DEVELOPMENT OF WEATHER BASED FOREWARNING MODEL FOR MAJOR PESTS OF RICE

By

N. MANIKANDAN, M.Sc., (Ag.)

I.D. No. 10- 605-004

AGRO CLIMATE RESEARCH CENTRE
DIRECTORATE OF CROP MANAGEMENT
AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE-641 003

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Thesis submitted in part fulfillment of the requirements for the award of Degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)**
IN
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to the
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CERTIFICATE

This is to certify that the thesis entitled **“DEVELOPMENT OF WEATHER BASED FOREWARNING MODEL FOR MAJOR PESTS OF RICE”** submitted in partial fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURAL METEOROLOGY AND CLIMATOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. N. MANIKANDAN, M.Sc. (Agri.)** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles. However, part of the thesis work has been published in peer reviewed scientific Journal of National/ International repute.

Place: Coimbatore **(Dr. J.S. KENNEDY)**
Date : Chairman

Approved by

Chairman : **(Dr. J.S. KENNEDY)**

Members : **(Dr. V. GEETHALAKSHMI)**

(Dr. K. SATHYAMOORTHI)

(Dr. S. ENAYATHULLAH SHAH)

External examiner :
Date :

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Talents bloom in compatible climate; efforts capture enviable acclaim in unexpected moments, Odds are prone to over-shadow a sensitive soul in an insensitive age. At some point of time, I thought, I was diffident in my venture. However, as time rolled on, to my delight, I found myself transforming into an entirely different boy, capable of capturing the heights. I have come to believe the incredible. If with profound satisfaction, I could present this piece of investigation work in its present form, I owe a great deal to several of those who showered unstinted support on me throughout. I need no second thought to place on record resplendent letters, the overwhelming patronage granted to me by these noble souls but for which I would have been only groping in dark.

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(N.MANIKANDAN)

ABSTRACT

DEVELOPMENT OF WEATHER BASED PEST FOREWARNING MODEL FOR MAJOR PESTS OF RICE

By

N. MANIKANDAN

Degree	:	**Doctor of Philosophy (Agriculture) in Agricultural Meteorology and Climatology**
Chairman	:	**Dr. J.S. Kennedy D.Sc.,** Professor of Agricultural Entomology School of Post Graduate Studies Tamil Nadu Agricultural University Coimbatore – 641 003.

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Experiments were undertaken to study the behaviour of the major rice pests under different temperature regimes and corresponding thermal accumulation for growth and development and to develop a weather based forewarning model to forecast the pest population at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore during 2011-13. Experiments were carried out in Climate Control Chamber under five different constant temperatures (28.3°C, 30.6°C, 32.7°C, 34.3°C and 36°C) with major insects such as, Yellow Stem Borer (YSB), Brown Planthopper (BPH) and Rice Leaffolder (RLF). Observations on demographic parameters of insects and thermal requirement were recorded at different temperature regimes. Apart from this, data on weekly light trap catches of insects were collected from progress report of Directorate of Rice Research, Hyderabad for cauvery delta zone (Aduthurai) and a weather based forewarning model had been developed.

The results revealed that the number eggs laid by YSB and RLF increased with increasing temperatures. In case of BPH, the number of eggs was decreased with increasing temperatures. Hatching of eggs were decreased with increasing temperatures irrespective of the insect pests. The total lifespan of YSB extended to a maximum of 52 days at 28.3^{o}C, whereas it was only 38 days at 36^{o}C. BPH took as long as 44 days to complete the generation at 28.3^{o}C and as short as 32 days at 36^{o}C. RLF took 36 days to complete the generation at 28.3^{o}C, whereas it took only 27 days at 36^{o}C.

The age specific survivorship decreased with the progress of age at all the temperatures irrespective of the insect pests. The 50 per cent mortality was observed to be occurring earlier at higher temperature regimes than at lower temperature regimes for all the insects. The survival fraction remained higher for all the stages at lower temperature regime of 28.3^{o}C and drastically reduced at higher temperature regime of 34.3^{o}C for the insects under study. The apparent mortality and mortality survivor ratio were observed to be increasing with increasing temperatures, whereas indispensable mortality was observed to be decreasing with increasing temperatures. Generally YSB, BPH and RLF tend to be ‘K’ favoring at higher temperature from being ‘r’ favoring at lower temperature. All the population growth parameters (finite rate of increase, intrinsic rate of natural increase and doubling time) increased with increasing temperatures. However, the increase had a turnaround after a threshold temperature (34.3^{o}C) of the experiment and, hence, it was reduced at 36.0^{o}C.

The average degree days required to complete the development of YSB egg, larva and pupa were 136.3, 557.8 and 156.3, respectively. BPH eggs required an average of 123.3 degree days to hatch into nymph and the nymphal stage must accumulate 269 degree days to become adult. In the case of RLF, eggs and larval stage required an average of 98.1 and 344 degree days, respectively to complete the development.

Temperature (maximum and minimum of current, one and two weeks before) had a significant negative relationship with the number of light trap catches of all the insects, whereas relative humidity had a significant positive relationship. Weather based pest forewarning models for YSB, BPH and RLF were developed by using Generalized Linear Model.

From the above experiments, it is concluded that the temperature above the threshold of 32.7^{o}C is detrimental to the growth and development of these insects. The timing of the control measures like chemical spray to control these insects could be planned based on the thermal accumulation (degree days) of the insects, which will reduce the cost of spray and improve the efficiency. Weather based forewarning models developed for each insect could be used to forewarn the pest population at particular time, which will be useful in planning the cost effective control strategies.

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CHAPTER I

INTRODUCTION

Rice is the staple food for over half of the world's population. It provides 49% of dietary energy and 39% of dietary protein in the developing world (FAOSTAT, 2012). It is cultivated from 53°N to 40°S latitude where it is adapted to a wide range of environmental conditions, from uplands to waterlogged lowlands and is the primary source of income and employment for more than 100 million households in Asia and Africa. Consumption per capita varies greatly from 5.8 kg/year in countries of European Union to 292 kg/year in Combodia (Wailes and Chavez, 2012). It is one of the most important food crops of India in terms of area, production and consumer preference. India is the second largest producer and consumer of rice in the world with the production being 104.32 MT in 2011-12, accounting for 22.88 per cent of global production (MoA, 2013).

Today, rice is just as important to food security or more so, than it was in 1979, when the first Director General of the International Rice Research Institute (IRRI), R. F. Chandler, made the statement ***"So dependent upon rice are the Asian countries that throughout history a failure of that crop has caused widespread famine and death".*** In recent years, concern over food security is increasingly sensed, more in developing countries, where rice production did not match the increasing population. With reduced land availability and increased demand for enhanced production, attention is turning towards intensification through higher fertilizer inputs and cropping. Such efforts in turn increased pest intensities (Heong, 1996) and losses caused by pests remained an important constraint to achieve high rice yields (Waddington *et al.*, 2010).

Crop plants used as food by human beings are damaged by over 10,000 species of insects and cause an estimated annual loss of 13.6% globally (Benedict 2003) and 23.3 per cent in India (Dhaliwal *et al*., 2004). In India, the average annual losses have been estimated to be 17.5 per cent valued at US$17.28 billion in eight major field crops viz., cotton, rice, maize, sugarcane, rapeseed, mustard, groundnut, pulses, coarse cereals and wheat. (Dhaliwal *et al.*, 2010). Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming.

Several improvements have been made to boost up productivity of rice but insect pests still continue to be the major limiting factor (Saxena and Shrivastava, 1992). Rice is attacked by more or less 100 species of insect pests in which 20 are of economic importance (Pathak and

Dhaliwal, 1981). A few species, however, do cause significant damage and are extremely important. The Yellow Stem Borer (YSB), Brown Planthopper (BPH) and Rice Leaffolder (RLF) are the major pests of economic importance in India and are among the production constraints consistently encountered in various rice growing environments (DRR, 1965–2003; DRR, 1975–2003).

The YSB, *Scirpophaga incertulas* Walker (Pyralidae: Lepidoptera) is one of the major pests in all rice producing areas of Asia, in south east Asia and India in particular and accounts for 6-10% loss in the crop yield (Muralidharan and Pasalu, 2005). The BPH, *Nilaparvata lugens* (Stål) has in recent years caused extensive damage to the rice crop in Asia. Although an important pest in Japan for many years, it was formerly only a minor pest in most tropical countries of Asia. However, BPH populations have greatly increased and caused severe yield losses in several countries. Largescale damage by the insect has been reported in India, Indonesia, the Philippines, and Sri Lanka (Dyck and Thomas, 1979). RLF, *Cnaphalocrocis medinalis* (Guen.) was considered as pests of minor importance have increased in abundance in late 1980s and have become major pests in many parts of India. The yield loss is from 30 to 80 per cent due to RLF epidemic situation (Baby Rani, 2007).

Insects flourish in all climates. Weather and climate influence often vary significantly, the development rate, survival, fitness and level of activity of individual insects; the phenology, distribution, size, continuity of insect populations, migration and the re-establishment of populations following local extinction, the initiation of outbreaks, the susceptibility of crops and stock to insect attack and the capacity of producers to manage insect populations. Among all the climatic factors, temperature is probably the single most important environmental factor as insects are poikilothermic animals whose metabolism, rate and magnitude of growth, development and overall behavioral activities respond significantly to temperature change (Bale *et al.*, 2002).

Climate change, especially temperature increase, will affect insect physiology, behavior, and development as well as species distribution and abundance, evidenced by changes in the number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects (Huang *et al.*, 2010). The earth's climate has warmed by approximately 0.74^{o}C over the past 100 years with two main periods of warming, between 1910 and 1945 and from 1976 onwards (Walther *et al.*, 2002). The last assessment report from the Intergovernmental Panel on

Climate Change (IPCC) predicts an increment in mean temperature from 1.1 to 6.4^{o}C toward the year 2100 (IPCC, 2007). This Increase in temperature will accelerate the development of insect pests, possibly resulting in more generations per year. Hence, it is important to study the effect increasing temperature on pest populations.

Heat units derived from average temperature, are methods of quantifying a biological organism's thermal environment. Every insect requires a consistent amount of heat accumulation to reach certain life stages, such as egg hatch or adult flight. Proper use of heat units can provide a reliable means of predicting the growth and development of many crop pests (Marchioro and Foerster, 2011). Hence, by determining the degree days for each stage of the pest, a possible prediction of emergence insects could be given to farmers for planning the control strategies.

Entomologists expect that insects will expand their geographic ranges and increase reproduction rates and overwintering success. It also is likely that farmers will experience extensive impacts on insect management strategies with changes in climate. Prevention of yield losses needs substantial consideration and accordingly forewarning of pests and diseases is essential for taking timely control measures. As we already aware, meteorological factors play an important role in seasonal abundance, distribution and population build up of insect pests (Lee *et al.,* 2009a). The weather based modeling for early warning of pest infestation may provide appropriate tool for investigating and predicting pest status. However, at present, little is known about the behavior of the insects to meteorological factors and their temporal variation in the spatial pattern in paddy fields. Several studies have been carried out on the population dynamics of insect pests in paddy fields, but most considered only one species or a small region (Kuno and Hokyo, 1970; Lee and Park, 1991; Matsumura, 1996). In light of these, it was decided to study the behavior of insects at different temperature regimes and to develop a model to forecast the occurrence of Yellow Stem Borer (YSB), Brown Planthopper (BPH) and Rice Leaffolder (RLF) with the following objectives.

1. To generate the information on population biology of major insect pests of rice such as YSB, BPH and RLF at different temperature regimes.
2. To establish the relationship between degree days and growth rates of different developmental stages of rice pests and to predict the pest occurrence by degree day accumulation.
3. To develop weather based pest forewarning model to predict the time of the pest occurrence and its severity.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Crop plants used as food by human beings are damaged by over 10,000 species of insects and cause an estimated annual loss of 13.6 per cent globally (Benedict, 2003) and 23.3 per cent in India (Dhaliwal *et al.*, 2004). In India, the average annual losses have been estimated to be 17.5 per cent valued at US$17.28 billion in eight major field crops (cotton, rice, maize, sugarcane, rapeseed, mustard, groundnut, pulses, coarse cereals and wheat) (Dhaliwal *et al.*, 2010). Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming.

Rice is one of the most important and extensively grown foods in the tropical and subtropical regions of the world. Several improvements have been made to boost up productivity, but insect pests still continue to be the major limiting factor (Saxena and Shrivastava, 1992). Rice is attacked by more or less 100 species of insect pests of which 20 are of economic importance (Pathak and Dhaliwal, 1981). The Yellow Stem Borer (YSB), Brown Planthopper (BPH) and Rice Leaffolder (RLF) are the most destructive group of insect pests of rice in India.

2.1. Climate and insects

Insects flourish in all climates. Weather and climate influence, often vary significantly, the development rate, survival, fitness, and level of activity of individual insects; the phenology, distribution, size, continuity of insect populations, migration and the reestablishment of populations following local extinction, the initiation of outbreaks, the susceptibility of crops and stock to insect attack and the capacity of producers to manage insect populations. It is difficult to find a direct cause and effect relationship between any single factor and pest activity because the impact of meteorological factor on pests is usually compounded (Garg and Sethi, 1980; Krishnaih *et al.,* 1996; Harinkhree *et al.,* 1998).

Hodkinson (1999) has reported that the population dynamics of insect species are largely determined by climatic factors. Climate affects the population dynamics of insects and is therefore a useful predictor of potential establishment and spread in new areas (Cammell and Knight, 1992; Gevrey and Worner, 2006; Hance *et al.,* 2007). Numerous authors cite climatic factors to influence the changes in population size of insects over longer time periods such as several generations (Pathak, 1968). Recently frequent references have been made to rainfall, relative humidity and temperature. Pradhan (1972a; 1972b) suggested that cooler seasons and cooler regions had higher yields due to fewer pest problems. In temperate regions, most insects have their growth period during the warmer part of the year. Due to this, species whose niche space is defined by climatic regime will respond more predictably to climate change (Bale *et al*., 2002). From the above, it is clear that the insect's abundance and distribution is mainly influenced by weather and climate of that particular region.

