that maximum temperature contributed only 10 per cent variability in adult catch population.

Table 4.13 Regression model for white stem borer population build-up during 2017

Regression equation	**R^2**
Light trap	
$Y = 124.2 - \mathbf{0.78\ RH_e} + \mathbf{0.73\ T_{min}}$	0.52
$Y = 7.21 - \mathbf{0.92\ RH_e} + \mathbf{0.76\ T_{min}} + 0.32\ T_{max}$	0.60
Adult catch	
$Y = 84.49 - \mathbf{0.80\ RH_e} + \mathbf{0.66\ T_{min}}$	0.49
$Y = 4.12 - \mathbf{0.95\ RH_e} + \mathbf{0.70\ T_{min}} + 0.35\ T_{max}$	0.59
Larval population	
$Y = 13.61 - \mathbf{0.50\ RH_e}$	0.25
$Y = -1.57 - \mathbf{0.67\ RH_e} + \mathbf{0.45\ T_{max}}$	0.43
$Y = -7.05 - \mathbf{2.00\ RH_e} + \mathbf{0.53\ T_{max}} + \mathbf{0.48\ T_{min}} + 1.04\ RH_m$	0.56
Plant infestation	
$Y = 71.08 - \mathbf{0.85\ RH_e}$	0.72
$Y = 60.91 - \mathbf{0.69\ RH_e} - 0.22\ \text{Rainfall}$	0.74

Values in bold are significant
RH: Relative humidity; T: Temperature
Subscript: max= maximum: min= minimum: m= morning; e= evening

Whereas, in larval population, regression analysis revealed that evening relative humidity, maximum temperature and minimum temperature were found to influence the larval population significantly and were depicted in predictive model. The equation also revealed that rainfall evening relative humidity alone contributed to 25 per cent in larval population. However, in case of plant infestation, evening relative humidity was found to be major factor influencing the plant infestation and alone contributed to 72 per cent. Furthermore, rainfall resulted in additive variation of 2 per cent.

Based on the data clubbed for three cropping seasons (2015-2017) it was evident that minimum temperature, maximum temperature and rainfall were observed to influence light trap catches significantly. Amongst them, maximum temperature and rainfall jointly contributed to 11 per cent. Furthermore, minimum temperature resulted in additive variation of 11 per cent. However, in case of adult catch by using sweep net, maximum temperature, minimum temperature and rainfall were found to be major factors influencing the adult catch. The equations obtained by stepwise multiple regression clubbed data depicted that both the factors resulted in 21 per cent variation.

Table 4.14 Regression model for white stem borer population build-up (based on pooled data for 2015-2017)

Regression equation	R^2
Light trap	
Y = - 81.25 + **0.30 T_{max} - 0.23 Rainfall**	0.11
Y = - 141.86 + **0.38 T_{max} - 0.35 Rainfall** + **0.35 T_{min}**	0.22
Adult catch	
Y = - 1.59 - **0.30 Rainfall** + **0.29 T_{min}**	0.12
Y = - 67.27 - **0.39 Rainfall** + **0.37 T_{min}** + **0.32 T_{max}**	0.21
Larval population	
Y = 2.58 - **0.46 Rainfall**	0.21
Y = - 3.23 - **0.50 Rainfall** + 0.19 T_{max}	0.24
Y = 16.08 - **0.56 Rainfall** + 0.23 T_{max} + 0.15 T_{min}	0.26
Plant infestation	
Y = 52.96 - **0.73 RH_m**	0.53
Y = 39.16 - **0.47 RH_m - 0.40 Rainfall**	0.62
Y = 54.77 - **0.36 RH_m - 0.42 Rainfall - 0.22 T_{max}**	0.66

Values in bold are significant
RH: Relative humidity; T: Temperature
Subscript: max= maximum: min= minimum: m= morning; e= evening

In case of larval population, the maximum temperature, minimum temperature and rainfall were found to influence the larval population and were depicted in predictive model. The equation also revealed that rainfall alone contributed significantly to 21 per cent in larval population. Further stepwise regression analysis revealed that other environmental factors *viz.*, maximum and minimum temperature contributed to 5 per cent variability in larval population. However, in plant infestation, maximum temperature, rainfall and morning relative humidity were significantly contributed to 66 per cent. Further, inclusion of morning relative humidity in stepwise regression analysis and significantly contributed to the extent of 53 per cent in plant infestation. These present investigations are closer or more similar to the findings of Rana et al. (2017) regression analysis of dead heart formation explained 60.20-61.60 per cent variability due to all tested environmental factors combined while in case of white ears the variability ranged from 63.90-73.50 per cent.

4.4 Associated natural enemies

At Malan, natural enemies belonging to two groups namely, predators and parasitoids were found associated with white stem borer.

4.4.1 Predators recorded using sweep net method

In the present study during *Kharif* season 2016 and 2017, three predators *viz.*, spiders, dragonflies and damselflies were found associated with white stem borer (Table 4.15-4.16 and Plate 4.4-4.5). During 2016, of all predators, spiders shared 49.4 per cent of total diversity of all the species. However, during 2017, spiders shared 51.2 per cent of total diversity of all the species.

Studies on the abundance of predators in paddy ecosystem indicated that predators first appeared in second fortnight of July (3.0 adults/ 125 sweeps) during 2016 and remained active up to second fortnight of October with population of 1.0 adult per 125 sweeps. The maximum numbers of predators recorded during second fortnight of September (25.0 adults/ 125 sweeps) which declined in subsequent observations. Whereas, during 2017, activity of predators was found from second fortnight of July (4.0 adults/ 125 sweeps) to second fortnight of October (2.0 adults/ 125 sweeps) and maximum population to the extent of 22.0 adults caught per 125 sweeps was obtained during second fortnight of September and the population showed declining trend till second fortnight of October.

Table 4.15 Predators associated with white stem borer collected by sweep net method during *Kharif* 2016

Predator groups	Adults caught per 125 sweeps									Relative proportion (%)
	July-I	July-II	Aug-I	Aug-II	Sept-I	Sept-II	Oct-I	Oct-II	Total	
Spiders	0.0	0.0	2.0	6.0	10.0	17.0	4.0	1.0	40.0	49.4
Damselflies	0.0	2.0	4.0	6.0	4.0	5.0	2.0	0.0	23.0	28.4
Dragonflies	0.0	1.0	3.0	5.0	5.0	3.0	1.0	0.0	18.0	22.2
Total	0.0	3.0	9.0	17.0	19.0	25.0	7.0	1.0	81.0	100.0