For developing any pest management programme for specific agro-ecosystem, information on abundance and distribution of pest in relation to weather parameters is a basic requirement (Patel and Shekh, 2006). Improved techniques for managing pests require weather and insect data from thoroughly maintained monitoring as well as climate information and forecast to determine their suitability (Lee *et al.,* 2009a; 2009b). There have been several attempts to establish associations between historic pest damage and climate conditions (Rosenzweig *et al.,* 2000; Yang and Schern, 1997). Major pest outbreaks have occurred during favorable regional weather conditions.

If the adverse effects of global warming on agriculture are to be mitigated, a better understanding of the population dynamics of insect pests in connection with meteorological factors is essential in order to be able to forecast outbreaks and apply effective pest control. However, at present, little is known about the temporal variation in the spatial pattern of insect pests in paddy fields. Several studies have been carried out on the population dynamics of insect pests in paddy fields, but most considered only one species or a small region (Kuno and Hokyo, 1970; Lee and Park, 1991; Matsumura, 1996).

2.2. Impact of climate change on insects

Pullin (1986) reported that the species which breed two or more generations a year may gradually adapt to the new climatic conditions by shifting the temperature thresholds, effective temperature totals and critical photoperiod lengths without showing any appreciable changes in their development. Porter *et al.* (1991) revealed that the changes in surrounding temperature regimes certainly involve alterations in development rates, voltinism and survival of insects and subsequently act upon size, density and genetic composition of populations, as well as on the host plant exploitation. Considering insect populations, it can be seen that climate change affects in many ways: it can cause a shift in geographical spread (Ward and Masters, 2007). Climate change, especially temperature increase will affect insect physiology, behavior, and development as well as species distribution and abundance, evidenced by changes in the number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects (Landsberg and Smith, 1992; Huang *et al.,* 2010).

High temperature is usually not favorable to the development of some insects in summer, while other insects are able to adapt or decrease the injury by physiological or habitat accommodation (Hoffman and Blows, 1993). Recent observations indicate that climatic change is altering biodiversity (Pounds *et al*., 1999; Beaugrand and Reid, 2003; Parmesan and Yohe, 2003; Menendez *et al.,* 2006). Because of the short life cycles of insects, mobility, reproductive potential, and physiological sensitivity to temperature, even modest climate change will have rapid impacts on the distribution and abundance of many kinds of insects (Ayres and Lombardero, 2000). Climate change can change the location, the timing and the magnitude of outbreaks of pests (Volney and Fleming, 2000). Arthropods can be used as indicators of environmental change more rapidly than the vertebrates (Scherm *et al.,* 2000; Gregory *et al.,* 2009). There is now ample evidence that these recent climatic changes have affected a broad range of organisms with diverse geographical distributions (Wuethrich, 2000; McCarty, 2001; Ottersen, 2001; Walther *et al*., 2002). Insects comprise 54 per cent of all known species and occupy every terrestrial habitat (Schowalter, 2000), so exploring the responses of insects to climate change will provide us with a good understanding of how climate change is affecting biological systems. Climate change can define the phenological or even the genetic properties of the species (Klok and Chown, 2001; Gordo and Sanz, 2006; Parmesan, 2007).

Insect populations respond directly to climate change. Evidence of faster development rates has been shown from all the long-running insect datasets in the United Kingdom (Harrington *et al.,* 2001). The connection between temperature tolerance and phenology of insects was investigated by Klok and Chown (2001). They defined how current climate change like increased temperature and decreased rainfall affect on physiological regulation and susceptibility. Insects are among the groups of organisms most likely to be affected by climate change because climate has a strong direct influence on their development, reproduction and survival (Bale *et al.,* 2002). Changes in climate and weather could profoundly affect the population dynamics and status of insect pests of crops. These may arise not only as a result of direct effects on the distribution and abundance of pest populations but also indirect effects on the host plants of insect pests, competitors and natural enemies (Bale *et al.,* 2002). Some pests which are already present outbreaks but only occur in small areas, or at low densities may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities (Bale *et al.,* 2002).

It has been recognized for many years that climate affects biochemical, physiological and behavioral processes in insects (Thomas and Blanford, 2003). According to the last assessment report from the Intergovernmental Panel on Climate Change (IPCC), climate change poses a considerable threat to some ecosystems and species extinction (Harte *et al.,* 2004; Thomas *et al*., 2004; Kittel *et al.,* 2011) because of changes in both temperature and precipitation. Mountain species and those restricted to high latitudes will be most likely to go extinct as a result of warming. These species are adapted to cold conditions so they will be forced to move uphill and to higher latitudes as the climate warms. But, even if they are able to move, they will eventually run out of habitable areas and will inevitably go extinct (Thomas *et al.,* 2004).

Plutella xylostella (Yponomeutidae) had been the most serious pest of *Brassica* plants until recently. Since the middle of the 1990s it has become less abundant and currently is considered a minor pest. Since the outbreak of 1994, *Helicoverpa armigera* (Noctuidae) has taken its place as a serious pest of vegetables. *Trichoplusia ni* (Noctuidae), which is a pest of vegetables in North America, has been an inconspicuous pest in Japan. However, since the early 2000s, it has occurred all over western Japan as a vegetable pest. Although the exact causes remain to be seen, global warming may have been involved in these changes of pest status (Yase, 2005).

Temperatures in most regions of the world are increasing and there are already indications that insects and plants are responding. Temperatures are not just the result of warmer summer days but also of fewer cold days, cold nights and frosts (IPCC, 2007). Insects have short generation times and high reproductive rates, so they are more like to respond quicker to climate change than long living organisms, such as plants and vertebrates. Warming can potentially affect several aspects of insect life cycle and ecology, especially those directly controlled by energy availability variables such as degree day (accumulative temperature needed for development). Consequently, potential responses include changes in phenological patterns, changes in habitat selection, and expansion and contraction of geographic and altitudinal ranges (Menendez, 2007).

Climate change on insect populations, however, forces us to assess the ecological, economical, and social risk of biotic disturbances (Merrill *et al.,* 2008). Change in a region's climate due to temperature increase could induce changes in the occurrence patterns of insect pests (Lastuvka, 2009). Climate change, especially temperature increase will affect insect physiology, behavior and development as well as species distribution and abundance, evidenced by changes in the number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects (Huang *et al.*, 2010). There are two distinct mechanisms by which climate change can impact the relationship between pests and crop plants. Firstly, changes in climate have a direct impact on the biology of insects including vectors, leading to differences in their survival, reproduction and spread. Secondly, there are the likely changes in agricultural practice that will take place as a result of climate change, and the influence of these changes on the availability of host plants for the pest species; e.g. the introduction of new crop species and plant genotypes, and changes in husbandry practice (Roos *et al.*, 2010). Shi *et al.* (2012) also found that the minimum annual temperature, which indirectly reflects climate warming, has significant influence on annual population growth rates. The biogeography of the insect pests was expected to increase with elevated air temperature influenced by global warming based on the Intergovernmental Panel on Climate Change (IPCC) A1B scenario (Kwon *et al*., 2012).

2.3. Impact of temperature on the biogeography of insects

The speed of development of an insect is generally studied under controlled temperature to measure its growth rate (Andrewartha and Birch, 1954) and is regarded to be very useful in forecasting the appearance of insects of economic importance in any locality. It is reported that among all the climatic factors, temperature has probably the greatest effect on insect development (Taylor, 1981; Pedigo, 1989). Insects are known to live in a wide range of thermal climates, but there is very little variability in the maximum temperature (40–50°C) which they can survive (Heinrich, 1981). Insects are poikilothermic animal whose metabolism, rate and magnitude of growth, development and overall behavioral activities respond significantly to thermal change on a daily, seasonal and annual basis (Ward and Stanford, 1982). Optimal growth and development of insects falls within a fairly broad range of temperatures (Rock and Shaffer, 1983).

The extent to which warmer temperatures influence the life history characteristics and biogeography of aquatic insect species will depend largely on the magnitude and rate of temperature change. Temperature influences the growth dynamics of aquatic insects, through its influence on rates of ingestion, assimilation, activity, metabolism etc. (Sweeney, 1984). Temperature may play a key role in determining both the physiology and the ecology of insect pests, especially their distribution, development rate, and phenology (Mochida *et al.,* 1987; Huang *et al.,* 2010). Kiritani (1988) suggested that tropical and subtropical species may be able to advance poleward continuously for as long as their cold hardiness allows, because they usually lack diapause in their life cycles. On the other hand, temperate species, which pass the winter in a definite diapause stage are able to overwinter successfully only when they have developed to diapause before winter. Therefore, these temperate species will not advance poleward until the temperature rises sufficiently to allow completion of an additional generation, thereby expanding their range stepwise.

Respiration increases in response to increasing temperature up to a critical upper limit and after this point, respiration decreases. An adequate supply of oxygen is essential for insects to survive heat stress (Whitting *et al.,* 1991). The possible biological consequences would not only be due to the increased temperature *per se*, but, probably more importantly to the rate of increase. A key prerequisite for predicting the effects of increased temperature is to describe how environmental change affects the dynamics of populations and communities of living organisms (Root and Schneider 1993). Many researchers have proved that, butterflies are good case for the analysis of the effects of temperature on distribution and abundance (Parmesan, 1996; Parmesan *et al*., 1999; Roy and Sparks, 2000; Thomas *et al.,* 2001). As insects are ectothermic organisms, the temperature of their body changes approximately with the temperature of their habitats. Therefore, temperature is probably the most important environmental factor influencing their behavior, distribution, development, survival and reproduction (Chu and Chao, 2000).

In discussing climate change, the focus is mainly on temperature, the climate variable for which there is most confidence in future predictions (Houghton *et al.,* 2001) and for which evidence of effects on insects is most plentiful. The potential rate of insect population is strongly dependent on temperature and their survival is impaired at temperature extremes. Changes in both mean temperature and the extent and frequency of extremes can hence have major impacts on insect populations. The total number of male *Spodoptera litura* captured by pheromone traps in 1998 was the largest of the previous 14 years. There was a positive correlation between the abundance of males and the mean annual temperatures during this period. In contrast, *Homona* *magnanima, Adoxophyes honmai* and aphids were less abundant in 1998, suggesting that an elevation in the mean temperature of 2^{o}C would impact the phenology of insects, but the response would greatly vary among species (Yamaguchi *et al.*, 2001). Exposure to temperatures beyond the favourable limits, extremely low or high may retard growth and development of insect stages or may even cause its death (Dhaliwal and Arora, 2001).

Depending on the development strategy of an insect species, temperature can exert different effects on it. The effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.*, 2002). For poikilothermic organisms, phenology is largely determined through adaptive evolution with the prevailing climate and in particular, annual temperature cycles (Logan and Regniere, 2003). Changes in both mean temperature and the extent and frequency of extremes can have major impacts on insect populations (Fleming and Candau, 2004). Each insect species and even each population might have a different optimum temperature for survival and reproduction. In colder regions (higher latitudes) with distinctive seasons, insects have broader thermal tolerance and are living in climates that are currently cooler than their optima (Deutsch *et al.,* 2008).

2.4. Impact of temperature on insect phenology

The number of generations of small brown planthopper, *Laodelphax striatellus* (Fallén) increases with a decrease of latitude until six generations are completed in the subtropical zone, tentatively calculated by the total effective temperature (Kisimoto and Dyck, 1976). Many researchers have reported that the duration of different aphid instars shortened as temperature increased (Komazaki, 1982, Mink and Harrewijn, 1987, Hirano *et al*., 1996, Wang and Tsai, 2001). Temperature has been considered as one of the most important physical factors to influence the developmental rate, reproduction and survival of aphids (Barlow, 1962; Dixon, 1987). Although insects do not live in a stable environment without temperature fluctuation, the results of studies under constant temperatures are still very useful in understanding the population dynamics of *Acyrthosiphon kondoi* Shinji (Summers *et al*., 1984). For all the insect species, higher temperatures, below the species upper threshold limit, will result in faster development and rapid increase in pest populations as the time to reproductive maturity will be reduced considerably. In addition to the direct effects of temperature changes on development rates, improvement in food quality due to abiotic stress may result in dramatic increases in growth of some insect species (White, 1984), while the growth of certain insect pests may be adversely affected (Maffei *et al*., 2007).

An increase of 3°C in mean daily temperature would cause the carrot fly, *Delia radicum* (L.) to become active a month earlier (Collier *et al*., 1991) and temperature increase of 5 to 10°C would result in completion of four generations each year, necessitating adoption of new pest control strategies. It is reported that the incubation period of *Scirpophaga incertulas* decreases with temperature increase, beginning at 30°C and continuing up to 35°C. The optimum egg hatching temperature is 24-29°C for *S. incertulas* and it requires 90-100 per cent relative humidity; hatching is severely reduced below 70 per cent relative humidity. The rate of *S. incertulas* larval development is positively correlated with temperature between 17 and 35°C. Most larvae undergo five instars when reared at 23-29°C, but only four at 29-35°C. In lepidopterous and diopsid species, the larval period usually lasts from 20 to 30 days. The pupal period in lepidopterous and diopsid species lasts for 9-12 days (Pathak and khan, 1994).

The abundance of planthoppers is attributed to high temperature and high humidity. Adult *Nilaparvata lugens* remain active from 10 to 32°C. They usually live for 10-20 days in summer and 30-50 days during autumn. Females kept at 20°C have an oviposition period of 21 days, which is reduced to 3 days if they are kept at 30°C. The incubation period is 4-8 days. In most species, egg and nymph develop fastest at 25-30°C. *N. lugens* eggs usually do not hatch if incubated at 33°C, but more eggs hatch and growth is faster at 27°C than at 25°C. A temperature of 33°C is lethal to freshly hatched nymphs and greatly reduces the life span of the adults. The nymphs exhibit a positive relationship between rate of nymphal development and temperature of 11.6-27.7°C. The rate of egg and nymphal development of is highest at 27-28°C. The fourth- and fifth instar nymphs remain active at 12-31°C. It is widely accepted that for most rice leafhopper and planthopper species, the optimum temperature is 25-30°C. Insects reared at higher temperatures do survive, but they are less fertile and often many eggs do not hatch. Oviposition in rice leaffolder eggs starts two to three nights after mating. The female moth of leaffolder usually lives for as long as 8-9 days and lays 50-300 eggs. The eggs hatch 3-4 days after oviposition. Five larval instars are completed in an average period of 20-30 days (Pathak and Khan, 1994).