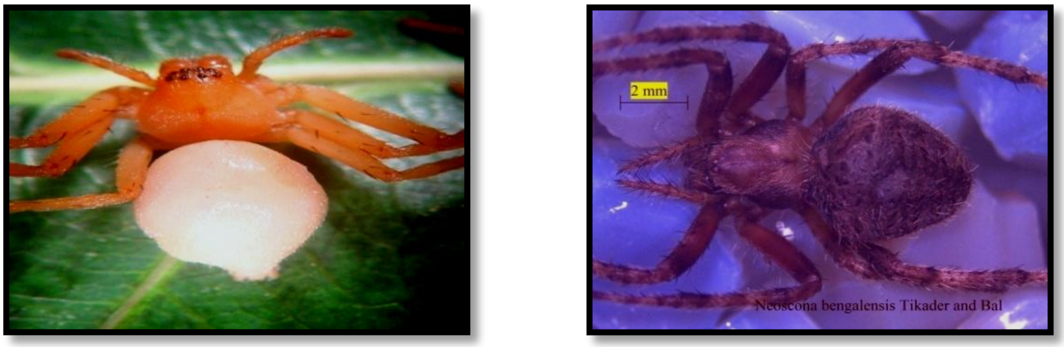
I: First fortnight II: Second fortnight

Table 4.16 Predators associated with white stem borer collected by sweep net method during *Kharif* 2017

Predator groups	Adults caught per 125 sweeps									Relative proportion (%)
	July-I	July-II	Aug-I	Aug-II	Sept-I	Sept-II	Oct-I	Oct-II	Total	
Spiders	0.0	1.0	3.0	5.0	11.0	15.0	6.0	2.0	43.0	51.2
Damselflies	0.0	2.0	3.0	7.0	4.0	4.0	2.0	0.0	22.0	26.2
Dragonflies	0.0	1.0	2.0	5.0	6.0	3.0	2.0	0.0	19.0	22.6
Total	0.0	4.0	8.0	17.0	21.0	22.0	10.0	2.0	84.0	100.0

I: First fortnight II: Second fortnight

(a) *Lycosa* sp. **(b) *Pardosa birminica***



(c) *Heteropoda* sp. **(d) *N. bengalensis***

Plate 4.4 Spider fauna associated with white stem borer

(a) ***Orthetrum triangulare***

(b) ***Zyxomma*** **sp.**

(c) ***Crocothemis servelia***

(d) ***Orthetrum pruinosum***

(e) ***Ishnura aurora***

Plate 4.5 Odonatan fauna associated with white stem borer

The spiders preyed on the adults and first instar larvae, while predators belonging to the orders Odonata and Orthoptera preyed on the eggs of the borer (Chakravarthy 1987). Deng and Jin (1985) have reported *Conoeephalus* sp. as a predator of rice stem borer which preyed on the egg masses of rice stem borer. Bhardwaj and Pawar (1987) have also enlisted this insect as a predator of rice insect pests in Madhya Pradesh. Wang and Wu (1988) have reported *C. divergentus* preying on eggs of rice stem borer.

4.4.2 Parasitoids associated with white stem borer

Rearing of field collected egg masses, larvae and pupae of white stem borer resulted in emergence of parasitoids and the data on per cent parasitization by egg, larval and pupal parasitoids are being presented in Table 4.17-4.18 and Plate 4.6. The data recorded on emergence of parasitoids during 2016 presented in Table 4.17 revealed that four species of parasitoids *viz.*, *Telenomus* sp., *Tetrastichus* sp., *Stenobracon* sp. and *Xanthopimpla punctata* were found to be associated with white stem borer.

Table 4.17 Parasitization of white stem borer egg masses, larvae and pupae by associated natural enemies during *Kharif* 2016

Period	**Parasitization (%)**				**Total parasitization (%)**
	Egg parasitoid		**Larval parasitoid**	**Pupal parasitoid**	
	Telenomus sp.	*Tetrastichus* sp.	*Stenobracon* sp.	*Xanthopimpla punctata*	
July-I	0.0	0.0	0.0	0.0	0.0
July-II	0.0	0.0	0.0	0.0	0.0
Aug-I	0.0	0.0	0.0	0.0	0.0
Aug-II	3.8	4.3	0.0	0.0	8.1
Sept-I	11.5	8.9	0.0	0.0	20.5
Sept-II	13.6	22.8	0.0	0.0	36.4
Oct-I	0.00	0.00	36.8	16.7	53.5

I: First fortnight II: Second fortnight

The parasitization initiated from second fortnight of August and remained until first fortnight of October. During first fortnight of October, larval parasitization

(36.8%) was maximum by larval parasitoid followed by *Xanthopimpla punctata* with 16.7 per cent parasitization and the total parasitization was 53.5 per cent.

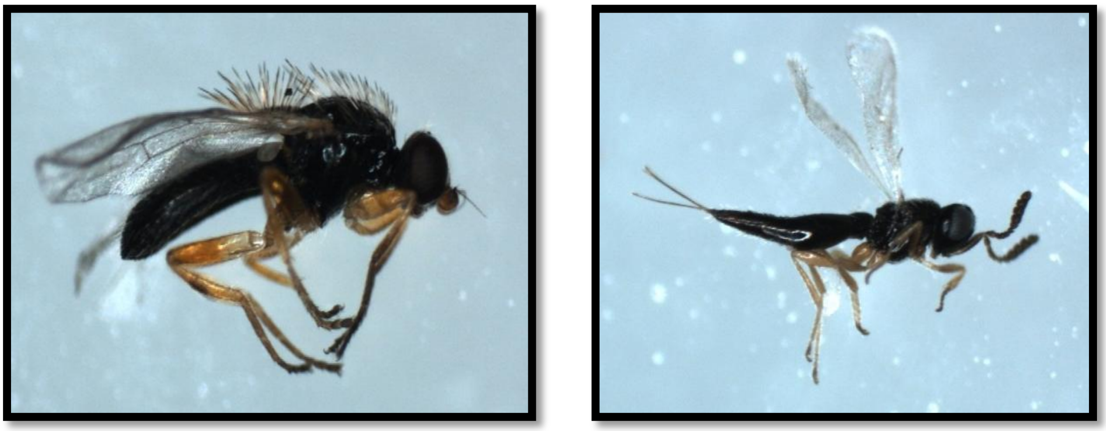
Observations recorded on number of parasitoids emerging from egg masses, larvae and pupae of white stem borer and per cent parasitization during 2017 presented in Table 4.18 revealed that the parasitization varied during different observation periods. The parasitization was first observed in first fortnight of August with 3.7 per cent parasitization and it kept on increasing and reached peak during first fortnight of October (62.0%). The parasitization by *Xanthopimpla punctata* was (25.0%) followed by larval parasitoid (24.1%) during second fortnight of September.

Table 4.18 Parasitization of white stem borer egg masses, larvae and pupae by associated natural enemies during *Kharif* 2017

Period	**Parasitization (%)**				**Total parasitization (%)**
	Egg parasitoid		**Larval parasitoid**	**Pupal parasitoid**	
	Telenomus sp.	*Tetrastichus* sp.	*Stenobracon* sp.	*Xanthopimpla punctata*	
July-I	0.0	0.0	0.0	0.0	0.0
July-II	0.0	0.0	0.0	0.0	0.0
Aug-I	0.0	3.7	0.0	0.0	3.7
Aug-II	9.1	0.0	0.0	0.0	9.1
Sept-I	7.4	11.8	0.0	0.0	19.2
Sept-II	0.0	0.0	24.1	25.0	49.1
Oct-I	0.0	0.0	0.0	62.0	62.0

I: First fortnight II: Second fortnight

Present study corroborated the findings of Alagar et al. (2008) who found that two parasitoids *i.e. Telenomus* sp. and *Tetrastichus* sp. with mean egg parasitization from 45.0 per cent to 95.8 per cent of the stem borer egg masses throughout the season. Additionally, Chakraborty (2012), Manju et al. (2002), Kishore et al. (2003), Van der Goot (1948) and Rothschild (1970) reported that egg masses were parasitized by the *Telenomus beneficiens, Trichogramma japonicum* and *Tetrastichus schoenobii.* Lakshmi et al. (2010) revealed that egg parasitoids played an important role in population regulation of stem borer by parasitizing 95 per cent of the egg masses.