Early adult emergence and an early arrival of migratory species have been reported in the UK for aphids group (Zhou *et al*., 1995). An increase of 2°C will reduce the generation turnover of the bird cherry aphid, *Rhopalosiphum padi* (L.) by varying levels, depending on the changes in mean temperature (Morgan, 1996). Increased temperatures will accelerate the development of insects possibly resulting in more cycles of generations (and crop damage) per year (Awmack *et al.,* 1997). Yamamura and Kiritani (1998) suggested that aphids are amongst the insects best adapted to take advantage of a warming climate. In case of aphids, 2°C temperature increase causes one to five additional life cycles per season. In general, assuming a constant temperature rise over the year, species with lower threshold temperature (T_0) and small thermal constants (K) are predicted to have an increasing number of annual generations and an earlier appearance of overwintering individuals (Yamamura and Kiritani, 1998; Yamaguchi *et al*., 2001). An increase of 2^{o}C is expected to produce an additional two to four generations each year in most of the insect predator and parasitoid groups. On the other hand, most of the rice pests would increase at most by one generation except for mirids and delphacids (Kiritani, 1999).

In Canada, where temperatures affecting physiological processes tend to be below optima for most insect species for most of the year, temperature increases will likely to accelerate these processes thus causing faster development, more activity and movement, reduced mortality from climatic factors and possibly even more generations in a season (Yamamura and Kiritani, 1998, Hansen *et al.,* 2001). Experimental results revealed that under a rise in temperature insects will pass through their larval stages faster and will become adults earlier. Thus, observed responses include both an advance in the timing of adult emergence and an increase in the length of the flight period. In this regard, lepidoptera are by far the best documented group. Changes in butterfly phenology have been reported in the UK (Roy and Sparks, 2000) with species advancing their flight periods by around 2–10 days for every 1ºC increase in temperature. This has resulted in an extended flight period, especially for multivoltine species.

To project the influence of global climate changes on insects, Yamaguchi *et al.* (2001) examined the occurrence of arthropod pests in 1998 in Kagoshima Prefecture, southwestern Japan. The average temperature of 1998 was 2^{o}C higher than that of 1960–1997. Several arthropod species emerged earlier than in previous years because of the unusually high average temperature. All the species have developmental zeros less than 10^{o}C. In contrast, *S. litura* and *Helicoverpa armigera*, whose developmental zeros are above the mean winter temperature, emerged as usual in the spring. A possible increase in the number of generations per year was not clearly shown by the trap-capture records, but all species are likely to have one or more generations. Higher temperatures in winter or spring are likely to stimulate the reproduction of overwintering adults and leading to faster population growth and an additional generation in some insect pests (Harrington *et al*., 2001; Kiritani, 2006). In response to global warming, butterflies have advanced their first appearance between one and seven weeks in a period of 15 year in Spain (Stefanescu *et al*., 2003) and by around eight days per decade in California (Forister and Shapiro, 2003). Where life cycle events are controlled by temperature, they may be expected to occur earlier and higher temperatures are likely to facilitate extended periods of activity at both ends of the season, subject to constraints that other factors such as day length and drought might impose (Fleming and Candau, 2004).

The effect of seven constant temperatures from 10 to 40°C (10, 15, 20, 25 30, 35 and 40°C) on the development of eggs, larvae and pupae of rice stem borers viz., *Chilo polychrysa*, *C. suppressalis*, *C. partellus*, *S. incertulas*, *S. innotata* and *Sesamia inferens* were studied. The mean percent of development per day of egg, larva and pupa of all borers gradually increased with the increase of constant temperatures. The total developmental period was inversely decreased with the increase of constant temperatures. The lower threshold temperature was found between 10-15^{o}C and higher threshold temperature between 35-40°C, where no development took place. Gordo and Sanz (2005) observed a common phenological response in four unrelated species of insects (a butterfly, a bee, a fly and a beetle). During the last 50 years all four species showed significant temporal changes in their first appearance date. In all cases their appearance earlier in the year was correlated with the increase in spring temperature observed in the area during the same time period.

Significant differences were detected in preoviposition period, oviposition period, longevity, total fecundity, daily oviposition rate and egg viability among cohorts of adult *Otiorhynchus sulcatus* tested at 9 temperatures. The mean number of days from eclosion to first feeding was 11 days at 11^{o}C, 3 days at 30^{o}C. At temperatures between 15 and 27^{o}C, the duration of oviposition period decreased as the temperature increased. The duration of the preoviposition period was significantly longer at 11^{o}C than at 15, 18, 21, 24, or 27^{o}C. The duration of the oviposition period was significantly longer at 15, 18, and 21 ^{o}C than at 11 or 27^{o}C (Son and Lewis, 2005). Experiments conducted by researchers proved that, polyvoltine species will profit from accelerated development rates allowing for an earlier completion of life cycles and the establishment of additional generations within a season (Lange *et al.,* 2006; Jonsson *et al.,* 2009). Temperatures above the specific optimum range lead to decreased growth rates (Rouault, 2006).

Among the six constant temperatures tested, *Tetraneura nigriabdominalis* reared at 30^{o}C had the shortest nymphal developmental time, which averaged 8.5 days. The developmental time of each instar was reduced by more than 50 per cent with increasing temperature from 10 to 25^{o}C. From 25 to 30^{o}C, the increase became more gradual. This result was also found on the total nymphal developmental time; the nymphal time decreased from 46.3 days at 10^{o}C to 8.5 days at 30^{o}C. At 35^{o}C, however, only 12.5 per cent of nymphs survived, and the nymphal developmental time increased to 10.2 days. In comparison with results of all temperatures used in this study, authors have found that, 30^{o}C was the temperature closest to the optimal temperature for nymphal development (Kuo *et al.,* 2006). Results of adult longevity and fecundity of *T. nigriabdominalis* at different temperatures shows that, adult aphids reared at 15^{o}C had the highest average longevity (23.3 days), but longevity decreased to 15.8 days at 10^{o}C and to 8.2 days at 35^{o}C (Kuo *et al.,* 2006).

The potential of evolutionary changes is great among insects, as they grow fast, have short generation times and high reproductive rates meaning populations may adjust rapidly to the new environmental conditions. Therefore, it is not surprising that most empirical evidence of evolutionary changes comes from insect species (Parmesan, 2006; Thomas, 2005). The winter survival rates of insects can be increased by an increase in winter temperatures, but the evidence for this is rather scarce (Kiritani, 2006). The rapid increase in butterfly species, which established on the Nansei Islands during the latter half of the twentieth century, is correlated with the elevation of surface temperature. An elevation in the annual mean temperature by about 1^{o}C is enough to allow *Stenotus rubrovittatus* (Miridae) to have one additional generation (Kiritani, 2006). Insect may also evade climate change stress through changes in life cycle. Insect populations from environments with higher temperatures may have higher fecundity and shorter growth stage to increase fitness. The egg duration of *H. armigera* was 10.4 days at 25°C and 7.9 days at 27-28°C (Dhillon and Sharma, 2007). The viability of eggs of *H. armigera* and day degrees required for egg hatching decreased with an increase in temperature from 10 to 27°C and egg age from 0 to 3 days. The degree day requirements were highest for zero day old eggs at 10°C and lowest at 27°C (Dhillon and Sharma, 2007).

Studies by Baby Rani *et al.* (2007) showed that the total life cycle period of the three species is in the following order, *Marasmia patnalis* (46.87 days), *Cnaphalocrocis medinalis* (36.67 days) and *Marasmia ruralis* (35.51 days) in the susceptible variety IR 20. The male population was higher than female. The ratio of male to female ranged from 1.01 to 1.15:1 in *C. medinalis.* By 2025, the flight initiation could take place, on average, 4–10 days earlier than 2005, and the European Corn Borer (ECB) life cycle will be completed 9–15 days earlier. Under present conditions, the individuals of ECB complete their first generation developmental cycle in early August, whereas by 2025 it is likely to be completed during the last 10 days of July. According to some scenarios, by 2050, the development of the first generation could be completed by the 10th of July (Trnka *et al.*, 2007). In Rice earhead bug, *Leptocorisa acuta*, the 0.5 and 2°C rise in daily average temperature caused no effect on the generation time but 3°C rise caused 1 to 3 days increase in generation time (Reji and Chander, 2008). Greenhouse studies by Padmavathi *et al*. (2008), revealed that the females of leaffolder lived for about a week with pre-oviposition period of 3-4 days and oviposition period of 4-5 days. Total development period from egg to adult was found to be 24.8 days. The developmental time of the cotton aphid significantly decreased with increasing constant temperatures ranging from 13.0 days at 15.0°C to 4.0 days at 30.0°C. Similarly, the green peach aphid developed significantly faster at warmer temperatures than at cooler temperatures (Satar *et al.,* 2008).

Experiments conducted by Ramya *et al.* (2012) showed that, Yellow Stem Borer (YSB) took 8.1 mean days for hatching out into larvae at 30°C. However, at higher temperature it was found to be decreased. In the same way larval and pupal period showed a decrement. Like YSB, the same trend was observed in BPH. It took 6.7 mean days for hatching out into nymphs. This development time decreased significantly at higher temperature. Decreased developmental duration of instars observed at increasing temperatures might be connected with faster larval growth at these temperatures. Insects develops faster will oviposit early and hence the population will grow earlier than expected. YSB took 40.15 days duration before adult stage at 30°C. But, it took only 32.78 days to develop into adult at 38°C. YSB lived out its life in 6.0 days at 30°C and lived only 5.2 days at 38°C. The same trend was observed in BPH.

Hu *et al.* (2010) reported that increasing winter temperature due to global warming appears to be a factor accelerating outbreaks of *N. lugens* in Asia. Number of generations per unit time, voltinism, has a definite bearing on the insect population size and increase. Climatic warming is understood to trigger around 44 species of European Butterflies to increase their voltinism after 1980 (Altermatt, 2010). The developmental time of sycamore lace bug was found to significantly decrease with increasing temperature. Longevity of females was found to be the shortest, 17.7 days at 33°C and the longest, 58.9 days at 16°C (Ju *et al.*, 2011). The data on age and stage specific life-table of *Coccinella septempunctata* at varying temperature revealed that it took maximum period (68 days) to complete generation at 20±1°C followed by (61 days) at 24±1°C and (53 days) at 28±1°C (Ali and Rizvi, 2010). In Korea, the occurrence of first generation and the second generation of *Chilo suppressalis* were advanced, respectively, by 5–30 days and 5–20 days after 1980, compared to the 1960–1970s (NIER, 2011).

The duration of the immature stages and the time required to complete the cycle from egg to adult of *P. xylostella* were significantly affected by temperature. In general, the development time of the immature stages decreased linearly with the increase of temperature between 10°C and 30ºC. Above 30ºC, the development rate was clearly reduced, indicating that the optimum temperature is close to this value (Marchioro and Foerster, 2011). Observations on the phenology of some important coleopteran, lepidopteran and hemipteran pests of rice in Japan showed an increased voltinism as the climatic temperature exceeds the mean ambient level of 15°C by 2°C in 1998 (Swaminathan, 2011). With temperatures within their viable range, insects respond to higher temperature with increased rates of development, more number of generations with less time between generations. Very high temperatures reduce insect longevity (Das *et al*., 2011).

2.5. Impact of temperature on life table parameters

Deevey (1947) reported that a life table is a concise summary statement for every interval of age, the number of deaths (d_x), the number of survivors at the beginning of the age class x (l_x), the rate of mortality (q_x), and the expectation of life remaining for individuals of age x (e_x). The table also includes numbers living between the ages x and x+1, which is the age structure (l_x). Research by many scientists showed a decline in fertility when codling moth was reared at elevated temperatures as the duration of exposure to the elevated temperature was increased (Proverbs and Newton, 1962; White, 1981). Among the population growth parameters, the value of r_m has been considered an ideal parameter to compare the growth differences of a population under various conditions (Wang and Tsai, 2001). Oviposition which results in the initial population of the following generation is often under the strong, direct influence of climatic factors and the indirect influence of the seasonal change of habitat (Kisimoto and Dyck, 1976).

Analysis of life tables is the most suitable method to evaluate natality and reproduction of a population (Southwood, 1978; Price, 1997).

Waldbauer and Marciano (1979) reported that survival from first instar to the adult of BPH in 22 sleeves ranged from 78.6 to 97.3 per cent and averaged 87 per cent. Significant components to measure when evaluating the reproductive success of insects include total fecundity per female, preoviposition period, oviposition period, life duration, and egg viability. However, most quantitative investigations on *O. sulcatus* reproduction have been conducted exclusively on the preoviposition duration under a limited range of temperatures (Stenseth, 1979; Masaki and Ohto, 1995). Experiments conducted by Regniere (1983) revealed that the spruce budworm is benefitted from warmer temperatures. The number of eggs laid by this pest of conifers is 50 per cent greater at 25°C than at 15°C.

In life table studies, developmental times and survival rates of each stage, longevity of adults, and daily fecundity of females are recorded for every individual (Chi, 1988). High midsummer temperatures affect the survival and fecundity of BPH. Averages of 31°C during mid-July to early August usually cause the highest BPH mortality in subtropical rice areas. Survival of BPH nymphs at 31, 35, and 38°C was significantly lower than that at 26°C. BPH females laid up to 140 eggs after 12 days at 26°C. Fecundity decreased rapidly as temperature increased. Results indicate that average rice field temperatures of more than 31°C would have obvious inhibitory effects on the survival and fecundity of BPH (Xiaoping *et al., 1992*). *S. incertulas* lays maximum number of eggs at 29°C and 90 per cent relative humidity (Pathak and khan, 1994).