(a) ***Telenomus*** **sp.**

(b) ***Tetrastichus*** **sp.**

(c) ***Stenobracon*** **sp.**

(d) ***Xanthopimpla punctata***

Plate 4.6 Parasitoids associated with white stem borer

4.5 Assessment of yield losses due to white stem borer

4.5.1 Per cent dead hearts and white ears incidence at various release levels

Data on the effect of different release levels of white stem borer larvae are presented in Table 4.19. The different treatments were artificially infested at tillering stage by releasing 2, 4 and 6 larvae per hill and thereafter observations were recorded on 42 and 72 DAT.

A perusal of the data revealed that per cent dead hearts and white ears incidence varied significantly amongst all release levels during both the cropping seasons. During 2016, the dead hearts and white ears incidence varied from 6.7 to 12.1 per cent and 5.8 to 10.8 per cent, respectively. Whereas, during 2017, it varied from 6.4 to 12.4 per cent and 5.9 to 11.2 per cent, respectively. The mean based on two cropping seasons indicated that the maximum incidence was 11.6 per cent at the release level of 6 larvae per hill and lowest at release level of 2 larvae per hill (6.2%).

Table 4.19 Dead hearts and white ears incidence in different release levels of *Scirpophaga fusciflua* larvae

Release levels (No. of larvae/ hill)	**Plant infestation (%)**						**Over all mean**
	2016			**2017**			
	42 DAT	**72 DAT**	**Mean**	**42 DAT**	**72 DAT**	**Mean**	
0	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)
2	6.7 (2.68)	5.8 (2.50)	6.3 (2.60)	6.4 (2.62)	5.9 (2.54)	6.2 (2.58)	6.2 (2.59)
4	9.6 (3.17)	8.0 (2.92)	8.8 (3.05)	9.8 (3.20)	8.2 (2.94)	8.9 (3.07)	8.8 (3.06)
6	12.1 (3.55)	10.7 (3.35)	11.5 (3.45)	12.4 (3.58)	11.2 (3.43)	11.8 (3.50)	11.6 (3.48)
Mean	7.1 (2.75)	6.1 (2.57)	6.6 (2.66)	7.1 (2.76)	6.3 (2.61)	6.7 (2.69)	

CD (P=0.05)

Years (A)	: NS	A×B	: NS
Days after transplanting (B)	: 0.03	A×C	: 0.07
Released levels (C)	: 0.05	B×C	: NS
		A×B×C	: NS

Figures in parentheses are the square root transformed values DAT: Days after transplanting

Amongst different intervals of observations, infestation was non-significant during 2016-2017. The interaction between release levels of white stem borer larvae and cropping seasons revealed that no infestation was observed at pest free level.

4.5.2 Effect of release levels on plant infestation and yield

The perusal of data presented in Table 4.20 revealed that grain yield showed decreasing trend with increasing release levels during 2016. The grain yield was minimum in the highest release level *i.e*. 6 larvae per hill (11.3 g hill^{-1}) where plant infestation were 11.5 per cent followed by 4 and 2 larvae per hill with corresponding values of grain yield as 13.5 and 15.5 g per hill, respectively. However, highest yield (16.7 g hill^{-1}) was obtained in the treatment with no incidence. During 2017, similar trend was observed with highest (16.5 g hill^{-1}) and lowest grain yield (11.5 g hill^{-1}) at release levels 0 and 6 larvae per hill, respectively, and the plant infestation were 11.8 per cent at 6 larvae per hill.

Grain yield decreased gradually with increasing white stem borer infestation but a drastic decrease in yield was observed with increase in release levels above 2 larvae per hill (Fig 4.5).

4.5.3 Extent of losses inflicted by White stem borer

4.5.3.1 Avoidable losses

The avoidable losses were worked out on the basis of yields obtained in different release levels during 2016 and 2017. The avoidable losses varied from 7.5 to 32.3 and 7.8 to 30.5 per cent during 2016 and 2017, respectively.

The variations in per cent avoidable losses caused by white stem borer in comparison to our findings may be due to different method of estimation of losses and differential responses of the different varieties to the pest.

Table 4.20 Yield and per cent avoidable losses obtained at various release levels of *Scirpophaga fusciflua* larvae

Release levels (No. of larvae/ hill)	Yield and Avoidable losses			
	2016		2017	
	Yield (g/hill)	Avoidable losses (%)	Yield (g/hill)	Avoidable losses (%)
0	16.7 (4.15)	-	16.5 (4.13)	-
2	15.5 (4.00)	7.5	15.3 (3.97)	7.8
4	13.5 (3.75)	19.0	13.4 (3.72)	19.3
6	11.3 (3.44)	32.3	11.5 (3.46)	30.5
Mean	14.3 (3.84)	-	14.2 (3.83)	-
CD (P=0.05)				
Release levels (A)	: 0.68			
Years (B)	: 0.48			
A×B	: 0.96			

Figures in parentheses are the square root transformed values

4.5.3.2 Relationship between infestation levels and damage inflicted by white stem borer

The linear regression equation worked out between grain yield and release levels of white stem borer larvae presented in Fig. 4.5 revealed that a unit increase in white stem borer infestation during 2016, 2017 and pooled data, resulted in reduction in yield to the extent of 0.985, 0.993 and 0.99 g hill^{-1}, respectively.

Correlation was worked out between release levels and yield and ‘r’ value was found to be significantly negatively correlated (r= -0.994) which indicated that with increase in infestation levels there was decrease in yield.

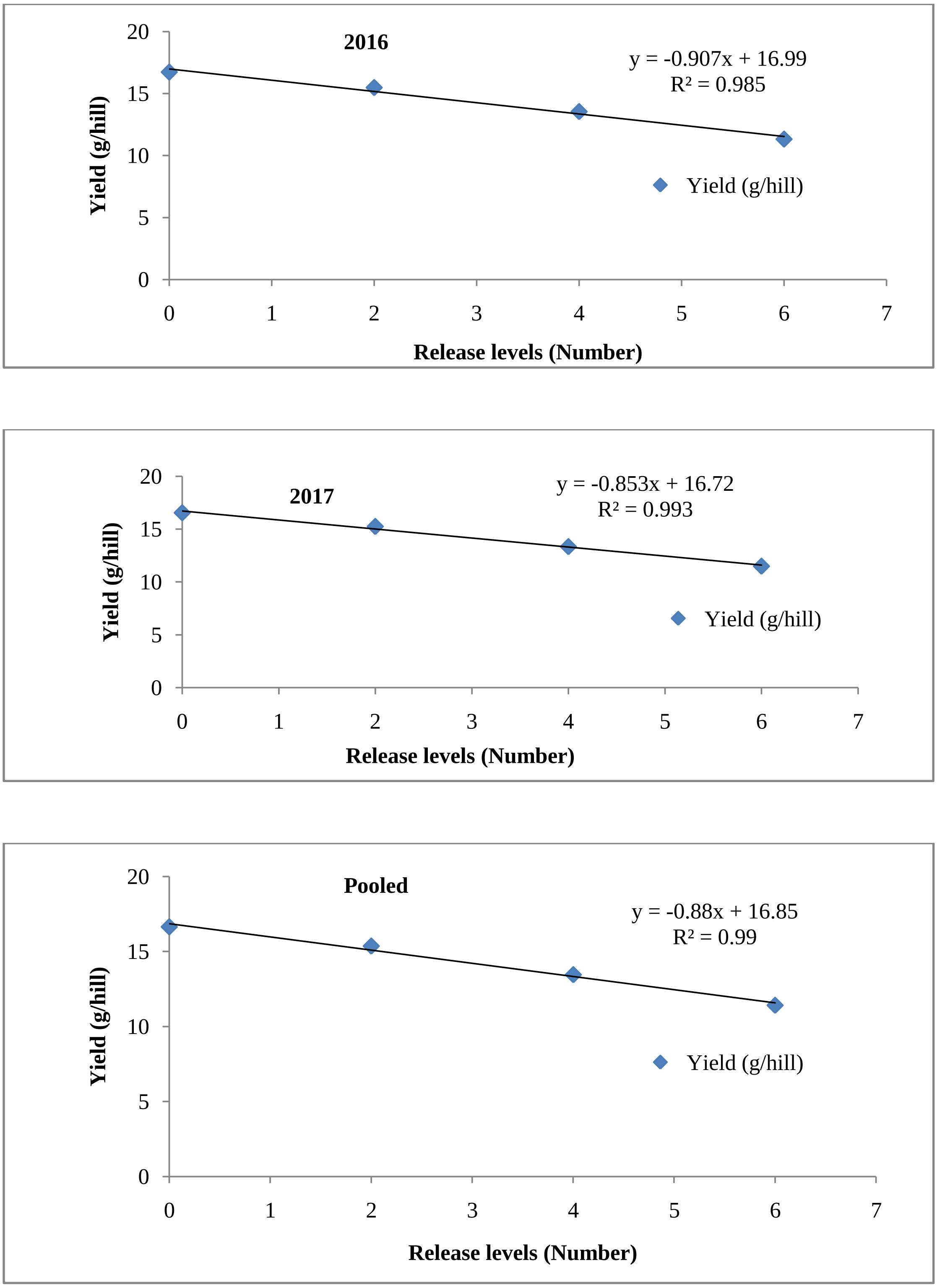


Fig. 4.5 Linear regression analysis of yield and release levels of white stem borer

The present findings are similar to Daryaei (2005) who revealed that at 5, 15, 30 and 60 per cent infestation the grain yield recorded as 5287, 4953, 4656 and 4440 kg ha^{-1} at vegetative stage; 5095, 4628, 3643 and 3155 kg ha^{-1} at panicle initiation stage. Additionally, Muralidharan and Pasalu (2005) reported due to 1 per cent dead hearts or white ears, stem borer damage are 2.5, 4.0 and 6.4 per cent yield loss, respectively. Islam and Karim (1997) revealed that grain yield at 1-10, 11-15, 16-20, 21-30 and 30 per cent white ears infestation recorded 15.9, 16.2, 12.9, 10.5 and 5.2 g hill^{-1}, respectively. Also, Pradhan and Rath (2014) reported the reduction of panicle size, grain formation and grain weight.

4.6 Management of *S. fusciflua* using insecticides and biopesticides

The field efficacy of four synthetic insecticides (flubendiamide 48% SC @ 50 ml ha^{-1}, rynaxypyr 20 SC @ 150 ml ha^{-1}, dinotefuran 20 SG @ 200 g ha^{-1}, monocrotophos 36 SL @ 850 ml ha^{-1}) and two biopesticides (melia and eupatorium 5% extract @ 2.5 L ha^{-1}) along with an untreated control was assessed in terms of per cent dead hearts and white ears infestation caused by *S. fusciflua* and the results are presented as follows:

4.6.1 *Kharif* 2015

One day before first spray, the per cent infestation due to rice white stem borer in different treatments was recorded and it varied from 8.6 to 10.4 per cent among treatments (Table 4.20).

First spray: Seven days after spray (DAS), all the treatments showed non-significant reduction in plant infestation as compared to untreated control, where the per cent dead hearts infestation increased to 12.7 from an initial of 9.6 per cent as recorded prior to first spray. Among different treatments, monocrotophos showed minimum of 9.3 per cent dead hearts infestation. The next better treatments in descending order were dinotefuran > flubendiamide > eupatorium > rynaxypyr > melia with per cent dead hearts infestation of 10.0, 10.0, 10.8, 10.9 and 10.9, respectively. After fifteen days of first spray, rynaxypyr regain the minimum per cent dead hearts infestation *i.e.* 12.0. This was followed by treatments monocrotophos, flubendiamide and dinotefuran (12.4, 12.4 and 12.8 % dead hearts infestation). The next treatments that recorded lesser dead hearts infestation compared to control were eupatorium and melia.

Second spray: The plots treated with flubendiamide show minimum dead hearts infestation after seven days of second spray and the same trend was observed after fifteen days. The per cent dead hearts infestation after seven days of second spray was 12.4 in flubendiamide followed by 13.7, 14.0 and 14.0 in dinotefuran, rynaxypyr and monocrotophos respectively. Eupatorium and melia were least effective with 17.4 and 17.8 per cent dead hearts.

Fifteen days after spray (DAS), the overall increase in white ears in control (14.7%) was very small indicating that there was not much more pressure due to white stem borer. However, there was significant reduction in plant infestation in all the treatments over control with minimum of 2.7 per cent white ears recorded in flubendiamide. Rynaxypyr, dinotefuran and monocrotophos were the next best treatments. Melia showed maximum white ears infestation (11.1%) as compared to eupatorium (9.5%).

Data contained in Table 4.21a revealed that second spray was efficacious and helped in reducing the per cent plant infestation due to white stem borer to 11.7 from 12.4 that was observed after first spray and both varied significantly. While, per cent plant infestation also depends on days after spraying. It was observed that per cent plant infestation after 15 days of spraying decreases to 10.9 from per cent plant infestation of 13.3 after 7 days of spraying. Hence we can say that fifteen days after second spray was most efficacious and resulted in minimum infestation of 7.7. While, seven days after spray was least effective with maximum infestation of 14.0.