Danks (1994) suggested that insect reproduction is governed by interactions between intrinsic life history traits and extrinsic factors such as temperature, food, moisture, light intensity, chemicals, and pathogens. According to Heong *et al.* (1995), the adult survival of the BPH remained almost unchanged between 25 and 35°C, but was drastically reduced at 40°C. The oviposition of females at 35 and 40°C was relatively higher than at 25 and 30°C, but egg survival was markedly reduced at 35°C. At the higher temperatures, durations of pre-oviposition periods were also reduced. Clearly, temperatures above 35°C are likely to limit BPH development. The global warming is likely to increase BPH abundance in areas with temperatures below 30°C. Survival of the different stages of the rice leaffolder *C. medinalis* was greatly affected at 35°C. Adults emerging from pupae reared at 35°C were unable to lay eggs.

The upper temperature threshold for survival of this species appears to lie between 30 and 35°C (Heong *et al.*, 1995).

It is reported that, higher temperatures can shift the timing of reproduction in spruce budworms so that they may no longer be affected by the parasitoids that usually keep populations down (Fleming and Volney, 1995). YSB, a dominant rice pest in Bangladesh, experiences high mortality above a temperature of 34°C (Catling and Islam, 1995). Although most literature tends to emphasize climate-induced increases in abundance of insect population, it is logical that climate change will also reduce insect abundance in some aspects. For instance, many insects overwinter in forest litter may face higher mortality rates due to the decreased snow depth (Ayres and Lombardero, 2000). Carey (2001) suggested that, construction of life tables is an important tool for understanding the population dynamics of an insect. Age-specific life tables serve as a framework for organising data on mortality and natality. Additionally, it provides a detailed transparent description of the actual properties of the cohorts. It generates simple summary statistics including life expectancy and natality rate. It also has a basic form that can be expanded, condensed or modified for analyzing different types of data such as mortality by various factors.

Many pest species are favored by warm and humid conditions. Insects respond to higher temperature with increased rates of development and with less time between generations (Rosenzweig *et al*., 2001). In Canada, where temperatures affecting physiological processes tend to be below optimum for most insect species for most of the year, temperature increase will likely accelerate these processes thus causing faster development, more activity and movement, reduced mortality from climatic factors and possibly even more generations in a season (Hansen *et al.*, 2001; Yamamura and Kiritani, 1998). Many researches revealed that, behaviorally avoiding high temperatures costs a lot of time and resources of aphids and thus potentially reduces other living activities such as development and reproduction. At high temperatures, most aphids were found to stay in soil gaps to avoid heat stress (Ma, 2000; Ma and Ma, 2007a; 2007b; Wiktelius, 1987), suggesting that the aphids have to endure starvation during their heat avoidance. If the mortality per generation does not change, the insect population will become potentially larger under global warming (Yamamura and Yokozawa, 2002). The influence of temperature is important because elevated CO_2 causes increased leaf temperatures and a small increase in temperature can affect fecundity of insects, as suggested by Heagle *et al.* (2002).

Developmental rate is the speed of temporal progression through an instar or stage and is dependent on temperature in a predictable fashion. Assuming that it is the same function throughout a stage, the developmental rate at a constant temperature is the inverse of the time required to complete that life stage (Logan *et al.*, 2003). The increase of starvation time caused by avoiding stressful conditions significantly reduced the reproduction and population growth of the pea aphid *Acyrthosiphon pisum* (Nelson *et al.*, 2004). Temperature affected both *per capita* total egg production and egg viability. There was a significant reduction in egg production and egg viability per adult at extreme temperatures (Son and Lewis, 2005). Temperatures above the specific optimum range also lead to reduced fecundity and increased rates of mortality for a multitude of species (Rouault, 2006).

Average number of nymphs produced per female at 35^{o}C was zero, and the highest number was 29.8 at 25^{o}C. The fecundity dropped substantially to 0.8 at 10^{o}C (Kuo *et al.*, 2006). The intrinsic rate of natural increase ($r_{m)}$,net reproductive rate (R_o) and Generation Time all varied with temperatures from 10 to 30^{o}C; aphids reared at higher temperature had higher r_m and shorter Generation Time. The values of r_m indicated that aphid population declined at 10^{o}C, whereas the populations grew when reared at other temperatures (Kuo *et al.*, 2006). The fecundity of *Lissorhoptrus oryzophilus* was greatest at 32^{o}C within a temperature range of 15–32^{o}C (Kiritani, 2006). The life history of *Bemisia argentifolii* Bellows&Perring (Homoptera: Aleyrodidae) on tomato (*Lycopersicum* spp.) was studied based on the age-stage, two-sex life table at 15, 20, 25, 28, 30, and 35^{o}C. The r_m at these temperatures is 0.0176, 0.0667, 0.1469, 0.1611, 0.1745, and 0.0989 per day, respectively. The relationship among the gross reproductive rate (GRR), R_o and the pre adult survivorship (l_x) is consistent with GRR > l_x. GRR > R_o for all results at different temperatures. The mean generation time is 81.9, 48.6, 28.4, 25.3, 22.1, and 18.2 days, respectively (Yang and Chi, 2006).

Enhanced reproductive capacity and changes in distribution (if host plants will be available) are to be expected under milder winters and decreasing frequencies of temperature extremes for a variety of pest species. For instance, increased survival of hibernating eggs in fringe areas of occurrence is prognoses for the winter moth, *Operophthera brumata* and the autumnal moth, *Epirrita autumnata* and the gypsy moth, *Lymantria dispar* in North America (Moore *et al.*, 2008). *Aphis gossypii* have had a considerable higher mortality during development at cooler temperatures of 15.0 and 17.5°C and again at warm temperatures of

32.5°C. Total nymphal mortality rates of *Myzus persicae* were highest at 30.0°C, but low at cool temperatures. For the green peach aphid, the constant temperature of 32.5°C was lethal to early nymphal stages (Satar *et al.,* 2008). Survival rates of adults of *A. gossypii* and *M. persicae* sharply decreased right after the peak of nymph production at higher temperatures, while a relatively long post-reproductive period was observed between 15.0°C and 27.5°C. The R_o of the cotton aphid was highest at 22.5°C and lowest at 32.5°C. Reproduction rates of the green peach aphid were in general higher at temperatures between 20.0 and 27.5°C and decreased with an increase in temperature. *A. gossypii* populations kept at warmer temperatures showed higher per capita growth rates, being highest at 30.0°C. The lowest r_m occurred at 15.0°C for the cotton aphid and at 30.0°C for the green peach aphid. For temperature above 15.0°C, the r_m of *A. gossypii* on pepper were statistically significant higher than those of *M. persicae*. In contrast, the green peach aphid had significantly higher r_m at 15.0°C than the cotton aphid (Satar *et al.,* 2008).

Analysis of the life table data of rice leaffolder based on natural field population revealed various mortality factors responsible for the fatality of leaffolder at different stages. K - values indicated that the total generation mortality was 72.33 per cent in Dry and 54.15 per cent at wet seasons. Series of stage specific mortalities showed maximum mortality in the pupal stage followed by late larval stage. Survival rates from greenhouse studies indicated higher mortality early in the life cycle i.e., egg and larval stage. The r_m was 0.183 females per female per day and finite rate of increase (λ) was 1.2008 females per female per day. Female moth of leaffolder started laying eggs after 27th day of pivotal age which lasted up to 33rd day with l_x (Number of living females) values being 0.56 - 0.04, respectively. The R_o was 210.77 indicating that the population of *C. medinalis* would be able to multiply 210.77 times per generation. The mean length of generation (T_c) was 29.24 days. The population multiplied 3.6 times per week and doubled in 4.75 days (Padmavathi *et al.,* 2008). Experiments conducted by Iranipour *et al.* (2010) on sunn pest at different constant temperatures revealed that the r_m increased linearly with temperature. Generation time ranged from 121 days at 22°C to 40 days at 30°C. Lifetime female fecundity ranged from 123.1 at 22°C to 209.4 at 30°C. All life history parameters of sunn pest increased in magnitude with increasing temperature, except for generation time and doubling time which demonstrated the opposite trend.

Experiments conducted by Ramya *et al.* (2012), revealed that in the case of YSB, 50 per cent mortality occurred between 3 – 5 days. Since the duration getting started at higher temperatures, significant shift at the mortality pattern was shown. Generally, YSB lived shorter period of time when the temperature goes higher. The linear pattern of survivorship is more pronounced in BPH than YSB. As in the case of YSB, BPH also survived shorter duration when the temperature goes higher. Consequently there was a shift in 50 per cent mortality in between 10 – 13 days. At higher temperature, BPH died faster than at lowest temperature. In the case of YSB, the developmental rate at 30°C was 0.2513, whereas it was 0.03032 at 38°C. In the case of BPH, the development rate at 30°C was 0.0446, whereas it was 0.05519 at 38°C (Ramya *et al.*, 2012). Value of r_m for YSB at 30°C was 0.0846 and this parameter was found to be increased at in increasing temperatures. At a constant temperature of 30°C, the population of YSB doubles in 8.19 days, whereas it doubles in 6.71 days at 38°C. The R_o was 42.79 individuals and the generation time (T) was 44.05 days at 30°C. However, at 36°C R_o was 51.0 individuals and T was 37.56 days. Ramya *et al.* (2012) also reported that the value of r_m of BPH was found to be increased at increasing temperatures. At a constant temperature of 30°C, the population of BPH doubles in 4.93 days where as it doubles in 4.50 days at 38°C. The R_o was 64.43 individuals and the T was 29.56 days at 30°C. However, the same was 77.71 individuals and 28.27 days at 38°C.

Ju *et al.* (2011) showed that, fecundity was the highest for *Corythucha ciliata* at 30°C over an oviposition period of 8.9 days. Female lifetime fecundity was reduced at other temperatures, being the lowest at 19°C. The population trend index (I) of *C. ciliata* was the highest at 30°C and the lowest at 19°C. The survivorship and mortality curve showed an irregular pattern with sharp high peaks and negative low peaks. The expectancy of life exhibited a continuous decline with advancement of age. As far as stage specific life table concerned, the developmental stages of *Coccinella septempunctata* showed highest survivor fraction and lowest apparent mortality, mortality survival ratio, indispensable mortality and K - values at low temperature as compared to high. On the other hand, minimum total generation mortality (K) was recorded (0.1079) at 24±1°C followed by (0.2076) 20±1°C and (0.2676) 28±1°C. The study revealed that among three different constant temperatures, 24±1 °C has been proved as a most suitable for the life cycle of *C. septempunctata* (Ali and Rizvi, 2010). Life tables and population parameters of the BPH were constructed in an environment with unlimited food supply and that was free of natural enemies. The highest mortality occurred in the immature stage, especially in the first and second instars. The life table analysis showed that the population density of BPH decreased gradually. The survival ratio of male to female was 0.512 : 0.488. The trend of oviposition showed a peak at around the tenth day of the female life. The highest number of eggs produced per female per day was 9.63. The r_m in egg production per female per day was 0.0677 and the daily λ was 1.0688 females per female per day, with a T of 34.05 days. The R_o of the population was 10.02. The population doubling time was 10.42 days (Win *et al.,* 2011).

The lowest and highest temperatures evaluated had a deleterious effect on the survival of *P. xylostella*. Larval survival at 10°C, 30°C and 32.5°C was significantly lower than at 15°C and 25°C. Similarly, when *P. xylostella* was maintained at 10, 30 and 32.5°C, the percentage of survival from egg to adult was lower than at 15°C, 20°C and 25°C. The survival curves obtained by Kaplan-Meier´s estimation showed significant differences according to the temperature, and an increase in temperature resulted in a decrease in survival time (Marchioro and Foerster, 2011). The highest total mean fecundity rate of mite was recorded at 30^oC. Sex ratio was affected by temperature as proportion of female increased. In addition, the values of r_m and λ increased with temperature increase, while T and doubling time values decreased with temperature increase, thus the reproduction of mites increased (Wahed and Halawany, 2012). Climatic factors which result in insect mortality are difficult to identify, and often are categorized as unknown factors or as physiological death. These usually rank high among the total mortality factors in life table analysis, now a fashionable technique in population ecology. The unrealized part of potential reproduction of a given population is considered a mortality factor in life table studies.

2.6. Weather pest relationships

The outbreaks of *C. suppressalis* are taking place in association with cool and wet summers or in July, because of the high survival rate of the first generation larvae (Mishima and Kuwabara, 1944; Tsutsui, 1954; Kiritani and Iwao, 1967; Utida, 1958). Miyashta (1963) reviewed records of outbreaks of various insect pests, and found that outbreaks of *Mythimna separat*a in 1949 covering the whole of Japan except Kyushu were related to low temperature and heavy precipitation during the late spring and summer. Chen *et al.* (1968) concluded that weather conditions are important factors affecting population outbreaks of the yellow rice borer in China. Paddy water temperature above 35^oC was believed to be a main factor affecting the sudden decrease of the population of *C. suppressalis* during July and August in Taiwan (Chang, 1968). In analyzing outbreaks of *N. lugens* in Japan, Chiba *et al.* (1969) found that high air temperature was favorable for the increase of this insect. In Taiwan an attempt was made to forecast an outbreak of *N. lugens* by accumulating temperature over winter. If the accumulation exceeded 2100 degree days, then an outbreak was expected (Ho and Liu, 1969). Light trap catches of *N. lugens* in Korea were highest under conditions of low rainfall and high temperature (Kim, 1969). Humidity was also expected to influence the population density of insect pests. Kim (1969) found a positive correlation between the population densities of *Laodelphax striatellus* and relative humidity in May in orea.