Table 4.21 Efficacy of insecticides and biopesticides against white stem borer during *Kharif* 2015 (Kohala)

Treatment	Per cent plant infestation (DH/WE)				
	Prior to spray	First spray		Second spray	
		7 DAS	15 DAS	7 DAS	15 DAS
Flubendiamide 48% SC	9.6	10.0 (3.32)	12.4 (3.67)	12.4 (3.67)	2.7 (1.93)
Rynaxypyr 20 SC	10.4	10.9 (3.45)	12.0 (3.60)	14.0 (3.87)	3.8 (2.20)
Dinotefuran 20 SG	9.6	10.0 (3.32)	12.8 (3.72)	13.7 (3.85)	5.5 (2.55)
Monocrotophos 36 SL	8.6	9.3 (3.21)	12.4 (3.66)	14.0 (3.87)	6.6 (2.76)
Melia 5 %	9.0	10.9 (3.45)	15.6 (4.08)	17.8 (4.34)	11.1 (3.47)
Eupatorium 5 %	9.3	10.8 (3.43)	14.5 (3.92)	17.4 (4.28)	9.5 (3.23)
Control	9.6	12.7 (3.71)	18.4 (4.41)	21.4 (4.71)	14.7 (3.96)
Mean		10.7 (3.35)	14.0 (3.87)	15.8 (4.04)	7.7 (2.87)

CD (P=0.05)

Spray (A)	: 0.074	A×B	: 0.105
Days after spray (B)	: 0.074	A×C	: 0.197
Treatments (C)	: 0.139	B×C	: 0.197
		A×B×C	: NS

Figures in the parentheses are square root transformed values DAS: Days after spray DH= dead hearts, WE= white ears

Table 4.21a Interaction effect of sprays and days after spray on per cent plant infestation by white stem borer

Spray	**Per cent plant infestation**		
	7 DAS	**15 DAS**	**Mean**
I	10.7 (3.35)	14.0 (3.87)	12.4 (3.67)
II	15.8 (4.04)	7.7 (2.87)	11.7 (3.50)
Mean	13.3 (3.71)	10.9 (3.37)	

CD (P= 0.05)

Sprays (A)	: 0.074
Days after sprays (B)	: 0.074
A×B	: 0.105

Figures in the parentheses are square root transformed values DAS: Days after spray

A perusal of data contained in Table 4.21b revealed that per cent plant infestation varied from 9.4 to 13.8 in insecticide treatments, whereas in untreated control it was 16.8 varied significantly in treatments, number of sprays and at observational period of 7 and 15 days after treatment. Flubendiamide was the most efficacious insecticide in checking white stem borer infestation, differing significantly to other treatments and resulted in infestation level of 9.4 per cent (Table 4.21b) and were statistically at par with rynaxypyr that was next best treatment. Rynaxypyr was further at par with dinotefuran and monocrotophos that was the next best treatment. Among biopesticides eupatorium was found to be most effective and statistically at par to melia.

However, after first (Table 4.21b), monocrotophos was most effective having minimum per cent plant infestation with 10.9. Next best treatments were flubendiamide, dinotefuran and rynaxypyr and at par to each other. The per cent plant infestation after second spray, was 7.6 flubendiamide followed by rynaxypyr, dinotefuran and monocrotophos respectively, being statistically at par. Eupatorium and melia were least effective with 13.5 and 14.5 per cent plant infestation.

Table 4.21b Interaction effect of treatments and sprays on per cent plant infestation by white stem borer

Treatment	**Per cent plant infestation**		
	Spray I	**Spray II**	**Mean**
Flubendiamide 48% SC	11.2 (3.43)	7.6 (2.85)	9.4 (3.15)
Rynaxypyr 20 SC	11.4 (3.46)	8.9 (3.07)	10.2 (3.27)
Dinotefuran 20 SG	11.4 (3.45)	9.6 (3.19)	10.5 (3.32)
Monocrotophos 36 SL	10.9 (3.38)	10.4 (3.29)	10.6 (3.34)
Melia 5 %	13.3 (3.72)	14.5 (3.87)	13.8 (3.79)
Eupatorium 5 %	12.7 (3.63)	13.5 (3.73)	13.1 (3.68)
Control	15.6 (4.02)	18.0 (4.30)	16.8 (4.16)
Mean	12.4 (3.67)	11.7 (3.50)	
CD (P= 0.05)			
Sprays (A)	: 0.074		
Treatments (C)	: 0.139		
A×C	: 0.197		

Figures in the parentheses are square root transformed values

Data contained in Table 4.21c revealed that per cent plant infestation after 7 days of spray was 13.3 and decreased to 10.9 after 15 days of both spray. Flubendiamide was most effective after 7 and 15 days after spray. Least effective treatment was melia 15 days of spray with maximum plant infestation.

Table 4.21c Interaction effect of treatments and days after sprays on per cent plant infestation by white stem borer

Treatment	Per cent plant infestation		
	7 DAS	15 DAS	Mean
Flubendiamide 48% SC	11.3 (3.43)	7.6 (2.85)	9.4 (2.82)
Rynaxypyr 20 SC	12.5 (3.59)	7.9 (2.90)	10.2 (2.91)
Dinotefuran 20 SG	11.9 (3.52)	9.2 (3.10)	10.5 (2.99)
Monocrotophos 36 SL	11.7 (3.49)	9.5 (3.16)	10.6 (3.01)
Melia 5 %	14.4 (3.85)	13.4 (3.723)	13.8 (3.43)
Eupatorium 5 %	14.1 (3.82)	12.0 (3.54)	13.1 (3.32)
Control	17.0 (4.18)	16.6 (4.14)	16.8 (3.75)
Mean	13.3 (3.71)	10.9 (3.37)	
CD (P= 0.05)			
Days after spray (B)	: 0.074		
Treatments (C)	: 0.139		
B×C	: 0.197		

Figures in the parentheses are square root transformed values DAS: Days after spray

4.6.2 *Kharif* 2016

Observations recorded during *kharif* 2016 at Kohala (Farmer field) revealed that prior to first spray, white stem borer infestation ranged from 6.7 to 8.9 per cent with no significant differences among treatments (Table 4.22).

First spray: Seven days after first spray, non significant differences in term of percent dead hearts infestation was found among all the treatments as compared to untreated control. Fifteen DAS, all the treatments were significantly superior over untreated control in reducing the percent dead hearts infestation with dinotefuran observed having the minimum (7.6%) dead hearts infestation and flubendiamide and rynaxypyr having 8.5 and 7.9 per cent dead hearts infestation, respectively. Eupatorium and melia varied significantly with other treatments and recorded dead hearts infestation of 11.0 and 11.5 per cent, respectively. However, in control, the dead hearts infestation increased to 14.4 per cent.

Second spray: After seven days of second spray, the minimum infestation (8.6%) was observed in flubendiamide treated plots followed by rynaxypyr, and dinotefuran, where the respective dead hearts infestations were 8.6 and 10.2 per cent. The next best treatments were eupatorium, melia and monocrotophos that recorded 12.6, 13.2 and 13.2 per cent dead hearts infestation, respectively. All the treatments continued to be significantly superior over control even after fifteen days of second spray with flubendiamide and rynaxypyr showing minimum (2.7%) and (3.3%) white ears infestation, respectively. The next best treatments in decreasing order were dinotefuran > monocrotophos with white ears infestation of 5.5 and 6.8 per cent, respectively. Highest infestation was observed in untreated control (15.1%). Melia and eupatorium recorded 10.6 and 9.6 per cent white ears infestation and were least effective among different treatments.