Hino *et al.* (1970) noted that an infestation of *N. lugens* appeared to be related to dense plant growth, low solar radiation, high relative humidity (about 90 per cent or more), and with little difference between day and night habitat temperatures. Field studies in Japan indicated that temperature and precipitation had little bearing on the population regulation of *Nephotettix cincticeps* (Sasaba and Kiritani, 1971). Alam (1971) working in the Philippines, reported that cool weather adversely affected some populations and *N. lugens* numbers increased when the mean temperature increased. Rao *et al*. (1971) reported that steady temperatures with the least fluctuations between maximum and minimum, coupled with average high relative humidity, caused outbreaks of the rice hispa in India. Among other factors, mild winter temperatures and heavy rains in June and July may have been related to the 1971 outbreak of *C. medinalis* in Korea (Park *et al.*, 1971). Ngoan (1971) reported that, in South Vietnam, *C. suppressalis* was more serious on the wet season crop, and *S. incertulas* on the dry season crop. In India low rainfall in the kharif season (usually a wet season) is thought to favor outbreaks of stem borers (Rao, 1972; 1974).

Abraham *et al.* (1975), through correlation studies, found that there was a joint influence of rainfall, relative humidity and mean minimum temperature on stem borer infestation (*S. incertulas*). The percentage incidence of dead heart and of white heads was both correlated negatively with rainfall and minimum temperature, and positively with maximum temperature. In India, Kaiode (1974) cited high rainfall and very high or low temperatures as being unfavorable for stem borer population increase. According to Persson (1976), the meteorological parameters have a long term and permanent effect in insect population. The population of rice gundhi bug was found at a peak during September to October (Pathak, 1977).

Some efforts were made by Prasad and Phadke (1984) and Rana *et al.* (1993) and relating the temperature and relative humidity with the incidence and multiplication of aphid in the mustard crop. In Navasari, Pandya *et al.* (1989) studied the population dynamics of YSB in relation to weather conditions by using light traps between 1985 and 1986. Minimum temperatures and vapour pressure had influence on population abundance during summer while maximum temperature has an influence during kharif. Weather plays an important role on the population dynamics and distribution of pests and diseases. Temperature, rainfall, relative humidity, sunshine hours and wind speed are the chief weather parameters influencing the pest and disease incidence. Weather based pest and disease forewarning models have been developed to certain extent (Singh *et al.,* 1990; Jayanthi *et al.,* 1993; Prasad *et al.*, 2008). Experiments conducted by Nandihalli *et al.* (1990) revealed that there is a negative correlation between trap catches of leaffolder and average temperature and a positive correlation with average morning relative humidity.

Joseph *et al.* (1994) based on 19 years study by using light traps, observed that rainfall, temperature and relative humidity did not influence the populations of YSB. Ramakrishnan *et al.* (1994) developed a mathematical model relating to monthly seasonal indices of abiotic factors on light trap catches of YSB in rice which predicts the number of light trap catches expected at a point of time. Bhatnager and Saxena (1999) reported that minimum temperature played an important role in the population build up of green leafhopper and rice gundhi bug, besides rainfall and evening relative humidity. Fleming (2000) cites the work of a number of researchers as examples of pest weather relationships. In these examples, colder weather was associated with shorter outbreaks of the forest tent caterpillar in central Ontario and less frequent outbreaks of the European pine sawfly in Finland’s boreal forest. Warm, dry summers were associated with outbreaks of a number of other insect species in Canada's forests, mountain pine beetle, western spruce budworm and the spruce budworm.

According to Pandey *et al.* (2001), relative humidity played an important role in population build up of YSB. The YSB activity showed a significant negative correlation with minimum temperature and afternoon relative humidity during *kharif*, but exhibited a positive correlation with maximum and minimum temperature. However, during *rabi* their incidence was negatively correlated with morning and afternoon relative humidity (Kumar and Sudhakar, 2001). The common approach for analyzing the relationship between population size and climatic variables is by means of simple correlation or using the climate as an additive co variable in statistical models (Stenseth *et al.,* 2002). Based on the observation of Rehman *et al.* (2002), there were two peaks of moth population during the year, first in May on rice nurseries and second in September on rice crop. Analysis of weather data 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 - June). High temperature, high relative humidity and low rainfall; and during its survival on rice crop (July to October), low temperature, high relative humidity and rainfall resulted in YSB outbreaks. Occurrence of rainfall at the appropriate time was essential for YSB multiplication.

A study in Sweden showed that the catches in autumn of adult *Psammotettix alienus* in fields of winter wheat increased with higher temperatures. During weeks with an average maximum temperature below 10°C only few leafhoppers were caught in yellow water traps, but during weeks above 10°C, the numbers increased with temperature, with high insect numbers noted above 15°C (Lindblad and Areno, 2002). Sharma *et al.* (2004) reported that no other factor except rainfall had positive correlation in the population build up of rice gundhi bug. Upadhyay and Sharma (2004) used principal component analysis to find out the factors which play important roles in the population build up of YSB and rice gundhi bug. They reported that rainfall and relative humidity played a significant role in the population build up of YSB and in case of the population of rice gundhi bug, no meteorological variables were found to be significant. According to Mishra *et al.* (2005), stem borer damage had a positive significant correlation with maximum, minimum temperature and a negative correlation with relative humidity.

A significant relationship between detrended Colorado potato beetle occurrence and mean air temperature in May for the period 1980 – 2007 was established by using a simple linear model (Smatas *et al.,* 2008). Correlation between weather factors and leaffolder population indicated that the maximum temperature, minimum temperature, rainfall and sunshine hours have significant negative relationship while morning relative humidity and evening relative humidity exhibited positive relationship (Padmavathi *et al.*, 2008).

The results show that the population of leafhopper was found highest at temperature of 36.5^{o}C and relative humidity at 68 per cent. The lowest population was observed at the temperature of 31.5^{o}C and relative humidity at 75 per cent. The population of jassid was found highest at the temperature of 36^{o}C with relative humidity at 68 per cent and lowest population was found at 35^{o}C relative humidity at 70 per cent. The infestation of *Chilo partellus* was found highest at the temperature of 32.5^{o}C relative humidity at 68 per cent and lowest infestation of *C.*

partellus found at the temperature of 32.5°C relative humidity at 50 per cent. (Zulfiqar *et al.,* 2010). The population of whitefly, sesame leaf hopper, green sting bug and cotton aphid were found negatively correlated with minimum temperature, relative humidity and rainfall and positively correlated with maximum temperature (Kumar *et al.,* 2010).

The rice stem borer infestation was monitored during two year study period along with weather parameters. Results showed high pest incidence during months of March *(*Navarai – Rabi, 2005), August- September (Kuruvai – Kharif, 2006) and October- November (Samba – Rabi, 2006). The favourable weather conditions for high stem borer incidence were 27.6ºC, 30.1ºC, 26.1ºC as mean temperatures and relative humidity per cent ranged between 95.9 and 65.7, 82.2 and 54.5, 95.3 and 82.8 pertaining to the Navarai, Kuruvai and Samba seasons, respectively (Adroubane and Raja, 2010).

Abiotic conditions such as minimum temperature, temperature gradient, maximum relative humidity and average relative humidity had significant positive influence on *C. medinalis* population. In case of minimum relative humidity and sunshine hours a negative influence was observed. In addition, other factors such as maximum temperature, relative humidity gradient, average relative humidity, number of rainy days and rainfall imparted insignificant positive effect on population development (Chakraborty and Deb, 2011). The rice stem borer is often referred as a classical example of a monophagous species which is primarily distributed in the tropics but also occurs in temperate areas where the temperature remains constantly above 10 °C and the annual precipitation is more than 1000 mm (Jadhao and Khurad, 2012). Zafar *et al*. (2013) reported that maximum temperature during 2009 showed significant and positive correlation with the egg counts of *H. armigera,* whereas on cumulative basis relative humidity and rainfall had negative and significant correlation with the eggs count.

2.7. Prediction by degree day models

The concept of relating phenological growth to temperature was first proposed by Reaumur (1735). Degree-days can be defined as the units combining between time and temperature, used to measure the development of an organism from one point to another in its life cycle (Wilson and Barnett, 1983). This is commonly referred as growing degree days (GDD); accumulation of daily mean temperatures above a threshold temperature has become an established tool in building of plant, insect, and disease models (Higley *et al.,* 1986). The base temperature (T base) for the Degree Day Model was set at 10°C, as originally proposed by Apple

(1952) and recommended by numerous other researchers (Mason *et al.,* 1996; Porter *et al.,* 1991; Got and Rodolphe, 1989; Jarvis and Brindley, 1965), even though some studies suggest higher temperature thresholds for at least some stages (Birova, 1962). From the practical aspect, accumulated thermal units have been used to predict the seasonal development and emergence of various insects (Eckenrode *et al*., 1975; Sevacherian *et al.,* 1977; Farag *et al.,* 2009). The relationship between temperature and development in insects tends to be nonlinear over the full range of tolerable temperature (Logan *et al.,* 1976; Lactin *et al.,* 1995). According to Honek (1996), the lower thermal limits reduce as latitude increases. Thermal summations have been used to predict biological events critical to the management of a number of pests (Sevacherian *et al.,* 1977; Niazee, 1976; Reissig *et al.,* 1979).

Optimum temperatures during the diapause phase range from 5 to 10^{o}C, while optimal temperatures are 20 – 30^{o}C during the developing phase of insects (Ando, 1978). BPH adults emerged from the nymphs on plants in the sleeves 22 – 33 days after infestation at ambient temperatures that ranged from a mean daily high of about 31^{o}C to a mean daily low of about 25^{o}C (Waldbauer and Marciano, 1979). A thermal summation model based on heat units above 9°C accurately predicted peak hatch of eggs, an event critical to management of the alfalfa weevil, *Hypera postica* (Gyll.) in southern Ontario. The model also gave accurate predictions for maximum numbers of the larval and pupal stages, as well as other significant events such as cocooning and adult emergence (Harcourt, 1981).

Kiritani (1988) suggested that the use of the lower developmental threshold (T_0) and the thermal constant (K) that have been reported for insects would be useful in predicting the phenology of insect communities under global warming. Egg to adult development of green clover worm requires 486 degree-days (11°C developmental threshold) (Herbert *et al.,* 1988). Several common soy bean insect pests have 15°C developmental thresholds, including soybean looper, velvet bean caterpillar, corn earworm, and southern green stink bug. Approximately 425 degree-days are required for development of' one complete generation for most of these insects (Herbert *et al.,* 1988).

Although the relationship between temperature and development of *P. xylostella* has been studied in other countries (Sarnthoy *et al.,* 1989; Shirai, 2000; Liu *et al.,* 2002; Mohandass and Zalucki, 2004; Golizadeh *et al.,* 2007), the thermal requirements may vary among different populations (Lee and Elliot, 1998; Gomi *et al.,* 2003) mainly due to geographic differences in climate according to a gradient of latitude (Honek, 1996; Bediako *et al.,* 2000; Chen and Kang, 2004). Honek (1996) showed that in subtropical and temperate zones the lower development threshold decreases with increasing geographical latitude. Exceeding critical thresholds has implications, for instance, for mortality or fecundity, and increased cumulative temperature (in degree-days) potentially increases the number of generations (Porter *et al.,* 1991).

S. incertulas, distributed primarily in the tropics, also occurs in the temperate areas, where temperature remains above 10ºC. The threshold temperature for development of YSB eggs normally occurs at 16°C or higher although it shows some development at 13°C. The threshold temperature for YSB larvae is a minimum of 16°C. When reared at 12°C, the second and third instar larvae cannot molt and so die. The threshold temperatures for pupal development of YSB are 15-16°C (Pathak and khan, 1994). The European Corn Borer (ECB) initiation, 25, 50, and 75 per cent development and termination dates of each stage were estimated using a degree day model approach (DDM) that has been found to be as effective as more sophisticated methods (Got *et al.,* 1996).

Krishnaiah *et al.* (1997) developed the day degree method useful to predict out breaks of yellow stem borer by following total enumeration method (TEM) and maximum minimum method (MMM) with the help of green house data and information from literature. Patterson *et al.* (1999) provided an extensive list of climatic thresholds and responses for the phonological development of pest insects. Intensive studies aimed at quantifying the relationship between thermal time (growing degree days) and mustard aphid incidence, its multiplication were made by Kar and Chakravarty (2000) and Chakravarty *et al.* (2002). Based on the field experiments and using published data, Chakravarty and Gautam (2004) proposed a thumb rule relating aphid population and degree-days accumulation.

Insect life stage predictions are most often calculated using accumulated degree days from a base temperature and biofix point. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.,* 2002). Predicting the development time of an insect pest in relation to temperature can be an important tool for pest management (Roy *et al.,* 2002). Growing degree-days (GDD) were accumulated for different periods of the aphid development. Model equations were developed to predict the aphid population on real time basis three days in advance using accumulated GDD and the initial aphid population for individual cultivars was statistically significant (Neog *et al.,* 2004). In practice, the number of degree-days required for a particular phonological event can vary from one year to the next (Herms, 2004).

Degree days were accumulated during both the crop seasons and results revealed that the stem borer incidence was low, when DD accumulation was high and vice versa (Dhaliwal *et al.*, 2006). Egg incubation period can be predicted based on day degrees required for egg hatching, which decreases with an increase in temperature from 10 to 27ºC, and egg age from 0 to 3 days (Dhillon and Sharma, 2007). The relationship between the accumulated thermal heat units expressed as degree-days (DDs) and the population fluctuations of Peach Fruit Fly male indicated that there was discrepancy with an average of 3.6 days for expected and observed peaks. The accuracy of prediction that depends on DDs and population of *Bactrocera zonata* enable growers and pest control advisors to reduce monitoring periods to make a true decision for pest control in the proper time, which minimize costs and the hazard of chemical control (Farag *et al.*, 2009).

Experiments conducted by Iranipour *et al.* (2010) on sunn pest, revealed that the thermal threshold for post-diapause pre-reproductive development was 20° C, and 66.8 degree-days were required for its completion. Under current climate conditions, the mean values of thermal units required for complete peach fruit fly generation were 491, 495 and 493 units in North Sinai, El Beheira and Asyout, respectively (Khalil *et al.*, 2010). The linear model demonstrated that *P. xylostella* required 312.5 degree-days above a lower threshold of 6.3°C to complete development. The degree day model showed that the number of diamondback moth generations in the tropical region of Brazil was nearly twice the number in the subtropical region of the country (Marchioro and Foerster, 2011).