Data contained in Table 4.22a revealed that first and second spray were efficacious and statistically at par. While, per cent plant infestation also depends on days after spraying. It was observed that per cent plant infestation after 15 days of spraying decreases to 8.9 from per cent plant infestation of 10.2 after 7 days of spraying. Hence we can say that fifteen days after second spray was most efficacious and resulted in minimum infestation of 7.7.

Table 4.22 Efficacy of insecticides and biopesticides against white stem borer during *Kharif* 2016 (Kohala)

Treatment	**Per cent plant infestation (DH/WE)**				
	Prior to spray	**First spray**		**Second spray**	
		7 DAS	**15 DAS**	**7 DAS**	**15 DAS**
Flubendiamide 48% SC	8.3	8.3 (3.04)	8.5 (3.06)	8.6 (3.09)	2.7 (2.07)
Rynaxypyr 20 SC	7.7	7.7 (2.95)	7.9 (2.98)	8.6 (3.10)	3.3 (2.56)
Dinotefuran 20 SG	6.8	7.0 (2.83)	7.6 (2.94)	10.2 (3.34)	5.5 (2.55)
Monocrotophos 36 SL	8.9	9.1 (3.16)	10.2 (3.34)	13.2 (3.75)	6.8 (2.79)
Melia 5 %	6.7	8.4 3.06)	11.5 (3.53)	13.2 (3.76)	10.6 (3.41)
Eupatorium 5 %	6.9	8.7 (3.11)	11.0 (3.46)	12.6 (3.68)	9.6 (3.53)
Control	7.8	11.3 (3.50)	14.4 (3.91)	18.6 (4.13)	15.1 (4.02)
Mean		8.6 (3.03)	10.2 (3.27)	11.7 (3.51)	7.7 (2.86)

CD (P=0.05)

Spray (A) : NS A×B : 0.117
Days after spray (B) : 0.083 A×C : 0.219
Treatments (C) : 0.155 B×C : 0.219
A×B×C : NS

Figures in the parentheses are square root transformed values DAS: Days after spray

Table 4.22a **Interaction effect of sprays and days after spray on per cent plant infestation by white stem borer**

Spray	Per cent plant infestation		
	7 DAS	15 DAS	Mean
I	8.6 (3.03)	10.2 (3.27)	9.4 (3.15)
II	11.7 (3.51)	7.7 (2.86)	9.7 (3.20)
Mean	10.2 (3.27)	8.9 (3.07)	

CD (P= 0.05)

Sprays (A)	: NS
Days after sprays (B)	: 0.083
A×B	: 0.117

Figures in the parentheses are square root transformed values DAS: Days after spray

A perusal of data contained in Table 4.22b revealed that per cent plant infestation varied from 6.9 to 10.9 in insecticide treatment, whereas in untreated control it was 14.2 varied significantly in treatments, number of sprays and at observational period of 7 and 15 days after treatment. Rynaxypyr was the most efficacious insecticide in checking white stem borer infestation, differing significantly to other treatments and resulted in infestation level of 6.9 per cent (Table 4.22b) and was statistically at par with flubendiamide that was next best treatment. Among biopesticides eupatorium was found to be most effective and statistically at par to melia.

However, after first spray (Table 4.22b), dinotefuran was most effective having minimum per cent plant infestation with 7.4. Next best treatments were rynaxypyr, flubendiamide and monocrotophos. The per cent plant infestation after second spray was 5.7 in flubendiamide followed by rynaxypyr, dinotefuran and monocrotophos respectively, being statistically at par. Eupatorium and melia were least effective with 11.1 and 11.8 per cent plant infestation.

Table 4.22b Interaction effect of treatments and sprays on per cent plant infestation by white stem borer

Treatment	Per cent plant infestation		
	Spray I	Spray II	Mean
Flubendiamide 48% SC	8.4	5.7	7.0
	(2.98)	(2.49)	(2.75)
Rynaxypyr 20 SC	7.8	5.99	6.9
	(2.89)	(2.55)	(2.72)
Dinotefuran 20 SG	7.4	7.8	7.6
	(2.81)	(2.89)	(2.85)
Monocrotophos 36 SL	9.6	9.9	9.8
	(3.18)	(3.24)	(3.21)
Melia 5 %	9.9	11.8	10.9
	(3.23)	(3.52)	(3.38)
Eupatorium 5 %	9.8	11.1	10.5
	(3.22)	(3.41)	3.32)
Control	12.8	15.6	14.2
	(3.65)	(4.02)	(3.84)
Mean	9.4	9.7	
	(3.15)	(3.20)	

CD (P= 0.05)

Sprays (A)	: NS
Treatments (C)	: 0.155
A×C	: 0.219

Figures in the parentheses are square root transformed values

Data contained in Table 4.22c revealed that per cent plant infestation after 7 days of spray was 10.2 and decreased to 8.9 after 15 days of both spray. Flubendiamide and rynaxypyr were most effective after 7 and 15 days after spray. Least effective treatment was melia 7 and 15 days of spray with maximum plant infestation.

Table 4.22c Interaction effect of treatments and days after sprays on per cent plant infestation by white stem borer

Treatment	**Per cent plant infestation**		
	7 DAS	**15 DAS**	**Mean**
Flubendiamide 48% SC	8.4 (2.99)	5.6 (2.47)	7.0 (2.75)
Rynaxypyr 20 SC	8.2 (2.94)	5.66 (2.48)	6.9 (2.72)
Dinotefuran 20 SG	8.6 (3.02)	6.6 (2.66)	7.6 (2.85)
Monocrotophos 36 SL	11.1 (3.41)	8.5 (3.00)	9.8 (3.21)
Melia 5 %	10.8 (3.36)	11.1 (3.39)	10.9 (3.38)
Eupatorium 5 %	10.6 (3.34)	10.3 (3.29)	10.5 3.32)
Control	13.7 (3.76)	14.7 (3.90)	14.2 (3.84)
Mean	10.2 (3.27)	8.9 (3.07)	
CD (P= 0.05)			
Days after spray (B)	: 0.083		
Treatments (C)	: 0.155		
B×C	: 0.219		

Figures in the parentheses are square root transformed values DAS: Days after spray

4.6.3 Grain yield and incremental output input ratio

The data on grain yield in different insecticidal treatments are given in Table 4.23. Maximum yield (41.83 q ha^{-1}) was obtained from plots treated with flubendiamide followed by rynaxypyr and dinotefuran with respective yields of 40.62 and 38.38 q ha^{-1} and was at par with each other and also with flubendiamide. The other treatments recorded yields of 37.68, 34.86 and 33.96 q ha^{-1} for monocrotophos, eupatorium and melia, respectively, eupatorium and melia were at par with each other. Monocrotophos was at par with insecticide treatments.

Data obtained on the incremental output input ratio analysis of various treatments revealed that monocrotophos (1:10.32) and flubendiamide (1:10.31) were the most economically viable treatments on the basis of incremental output input ratio (Table 4.23). This was followed by dinotefuran (1:6.69) and rynaxypyr (1:6.03). Among the biopesticides, eupatorium (1:4.19) was showed comparatively higher incremental output input ratio as compared to melia (1:3.69).