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The occurrence of insect pests in rice fields is influenced by various factors including meteorological conditions, cultivation methods and rice variety. Among the meteorological conditions, temperature is the most important factor. It affects rice pests directly by limiting or expanding their distribution, growth, reproduction and dispersal as well as indirectly through plant mechanisms and natural enemies (Bale *et al.*, 2002). Temperatures in most regions of the world are increasing, and there are already indications that insects and plants are responding (IPCC, 2007). Warming can potentially affect several aspects of insect life-cycle and ecology, especially those directly controlled by energy availability variables such as degree day (Menendez, 2007).

To understand the effect of increase in temperature on rice insect pests, experiments were conducted at Agro Climate Research Centre (ACRC), Tamil Nadu Agricultural University (TNAU), Coimbatore during 2011-13. Insect pests of rice were kept under different temperature regimes in Climate Control Chamber. Observations were made on different biological and phenological characters of the insects and life tables were constructed to understand the behavior of insects at different temperature regimes. Historical pest surveillance data and corresponding weather data were also collected to develop forewarning model for the major pests. The different materials and methods used to carry out the above said experiment are furnished in this chapter.

3.1. Climate and weather at Coimbatore

Coimbatore is situated in the western zone of Tamil Nadu state at 11^{o} N latitude and 77^{o} E longitude and at an elevation of 427 m above the mean sea level. It is generally a dry district apart from the Noyyal River basin and occasional over flowing streams from the Western Ghats, which terminate in the city’s large tanks. The terrain is predominantly black soil, which is suitable for cotton cultivation, but it also has some amount of a type of red loamy soil.

Coimbatore experiences Semi Arid Tropic (SAT) climate with an average rainfall of 720.8 mm distributed in 47 rainy days. The average annual evaporation is 2018.1 mm with the highest month being March (203.9 mm) followed by June (199.1 mm). The mean annual maximum and minimum temperatures are $31.9^{o}C$ and $21.4^{o}C$, respectively. The morning relative humidity is 84.1 percent and 48.2 percent during afternoon hours. The mean bright sunshine hour is 6.9 hours day^{-1} and solar radiation is 311.4 $cal.cm^{-2}$ day^{-1}. Aduthurai, a part of Cauvery basin receives an average rainfall of 1139 mm. The temperature varies from 40.6 to 19.3°C with sharp fall in night temperatures during monsoon period.

3.2. Climate control chamber

Experiments were carried out in Climate control chamber (CCC), where temperature and relative humidity were controlled using fogger and a mist fan. The CCC has a total area of 25 m^2 (5mx5m) with a column height of 4m and fabricated using galvanized steel pipes (Plate 1). The roofing and outer walls are constructed with polycarbonate material. Weather sensors for recording air temperature and relative humidity at any required interval are placed inside the chamber. Required levels of temperature can be maintained by giving commands through the control panel. Temperature was recorded at hourly interval by the sensor and the sensor was connected to a data logger. All these data will automatically be stored in the data logger storage module. The data logger is connected to the computer and the data recorded is downloaded to the computer by Emcon GH 485/2 software programme at regular intervals. For this investigation, five different constant temperatures (28.3°C, 30.6°C, 32.7°C, 34.3°C and 36°C) were considered.

3.3. Culture techniques

Insects such as Yellow Stem Borer (YSB) *Scirpophaga incertulas* (Walker), Brown Planthopper (BPH) *Nilaparvata lugens* (Stål) and Rice Leaffolder (RLF) *Cnaphalocrocis medinalis* (Guenee) were mass cultured and used for different experiments. The mass culture techniques used for different insects are furnished hereunder.

3.3.1. Yellow Stem Borer (YSB)

For getting uniform population, *S. incertulas* was mass cultured following the method described by Saxena *et al*. (1990). Primary culture was established by collecting the borer moths with a sweep net in the rice fields during the day. The collected moths were placed in vials and were brought to the laboratory, where they were confined in wooden cages. The adult moths were fed with 10% sucrose solution soaked in cotton wool. Rice seedlings (ADT 43) of 40 - 50 day old plants were kept in the cage for oviposition (Plate 2). After oviposition, the egg mass deposited by the moths were collected by cutting off the leaf section with eggs. The leaf sections were placed on moist filter paper in petri dishes and stored at room temperature until the end of blackhead stage (about 5 days). The larvae hatched were used for the studies.

Plate 1. Overview of the Climate Control Chamber

Plate 2. Oviposition cage used for YSB and RLF

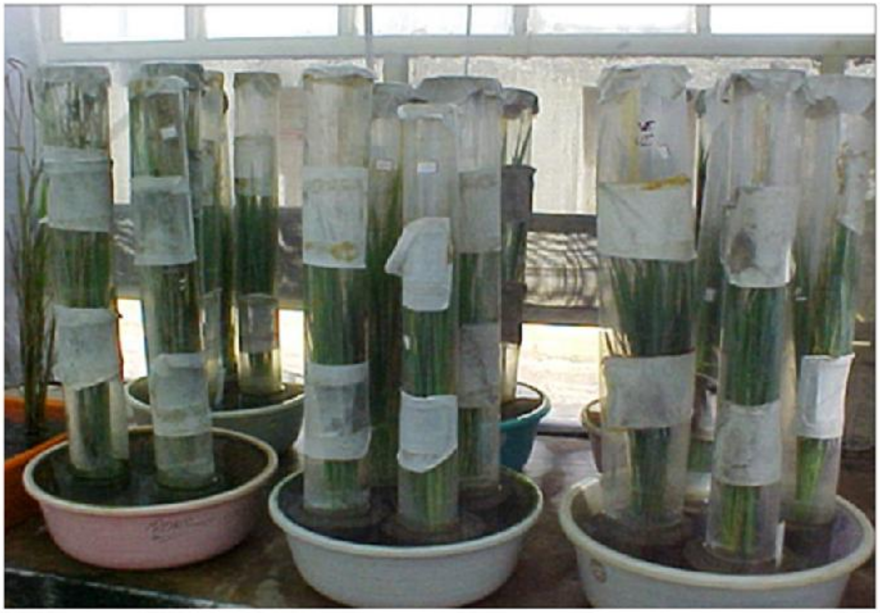


Plate 3. Oviposition cage used for BPH

3.3.2. Brown Planthopper (BPH)

BPH was mass reared separately on the susceptible rice variety ADT 43 as outlined by Heinrichs *et al*. (1985). Initial population was collected from the rice fields at Paddy Breeding Station, TNAU, Coimbatore. Adults were confined on 30 day old potted plants of ADT 43 placed in wooden wire netted and glass topped oviposition cages. The insects were removed three days after oviposition and the potted plants with eggs were collected and placed in separate cages to allow the eggs for nymphal emergence. The emerged nymphs were transferred to 15 day old ADT 43 rice seedlings raised in germination trays and these in turn were placed in galvanized iron (GI) trays (62 x 47 x 15 cm) containing 5 cm depth of water. ADT 43 seedlings in trays were changed periodically and thus continuous pure cultures of planthoppers were maintained.

3.3.3. Rice Leaffolder (RLF)

RLF was mass cultured following Waldbauer and Merciano (1979). Larvae collected from the field were transferred to 30 day old potted ADT 43 rice plants placed in the wooden wire netted insect cages (Plate 2). Pupae were collected and placed in petridishes padded with moistened filter paper. Immediately after adult emergence, these were transferred to oviposition cages with 15 day old potted ADT 43 plants and cotton wool moistened with honey solution was hanged as adult food. Eggs were collected with camel hair brush daily and placed in petridishes padded with moist filter paper. The emerging larvae were released singly using a fine camel hair brush on the axils of 15 day old plants. After three to four days, these were transferred to 30 - 40 day old potted plants of ADT 43 and this process was repeated so as to maintain the leaffolder culture throughout the experimental period.

3.4. Establishment of life and fecundity table

Demographers and population biologists are extremely interested in the dynamics of population growth and structure. A number of methods have been developed to present the vital statistics of populations and one of these is the life table. Life and fecundity table is a concise summary of certain statistics of a population (Deevey, 1947), originally set forth as a tool for the study of human and animal population. To understand the effect of temperature on the development of insects, life tables were constructed at different temperature regimes.

Life tables also are used to study population growth. The average number of offspring left by a female at each age together with the proportion of individuals surviving to each age can be used to evaluate the rate at which the size of the population changes over time. These rates are used by demographers and population ecologists to estimate population growth and to evaluate the effects of conservation efforts on endangered species. Birch (1948) and Andrewartha and Birch (1954) adopted and advocated life table technique for use in insect population investigations. Carey (1993) emphasised the importance of life and fecundity tables as an organizational framework model for economic entomologists.

3.4.1. Vital statistics

Life tables are used to calculate vital statistics of insects (Carey, 1993; Harari *et al.*, 1997; Medeiros *et al.*, 2000). These tables can describe duration and survival at each life stage. Daily fecundity data generated by these tables allow prediction of the population size and age structure of a natural enemy at any time (Southwood, 1995).

3.4.1.1. Fecundity (m_x)

Fecundity derived from the word fecund, generally refers to the ability to reproduce. In demography, fecundity is the potential reproductive capacity of an individual or population. In biology, the definition is more equivalent to fertility, or the actual reproductive rate of an organism or population, measured by the number of eggs (Fox, 1993). The eggs produced per surviving individual at each age (m_x) or individual fecundity, were measured as F_x (Total number of eggs) divided by a_x (Total number of female). The number of eggs produced per original individual at each age ($l_x m_x$) is an important value to consider in population studies.

3.4.1.2. Development time

Insects required certain time to develop from one stage to next stage or to complete its life cycle. It was called as development time (Jackson and Sweeney, 1995).

3.4.1.2.1. Egg development

Freshly laid eggs were incubated at different temperature regimes and regular observations were made on hatching. Development time was calculated from the date of oviposition and egg hatching.

3.4.1.2.2. Larval / Nymphal development

The freshly hatched larvae / nymphs were introduced into insect cages with rice plants at different temperatures and monitored regularly for their development. From the observations, time taken by each stage was calculated.

3.4.1.2.3. Pupal development

Pupae developed from the larvae were monitored regularly for the emergence of adults. Development time was calculated from the date of pupal formation until date of adult emergence from the pupae.

3.4.1.2.4. Longevity

Longevity is the duration of time taken by adults to complete the stage. For the study of longevity of adults, freshly emerged adult pairs were kept together in an insect cage with rice seedlings for mating. The pre oviposition period was calculated by observing the first laying of eggs by female moths. By observing the period between the emergence and death of the adults the longevity period was calculated for male and female separately.

3.5. Description of life table statistics

Life table describes the mortality and survival patterns of a population. On the basis of mortality ratios for each age or age group, these tables provide information on parameters such as the number of survivors, the number of deaths and the life expectancy (Dublin and Lotka, 1937). A life table is a generally a table with five columns. Column one of this table gives the age of life from birth to death. The second column shows the survivorship to each age of life, starting out at birth (age 0), and diminishing from age to age in accordance with the mortality. The figures in this column are generally denoted by the symbol l_x. The third column indicates the corresponding survival fraction (S_x) at each interval of life, being simply the fraction between l_x of the subsequent stage and l_x of the current stage. The fourth column gives the death rate in each day of life or to be more exact, the probability at a given age of dying in an interval, this being denoted by the symbol q_x.

The figures in the fifth and sixth column are the total number of females produced for total population and number of females produced per female, respectively. The seventh and eighth columns are auxiliary columns employed in computing the ninth column, which gives the expectation of life at each age. The ninth column gives the average number of insects living in each age of life. The figures in this column may also be interpreted as the number of days of life lived within a given age of life. Column eighth is obtained by cumulating the figures in column seventh beginning at the end. Lastly, column ninth, gives the expectation of life or the average after lifetime at each age class of life. It is obtained as the quotient of the figures in column eighth and the corresponding figures in column two, for this gives a total number of age class lived by survivors of a cohort after a given age, divided by the number of insects entering that age (Dublin and Lotka, 1937). The 10th and 11th columns are auxiliary columns used in the calculation of the 12th column denoted as intrinsic rate of natural increase (r_m).

3.5.1. Construction of age and stage specific life table

Temperature-dependent complete life tables for insect species are built by partitioning its life-cycle into distinct development stages (e.g., eggs, larvae, pupae and adults; eggs, nymphs and adults), and by evaluating the development time and survival or mortality for each individual stage. For females, the age-dependent and total oviposition (fecundity/reproduction) is determined.

Constructing a life table is often a simple method for keeping track of births, deaths and reproductive output in a population of interest. Basically, there are three methods of constructing such a table; (i) the cohort life table follows a group of same-aged individuals from birth (or fertilized eggs) throughout their lives, (ii) a static life table is made from data collected from all ages at one particular time and it assumes the age distribution is stable from generation to generation, and (iii) a life table can be made from mortality data collected from a specified time period and also assumes a stable age distribution.

3.5.1.1. Survivorship (l_x)

The proportion of live births that survive to the beginning of any age interval is defined as age specific survivorship (l_x). Proportion surviving to each life stage (l_x) can be found by dividing the number of individuals living at the beginning of each age (a_x) by the initial number of eggs (a_0). The first survivorship value entered in any life table (l_0) is always 1.0; one hundred per cent of the individuals are observed at the first stage (Priyanga and Romina, 2012). Subsequent values for l_x are calculated by dividing the number of individuals observed at a given stage by the original number of individuals (a_x/a_0). Survivorship was calculated by counting the number of eggs by using magnifying lens at the initial stage and number of larvae/nymph at subsequent intervals. Daily mortality was noted by observing the population regularly. Conversely, the proportion of the original cohort dying during each age (d_x) is found by subtracting counts l_x+1 from l_x.

3.5.1.2. Survivorship curves

Life tables follow the fate of a group of individuals born within the same population in the same age class. Of this group, or cohort, only a certain number of individuals will reach each age, and there is an age above which no individuals ever survive. Survivorship curves are simply an XY graph of survivorship (l_X) against age class. They provide a visual representation of how survivorship in a population changes with age and can be used to make quick assessments of differences between populations. Survivorship curves are usually displayed on a semi-logarithmic rather than an arithmetic scale (Gotelli, 2007). There are three general types of survivorship curves.

3.5.1.2.1. Type I survivorship curve

Species such as humans and other large mammals, which have fewer numbers of offspring but invest much time and energy in caring for their young (*K*-selected species), usually have a Type I survivorship curve. This relatively flat curve reflects low juvenile mortality, with most individuals living to old age (Figure 1).

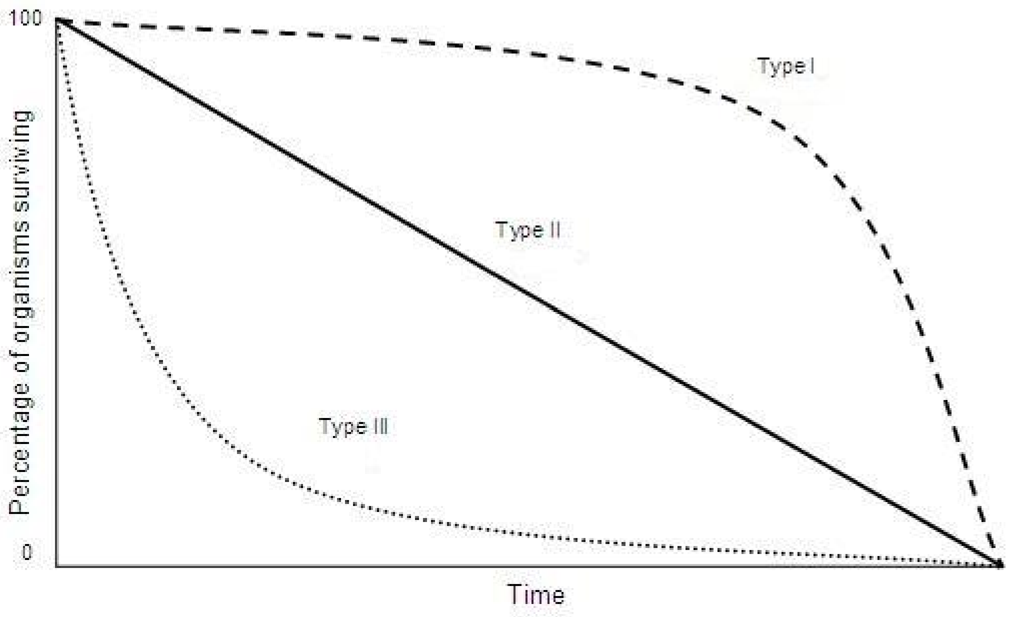
3.5.1.2.2. Type II survivorship curve

A constant probability of dying at any age, shown by the Type II survivorship curve, is evident as a straight line with a constant slope that decreases over time toward zero. Certain lizards, perching birds and rodents exhibit this type of survivorship curve (Figure 1).

3.5.1.2.3. Type III survivorship curve

In some species that produce many offspring but provide little care for them (*r*-selected species), mortality is greatest among the youngest individuals. The Type III survivorship curve indicative of this life history is initially very steep, which is reflective of very high mortality among the young, but flattens out as those individuals who reach maturity survive for a relatively longer time; it is exhibited by animals such as many insects or shellfish (Figure 1). Many populations have survivorship patterns that are more complex than, or fall in between, these three idealized curves. For example, passerine birds (perching birds such as finches) commonly suffer high mortality during the first year of life and a lower, more constant rate of death in subsequent years.

Figure 1. Types of survivorship curves



3.5.1.3. Fixation of survivorship curves

The probabilities of survival in function of age of insect pest follow logistic pattern (Type III curve). Hence fixation by Doesn't Use Derivative (DUD) method (Raltson and Jenrich, 1978), using the following equation.

$$\text{Probability of survival (y)} = \frac{1}{1 + \exp\left(\frac{x - a}{b}\right)}$$

Where, a: Day in which 50 percent mortality recorded.

b: Intercept

x: Age (days)

3.5.1.4. Survival fraction (S_x)

Data obtained on apparent mortality was used for the calculation of the stage specific survival fraction (S_x) of each stage by using the equation

$$s_x = \frac{l_x \text{of subsequent stage}}{l_x \text{of particular stage}}$$

3.5.1.5. Apparent mortality

It gives the information on number insects dying as percentage of number entering that stage and was calculated by using the formula

$$\text{Apparent mortality} = \frac{d_x}{l_x} \times 100$$

3.5.1.6. Mortality survivor ratio (MSR)

It is the increase in population that would have occurred, if the mortality in the stage, in question had not occurred and was calculated as follows:

$$\text{MSR} = \frac{\text{Mortality in particular stage}}{l_x \text{of subsequent stage}}$$

3.5.1.7. Indispensable mortality (IM)

This type of mortality would not be there in case the factor (s) causing it is not allowed to operate. However, the subsequent mortality factors operate. The equation is,

$$\text{IM} = \text{Number of adults emerged } \times \text{MSR of particular stage}$$

3.5.1.8. K-values

It is the key factor, which is primarily responsible for increase or decrease in number from one generation to another and was computed as the difference between the successive values for "log l_x". However, the total generation mortality was calculated by adding the K values of different development stages of the insect, which is designated/ indicated as "K" (Southwood, 1978).

$$K = K_E + K_{L1} + K_{L2} + K_{L3} + K_{L4} + K_P$$

Where, K_E, K_{L1}, K_{L2}, K_{L3}, K_{L4} and K_P are the K - values at egg, first instar, second instar, third instar, fourth instar, and pupal stage.

3.5.1.9. Net reproductive rate

The average number of offspring that a female produces during her lifetime is called as net reproductive rate (R_o). If all females survived to the oldest possible age for that population, the net reproductive rate would simply be the sum of the average number of offspring produced by females at each age. In real populations, however, some females die at every age. The net reproductive rate for a set cohort is obtained by multiplying the proportion of females surviving to each age (l_x) by the average number of offspring produced at each age (m_x) and then adding the products from all the age groups:

$$R_0 = \Sigma\, l_x m_x$$

Where, Ro : Net reproductive rate

$l_x m_x$: Equivalent to the number of offspring (normally females) per original females produced at the age interval '*x*' starting '*i*' to '∞'

A net reproductive rate of 1.0 indicates that a population is neither increasing nor decreasing but replacing its numbers exactly. This rate indicates population stability. Any number below 1.0 indicates a decrease in population, while any number above indicates an increase.

3.5.1.10. Intrinsic rate of natural increase

The intrinsic rate of natural increase r_m is the actual rate of natural increase of a specific population under stable age distribution, multiplying in specific constant environmental condition where space and food are *ad libitum*. It is also known as Malthusian parameter (Birch 1948; Carey 1993). Very simply, this rate can be understood as the number of births minus the number of deaths per generation time. To derive this value using a life table, the natural logarithm of the net reproductive rate is divided by the mean generation time:

$$\text{Intrinsic rate of natural increase } (r_m) = \frac{\text{Net reproductive rate } (R_o)}{\text{Generation time } (T)}$$

Values above zero indicate that the population is increasing; the higher the value, the faster the growth rate. The intrinsic rate of natural increase can be used to compare growth rates of populations of a species that have different generation times. Some human populations have higher intrinsic rates of natural increase partially because individuals in those groups begin reproducing earlier than those in other groups. Mice have higher intrinsic rates of natural increase than elephants because they reproduce at a much earlier age and have a much shorter mean generation time.

If a population has an intrinsic rate of natural increase of zero, then it is said to have stable age distribution and is neither growing nor declining in numbers. A growing population has more individuals in the lower age classes than does a stable population, and a declining population has more individuals in the older age classes than does a stable population. Many human populations are currently undergoing population increase, far exceeding a stable age distribution. Although the global human population has increased almost continuously throughout history, it has skyrocketed since the Industrial Revolution, primarily because of a drop in death rates. No other species has shown such sustained growth.

3.5.1.11. Finite rate of increase (λ)

The finite rate of increase is the antilog of the intrinsic rate (infinitesimal) increase

$$\lambda = e^{r_m}$$

In some circumstances it might be useful to calculate the finite rate of increase, i.e. the number of times the population multiplies in a unit of time. Thus in a population that is increasing exponentially, if there are N_t then in one unit of time later, the ratio will be

$$\lambda = \frac{\text{Effective initial size of the population } (N_{t+1})}{\text{Effective size of population at time } 't' \ (N_t)}$$

3.5.1.12. Mean generation time (T)

The other value needed to calculate the rate at which the population can grow is the mean generation time (*T*). Generation time is the average interval between the birth of an individual and the birth of its offspring. To determine the mean generation time of a population, the age of the individuals (*x*) is multiplied by the proportion of females surviving to that age (l_x) and the average number of offspring left by females at that age (m_x). This calculation is performed for each age group, and the values are added together and divided by the net reproductive rate (R_o) to yield the result.

$$T = \sum \left(\frac{l_x m_x}{R_o}\right)$$

Where, R_o : Net reproductive rate

$l_x m_x$: Equivalent to the number of offspring (normally females) per original females produced at the age interval ‘*x*’ starting ‘*i*’ to ‘∞’

3.5.1.13. Doubling time of population (t)

It is the effective time necessary for doubling of population and is arrived at by the following formula

$$t = \frac{\ln 2}{r_m}$$

3.6. Temperature regimes

The above said experiments were carried out at different constant temperature in Climate Control Chamber, where required level of temperature is controlled by giving commands through the control panel. For this experiments constant temperatures of 28.3°C, 30.6°C, 32.7°C, 34.3°C and 36°C were considered. In each temperature regime, insect cages (Height – 0.8 m, Width – 0.75 m, Length – 0.75 m, Netted in three side) with rice seedlings for insects were maintained throughout the experiment. The temperature data were continuously recorded by the sensor and stored in a Emcon data logger. The same was downloaded to the computer by Emcon GH 485/2 software programme at regular intervals.

3.7. Degree days

Degree days (DD) also called growing degree units (GDUs), are a heuristic tool in phenology. DD are a measure of heat accumulation used by horticulturists, gardeners and farmers to predict plant and pest development rates such as the date at which a flower will bloom or an insect reach maturity (Murray, 2008).

Insects like plants and many other organisms are dependent on temperature to develop. These organisms begin developing when the temperature exceeds the lower developmental threshold or base temperature. The rate of development increases as the temperature exceeds the base temperature and decreases as the temperature drops. Thus, insect development is accelerated during warm years and delayed during cooler years. Upper developmental thresholds, temperatures above which growth slows or ceases, are seldom used for insects since these thresholds are either not known or they live in habitats where the upper threshold is seldom exceeded. DD takes into account the average daily temperature by calculating the number of heat units received. The heat accumulation for any one temperature equals the difference between that temperature and the lower threshold multiplied by the days to develop, commonly referred to as "degree-days'' (Wilson and Barnett, 1983).

$$\text{Degree days} = (\mathrm{T} - \mathrm{T_b}) \times \text{Days to develop}$$

Where, T – Temperature at which pest is reared

T_b – Base temperature

3.7.1. Base temperature

It is the temperature below which the growth and development of insect ceases. The base temperature (*T* base) for the Degree day model was set at 10°C, as originally proposed by Apple

(1952) and recommended by numerous other researchers (Mason *et al.,* 1996; Porter *et al.,* 1991) even though some studies suggest higher temperature thresholds for at least some stages (Birova, 1962).

3.7.1.1. Yellow Stem Borer

The threshold temperature for egg was 13^{o}C and for larval pupal stages it was 16^{o}C (Pathak, 1975)**.** The temperature data during different stages (eggs, larva, pupa and adult) were collected and GDD was calculated by keeping the base temperature at 10^{o}C. The calculated GDD was accumulated for different stages at different temperature.

3.7.1.2. Brown Planthopper

As recommended by Krishnaiah *et al.* (2005), the base temperature for BPH eggs and nymphs and adults were 8.4^{o}C, 8.2^{o}C and 10^{o}C respectively. Accordingly GDD was calculated and accumulated for different stages.

3.7.1.3. Rice Leaffolder

The base temperature of rice leaf folder was assumed to be 10^{o}C. GDD was calculated under different temperature regimes and accumulated into different stages such as, eggs, larva, pupa and adult. The accumulated degree day units at different temperatures were compared and interpreted.

3.8. Collection of historical pest surveillance data

Monitoring population dynamics of insect pests in relation to changes in weather parameters is vital for designing ecologically sound and economical pest management strategies. Abiotic factors like temperature, humidity, sunshine hours, rainfall etc., influence the population dynamics of insect pests. Weather based forewarning models can also be developed by understanding the weather pest relationships. Hence, an effort was made to understand the population dynamics of rice insect pests with respect to weather parameters.

The data on weekly light trap catches of YSB, RLF and BPH of cauvery delta zone (Aduthurai) were collected from the progress report of Directorate of Rice Research, Hyderabad for a period of 17 years from 1990-2007. The weekly cumulative abundance of insect pests, weekly averages of rainfall, maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and sunshine hours are computed from the daily data. These data were used for developing forewarning model for YSB, BPH and RLF.

3.8.1. Development of weather based forewarning model

The data on the number light trap catches of the YSB, BPH and RLF were subjected to different statistical methods like Percentile, Pearson Correlation and Principal Component Analysis in order to make the data ready to develop the model. Generalised Linear Model (GLiM) was developed for YSB, BPH and RLF to predict the population at a given time. The statistical methods used were described hereunder.

3.8.1.1. Percentile

One of the values of a statistical variable that divides the distribution of the variable into 100 groups having equal frequencies. The 95th percentile is the value of a variable such that 95% of the relevant population is below that value. It is also called as centile. Percentile was used in our analysis to remove the outliers in the light trap catches of insect data.