The present findings are supported the result of Sekh et al. (2007) who reported that flubendiamide 480 SC @ 24 and 30 g a.i ha^{-1} effectively control the yellow stem borer. Gowda (2005) reported that flubendiamide 20 WDG at 25 and 50 g a.i ha^{-1} recorded low incidence of dead hearts (0.81 and 0.53 %) and white ears (1.26 and 1.20%) compared to other treatments. Dinotefuran 20% SG @ 200 ml ha^{-1} and monocrotophos 36 % @ 1390 ml ha^{-1} were effective against rice stem borer Rath (2012). Sandhu and Dhaliwal (2016) found flubendiamide 48% SC @ 50 ml ha^{-1} was most promising with minimum dead heart and white ears. Rana and Singh (2017) found chlorantraniliprole 18.5 SC was most effective and minimum infestation of *S. incertulas* with 2.73 per cent (DH) and 2.06 per cent (WE) after first and second spray, respectively. Considering the efficacy of low doses of flubendiamide 48% SC proved to be better and economically viable option for the management of rice white stem borer.

Table 4.23 Incremental output input ratio (IOIR) for the management of white stem borer

Treatment	Dose (/ha)	Cost of spray (Rs)	Yield (q/ha)	Value of additional grain yield (Rs)	IOIR
Flubendiamide 48% SC	50 ml	950	41.83	20924	10.31
Rynaxypyr 20 SC	150 ml	2100	40.62	19169	6.03
Dinotefuran 20 SG	200 g	1300	38.38	15921	6.69
Monocrotophos 36 SL	850 ml	364	37.68	14906	10.32
Melia 5 %	2.5 L	1500	33.96	9512	3.69
Eupatorium 5 %	2.5 L	1500	34.86	10817	4.19
Control	-	-	27.4	-	-
CD (P=0.05)			3.30		

Note: Cost of various management inputs and market value of rice grains are presented in Appendix IV

5. SUMMARY AND CONCLUSIONS

Present studies on “Bio-ecology and management of *Scirpophaga fusciflua* Hampson” were carried out during *Kharif* season 2015 to 2017 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Rice and Wheat Research Centre, Malan district Kangra (Himachal Pradesh). The results obtained are being summarized here as under:

Annual life cycle:

- Three generations of white stem borer were recorded under laboratory conditions. Life history of white stem borer comprised of four well-defined stages *viz.,* egg, larvae, pupa and adult. At the end of the crop season, as the temperature decreased, the full grown larvae diapaused in rice stubbles, adult of which emerged during last week of April to first week of May under laboratory conditions. While under field conditions, the fully grown larvae of this generation or the pupal stage undergo diapause and remain in the stubbles which get burried in the soil at the time of field preparation for winter season.
- The female moths on an average laid 58.4 to 65.6 eggs in masses in different generations with pre-oviposition, oviposition and post-oviposition period of 23.8 to 24.1, 24.9 to 26.0 and 6.0 to 6.6 hours, respectively. The larva passed through five instars to complete the larval development and the head capsule width increased with each instar. The larval body length varied from 1.95 mm (first instar) to 15.03 mm (fifth instar larvae). Length and width of pupa varied from 11.32 to 12.75 with an average of 12.14 mm and 2.1 to 2.18 with an average of 2.15 mm, respectively. Average pupal period varied from 7.6 to 10.5 days. The adult males were smaller than the females with body length of 8.06 mm, as compared to 11.87 mm in females. The adult longevity was found to be 43.2 to 47.1 and 55.2 to 56.1 hr for males and females, respectively.

Population build-up:

- Studies on population build-up of *S. fusciflua* were undertaken at three locations *viz.,* Kohala, Jia (both farmers' field) and Malan. The data revealed that the first appearance of adults took place in the last week of July. The highest numbers of adults were caught during 1st and 2nd week of September using sweep net.
- The adult population had a positive relationship with minimum and maximum temperature and relative humidity whereas, rainfall influenced adult population negatively. However, the larval population was found to be negatively correlated with minimum temperature, rainfall, relative humidity (morning and evening). The plant infestation was found to have significant negative correlation with temperature (maximum and minimum), relative humidity (morning and evening) and rainfall.
- Stepwise regression analysis based on the data clubbed for three cropping seasons (2015-2017) revealed that minimum temperature, maximum temperature and rainfall influenced the light trap and sweep net catch, significantly. In case of larval population, the maximum temperature, minimum temperature and rainfall were found to influence the larval population. However, in plant infestation, maximum temperature, rainfall and morning relative humidity significantly contributed to 66 per cent. Further, inclusion of morning relative humidity in stepwise regression analysis significantly contributed to the extent of 53 per cent in plant infestation.

Associated natural enemies:

- In the present study three predators *viz.,* spiders, dragonflies and damselflies were found associated with white stem borer in paddy ecosystem. The data recorded on emergence of parasitoids revealed that four species of parasitoids *viz*., *Telenomus* sp., *Tetrastichus* sp., *Stenobracon* sp. and *Xanthopimpla punctata* were found to be associated with white stem borer.

Yield losses:

- For studies on assessment of yield losses, white stem borer larvae were released at population levels of 0, 2, 4 and 6 larvae per hill at tillering stage.

The mean data based on two cropping seasons indicated that the maximum infestation was 11.6 per cent at highest release level (6 larvae per hill) and lowest (6.2%) at release level of 2 larvae per hill.

- The avoidable losses at release levels of 2, 4 and 6 larvae per hill were 7.5 to 7.8, 19.0 to 19.3 and 30.5 to 32.3 per cent during 2016 and 2017, respectively. Influence of different release levels of *S. fusciflua* larvae indicated that grain yield decreased significantly with increasing release levels.

Management:

- The application of various insecticides and biopesticides proved promising in checking the white stem borer infestation compared to untreated control. Flubendiamide 48% SC @ 50 ml ha^{-1} was significantly superior as compared to untreated control and other biopesticide treatments. It was followed by rynaxypyr 20 SC @ 150 ml ha^{-1}, dinotefuran 20 SG @ 200 g ha^{-1} and monocrotophos 36 SL @ 850 ml ha^{-1}. Among biopesticides, melia @ 2.5 L ha^{-1} was least effective compare to the eupatorium @ 2.5 L ha^{-1}.
- Maximum yield (41.83 q ha^{-1}) was obtained from plots treated with flubendiamide followed by rynaxypyr and dinotefuran with corresponding yield levels of 40.62 and 38.38 q ha^{-1} and was at par with each other and also with flubendiamide. Data obtained on the incremental output input ratio of various treatments revealed that monocrotophos (1:10.32) and flubendiamide (1:10.31) were most economically viable treatments on the basis of incremental output input ratio. This was followed by dinotefuran (1:6.69) and rynaxypyr (1:6.03). Among the biopesticides, eupatorium (1:4.19) was showed comparatively higher incremental output input ratio as compared to melia (1:3.69).

Conclusions

Three generations of white stem borer were recorded under laboratory conditions, whereas, two generations of white stem borer were observed in field conditions. The pest appearance initiated during the month of July and the peak activity of pest was recorded during the month of August and September. Maximum temperature was found important parameter influencing white stem borer population. Influence of different release levels of *S. fusciflua* larvae indicated that grain yield decreased significantly with increasing infestation levels. The efficacy of various insecticides and biopesticides revealed that the most effective insecticides were flubendiamide 48% SC @ 50 ml ha^{-1} and rynaxypyr 20 SC @ 150 ml ha^{-1}. Among biopesticides, eupatorium was found significantly superior over melia and control. Monocrotophos 36 SL @ 850 ml ha^{-1} and flubendiamide 48% SC @ 50 ml ha^{-1} were the most economically viable treatments on the basis of incremental output input ratio.

Further investigations, however, are needed to develop an integrated pest management module based on a predictive weather based forecasting model and exploiting various cultural, biological and chemical management options for the sustainable management of white stem borer under mid-hill conditions of Himachal Pradesh.

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APPENDICES

APPENDIX-I

Mean weekly meteorological data at RWRC, Malan (2015)

Standard Week	Date	Max. temperature (˚C)	Min. temperature (˚C)	Rainfall (mm)	Relative Humidity - M (%)	Relative Humidity – E (%)
27	2-8 July	31.43	17.96	139.60	73.86	71.86
28	9-15 July	31.26	17.41	101.10	84.00	83.14
29	16-22 July	31.34	18.03	151.40	85.71	82.86
30	23-29 July	33.21	18.14	110.00	78.57	76.00
31	30-5 Aug	32.04	18.34	209.44	85.71	82.57
32	6-12 Aug	31.71	17.63	247.70	89.43	86.57
33	13-19 Aug	31.56	17.67	89.50	89.28	86.28
34	20-26 Aug	31.75	17.88	20.00	87.14	83.14
35	27-2 Sep	32.20	18.10	17.64	74.86	71.28
36	3-9 Sep	32.67	17.28	10.30	68.00	64.57
37	10-16 Sep	32.96	18.77	12.90	66.86	62.86
38	17-23 Sep	31.01	16.83	52.60	71.00	69.57
39	24-30 Sep	29.21	15.44	0.00	69.14	65.43
40	1-7 Oct	29.38	14.83	0.00	67.43	62.28
41	8-14 Oct	29.55	14.82	2.00	65.20	61.20
42	15-21 Oct	26.10	12.86	6.00	63.00	52.43
43	22-28 Oct	25.36	10.50	10.20	67.71	50.43
44	29-4 Nov	27.74	12.01	0.00	48.43	43.86
45	5-11 Nov	28.03	12.31	11.20	56.14	53.14

APPENDIX-II

Mean weekly meteorological data at RWRC, Malan (2016)

Standard Week	Date	Max. temperature (˚C)	Min. temperature (˚C)	Rainfall (mm)	Relative Humidity - M (%)	Relative Humidity – E (%)
27	2-8 July	32.54	12.44	129.40	75.43	70.57
28	9-15 July	32.91	13.43	149.10	81.71	77.14
29	16-22 July	32.67	14.43	106.60	81.00	78.86
30	23-29 July	31.50	12.43	399.90	85.14	84.86
31	30-5 Aug	32.94	13.07	405.00	85.56	83.14
32	6-12 Aug	31.54	11.51	177.00	89.15	87.57
33	13-19 Aug	31.77	11.24	28.20	75.43	70.57
34	20-26 Aug	31.96	11.17	1.20	75.14	70.57
35	27-2 Sep	32.08	11.01	38.80	75.71	71.43
36	3-9 Sep	31.86	11.40	52.80	70.86	67.43
37	10-16 Sep	31.60	11.44	18.58	76.00	72.57
38	17-23 Sep	31.24	11.00	3.60	76.57	72.28
39	24-30 Sep	31.10	10.48	21.00	74.00	69.43
40	1-7 Oct	30.78	10.31	0.00	72.57	69.71
41	8-14 Oct	30.61	10.27	0.00	69.86	66.86
42	15-21 Oct	30.37	9.36	0.00	67.14	62.28
43	22-28 Oct	29.28	9.16	0.00	60.00	56.28
44	29-4 Nov	28.87	12.06	0.00	62.43	58.00
45	5-11 Nov	28.23	11.08	0.00	60.23	57.73

APPENDIX-III

Mean weekly meteorological data at RWRC, Malan (2017)

Standard Week	Date	Max. temperature (˚C)	Min. temperature (˚C)	Rainfall (mm)	Relative Humidity - M (%)	Relative Humidity – E (%)
27	2-8 July	30.29	23.57	15.00	82.29	80.00
28	9-15 July	29.86	23.00	142.40	85.43	84.14
29	16-22 July	29.00	23.29	206.60	84.00	81.57
30	23-29 July	29.43	23.00	150.00	87.57	87.14
31	30-5 Aug	27.29	23.57	299.60	84.57	83.29
32	6-12 Aug	27.57	23.43	295.60	80.86	78.29
33	13-19 Aug	29.14	21.14	55.20	80.29	77.14
34	20-26 Aug	29.86	21.00	49.40	68.43	69.14
35	27-2 Sep	27.43	22.57	37.60	74.29	73.29
36	3-9 Sep	27.86	20.00	56.00	71.29	68.57
37	10-16 Sep	28.86	19.43	6.40	69.14	63.00
38	17-23 Sep	29.71	20.71	27.00	69.29	69.14
39	24-30 Sep	28.71	19.29	0.00	76.86	73.14
40	1-7 Oct	29.14	18.14	0.00	70.29	67.00
41	8-14 Oct	29.43	17.86	0.00	71.57	70.57
42	15-21 Oct	29.43	15.00	0.00	71.71	68.57
43	22-28 Oct	26.29	13.43	0.00	67.71	64.14
44	29-4 Nov	24.00	13.71	0.00	66.67	63.33

APPENDIX-IV

Parameters used for benefit-cost-analysis

Particulars	Market rate (Rs)
Flubendiamide 48% SC	190/10 ml
Rynaxypyr 20 SC	2100/150 ml
Dinotefuran 20 SG	325/50 g
Monocrotophos 36 SL	428/ L
Melia 5%	60/100 ml
Eupatorium 5 %	60/100 ml
Labour charges	180/ day (2 sprays @ 3 man days/spray/ha)
Rice grains	1450/ q

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Academic Qualifications

Qualification	Year	School/Board/ University	Marks (%)	Division
10th	2006	HP Board of School Education, Dharamshala	81.10	First
10+2	2008	HP Board of School Education, Dharamshala	76.80	First
B.Sc. (Hons.) Agriculture	2012	CSK HPKV, Palampur	65.50	First
M.Sc. Entomology	2014	CSK HPKV, Palampur	67.00	First
Ph.D. Entomology	2018	CSK HPKV, Palampur	75.90	First

Thesis Title in M. Sc. - Queen cell production potential of *Apis mellifera* Linneaus

Publications:

Total: 6
Research papers: - 4
Review paper: - 2
Others: Nil

Visits abroad along with duration and purpose of visit: Nil