3.8.1.2. Pearson correlation

It was introduced by Karl Pearson to study the relationship between two variables. A correlation is a measure of the strength of the linear relationship between two measurable variables. The Pearson correlation coefficient, represented as r, gives the strength and direction of this relationship. The closer r is to 1 or to -1 then the stronger the linear relationship between the two variables. When high values of X are associated with high values of Y, a positive correlation exists. When high values of X are associated with low values of Y, a negative correlation exists. It is important to remember that Pearson's correlation provides information about the direction and strength of the linear relationship between the two variables. In our study weekly light trap catches were correlated with weather parameters of current, one and two weeks prior to light trap catches.

3.8.1.3. Principal component analysis (PCA)

PCA is a popular multivariate technique, mainly used to reduce the dimensionality of multi-attributes to two or three dimensions that accounts for most of the variance in the observed variables. The principal components may then be used as predictor or criterion variables in subsequent analyses. PCA is a variable reduction procedure. It is useful when there are data on a number of variables (possibly a large number of variables), and that there is some redundancy in those variables. In this case, redundancy means that some of the variables are correlated with one another, possibly because they are measuring the same construct. Because of this redundancy, it is to believe that it should be possible to reduce the observed variables into a smaller number of principal components (artificial variables) that will account for most of the variance in the observed variables. The following are some important terms which are used in PCA.

3.8.1.3.1. Correlation matrix

When correlations among several variables are computed, they are typically summarized in the form of a correlation matrix.

3.8.1.3.2. Eigen equation

Eigen equation was used to determine the regression weight to the variables in the PCA. The weights produced by these eigen equations are optimal weights in the sense that, for a given set of data, no other set of weights could produce a set of components that are more successful in accounting for variance in the observed variables.

3.8.1.3.3. Varimax rotation

A varimax rotation is an orthogonal rotation, meaning that it results in uncorrelated components. Compared to some other types of rotations, a varimax rotation tends to maximize the variance of a column of the factor pattern matrix (as opposed to a row of the matrix). This rotation is probably the most commonly used orthogonal rotation in scientific studies.

3.8.1.3.4. Principal component

Principal component can be defined as a linear combination of optimally-weighted observed variables. The words “linear combination” refers to the fact that scores on a component are created by adding together scores on the observed variables being analyzed. “Optimally weighted” refers to the fact that the observed variables are weighted in such a way that the resulting components account for a maximal amount of variance in the data set.

The number of components extracted in a principal component analysis is equal to the number of observed variables being analyzed. However, in most analyses, only the first few components account for meaningful amounts of variance, so only these first few components are retained, interpreted, and used in subsequent analyses (such as in multiple regression analyses). It is also assumed that the remaining components accounted for only trivial amounts of variance. These latter components would therefore not be retained, interpreted, or further analyzed.

3.8.1.3.5. Component score

Factor score (or component score) is a linear composite of the optimally-weighted observed variables. It is computed by

- determining the optimal regression weights
- multiplying subject responses to the questionnaire items by these weights
- summing the products.

The resulting sum will be a given subject's score on the component of interest, that a separate equation, with different weights, is developed for each retained component.

3.8.1.4. Generalised linear model

Generalized linear models (GLiM) extend linear models by allowing some non-linearity in the model structure and much more flexibility in the specification of the distribution of the response variable y. The model is characterized by the following three components.

Stochastic component

The yi are usually assumed to have independent normal distributions with $E(yi)$ = ui, with constant variance σ^2.

Systematic component

The covariates x*i* combines linearly with the coefficients to form the linear predictor

Link between the random and systematic components

The linear predictor is a function of the mean parameter via a *link* function, *g*(ui). Note that for the normal linear model, *g* is an identity.

GLiMs follow from two extensions of this setup: (1) stochastic components following distributions other than the normal; (2) link functions other than the identity.

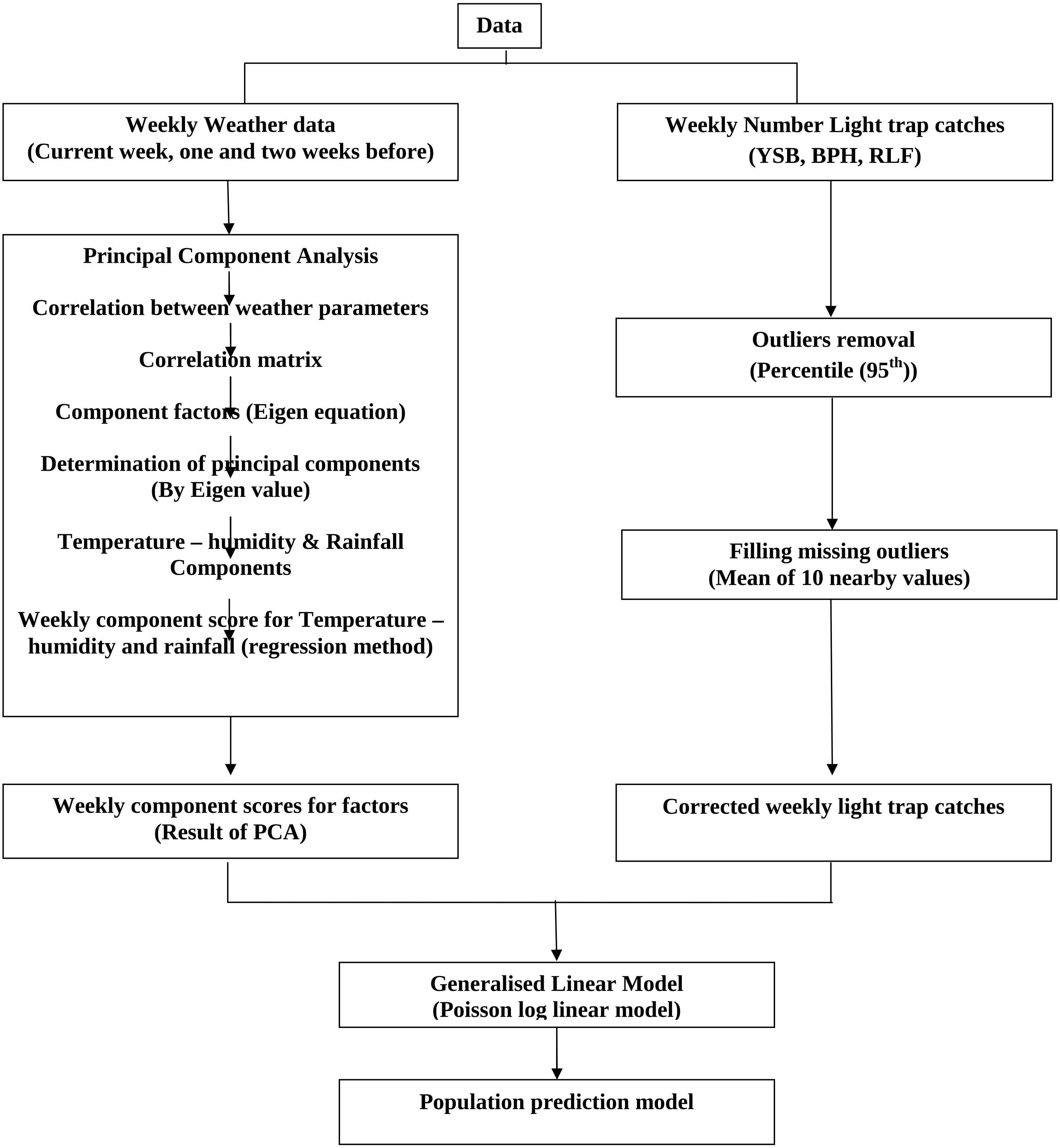
3.8.1.4.1. Poisson log linear model

Biologists often deal with data that are in the form of counts (number of organisms) and we commonly wish to model to a response that is a count variable. Counts usually have poison distribution, where the mean equals the variance and therefore linear models based on normal distributions may not be appropriate. One solution is to simply transform the response variable with a power transformation which tends to remove any relationship between the mean and variance. An alternative is to use a GLiM with a poisson error term and a log link function that is called log linear model. Log linear models are commonly used analyze contingency tables but can also be used effectively when the predictors are continuous and the response variable is count to produce a poisson regression model.

$$\text{Log}\ (y) = \beta_o + \beta x_i$$

By using the above method, poison log linear models had been developed for YSB, BPH and RLF.

Figure 2. Schematic diagram for the development of weather based forewarning model



Results

CHAPTER IV

RESULTS

Experiments were conducted at Agro Climate Research Centre, Tamil Nadu Agricultural University to study the effect of temperature on major pests of rice such as YSB, BPH and RLF and also to find out the degree day accumulation for each stage at different temperature regimes. Pest surveillance and corresponding weather data cauvery delta region were collected from Directorate of Rice Research, Hyderabad to develop weather based forewarning model for major pests. The results of the above studies are described below in detail.

4.1. Effect of elevated temperatures on the bionomics of major pests of rice

4.1.1. Oviposition

The number of eggs laid by YSB increased with increasing temperatures, whereas the percentage of hatching decreased with increasing temperatures. Females laid maximum number of eggs at 36^{o}C (176.5±6.61), which was followed by 34.3^{o}C (168±9.9) (Table 1). The lowest number of eggs were recorded at the temperature regimes of 28.3^{o}C (143±9.9), 30.6^{o}C (138.8±11.3) and 32.7^{o}C (148.5±14.8). Statistical analysis indicated that there was no significant difference in the number of eggs laid by BPH between the temperature regimes of 28.3^{o}C, 30.6^{o}C, 32.7^{o}C and 34.3^{o}C. Lowest number of eggs (116.5±13.2) was recorded at 36^{o}C. Total number of eggs laid by RLF increased with increasing temperature. However, it decreased when the temperature further increased to 36^{o}C. Highest number of eggs (181.3±11.7) was observed at 34.3^{o}C and the lowest number of eggs (146.3±9.46) was observed at 36^{o}C.

Table 1. Oviposition of YSB, BPH and RLF at different temperature regimes

Pests	Number of eggs oviposited									
	28.3^{o}C		**30.6^{o}C**		**32.7^{o}C**		**34.3^{o}C**		**36.0^{o}C**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
YSB	143a	9.9	138.8a	11.3	148.5a	14.8	168b	9.9	176.5b	6.61
BPH	216.3a	19.3	231a	15.9	226.3a	24.1	196.5a	11.3	116.5b	13.2
RLF	168.3a	9.3	156.5a	14.4	173.3b	13.3	181.3b	11.7	146.3c	9.46

Mean followed by a different letter are significantly different at $P < 0.05$ in terms of mean development time (ANOVA followed by Duncan's new multiple range test).

The percentage of hatching of YSB was more at 30.6°C (90.6) and lowest hatching was observed at 36°C (Table 2). There was a marked difference in hatching of BPH eggs as it decreased with increasing temperatures. Percentage of hatching was highest (90.7 %) at 28.3°C, whereas the lowest hatching (51.7 %) was recorded at 36°C. The percentage of hatching of RLF also decreased with increasing temperature and the percentage of hatching was highest (88.9) at 28.3°C, whereas, it was lowest (61) at 36°C.

Table 2. Egg hatching of YSB, RLF and BPH at different temperature regimes

	Egg hatching (%)				
Pests/Temp	**28.3°C**	**30.6°C**	**32.7°C**	**34.3°C**	**36.0°C**
YSB	89.5	90.6	85.9	70.8	58.5
BPH	90.7	87.9	81.0	59.7	51.7
RLF	88.9	85.9	74.0	65.7	61.0

4.1.2. Development time

Statistical analysis indicated that the main dependent variable (number of days) in the insect development data did not follow normal distribution (Kolmogrov Smirnov Z-5.61, $p<0.001$). Mathematical transformations (square root, exponential, logarithm (natural and base 10, arctan and arcsin) of the data also did not prove to change the data to conform to normality. In order to employ statistical methods that assume normal distribution in the data, it was essential that the data follows normal distribution. A near normality was sought, so that there will not be any kind of misinterpretation of the data. The natural log transformation performed on the data was the closest to normal distribution distribution (Kolmogrov Smirnov Z-2.37, $p<0.001$). Hence natural log transformed data was used for analysis. Descriptive statistics provided in the tables are untransformed data for easy interpretation, but other analytical figures provided (F and p values) are based on transformed values.

One way ANOVA was performed in order to find the influence of the temperature on the development time of each stage and the total development time (Egg to Pupa / Nymph). Duncan’s multiple comparison procedure was employed as post hoc test to identify homogenous temperatures and those that made a significant change in development time. Univariate General Linear Model (GLM), a technique to perform Analysis of Variance for experiments with two (temperature and stages) or more factors was performed on the log transformed data in order to determine the effect of temperature on the development time taking into account the different time periods spent on each stage.

4.1.2.1. Yellow Stem Borer

The development time was significantly ($p<0.05$) different between different temperature regimes for all the stages except third instar larva. The time taken by YSB eggs to hatch into larvae indicated that the incubation time decreased considerably with increasing temperatures (F-17.3, $p<0.0001$) (Table 3). At 28.3^{o}C, eggs took 8.5 days to hatch into larvae, whereas it took only 5.75 days at 36^{o}C. The results indicated that the change in temperature did inversely affect the number of days spent in the egg stage. Statistical analysis revealed that the temperature regimes can be grouped in to three homogenous sets based on its effect on the development time. There was no significant difference in the incubation period between 28.3^{o}C and 30.6^{o}C. But the difference in development time was felt significantly, when the temperature rises from 30.6^{o}C to 32.7^{o}C. Again, there was no significant difference in development time of egg between at 32.7^{o}C and 34.3^{o}C. However, the incubation period recorded at 36^{o}C was significantly different, when compared with the other temperature regimes.

The first instar larvae took 7.25 days at 28.3^{o}C to complete the stage, while it took 5.25 days under 36^{o}C and the difference was statistically significant (F-8.05, p-0.001). Duncan’s test indicated that the development time taken by the first instar larva at the temperature regimes of 28.3^{o}C, 30.6^{o}C, 32.7^{o}C (group a) were not significantly different. Likewise the development time observed for first instar larva at 34.3^{o}C and 36^{o}C (group b) were not significantly different.

The development time taken by second instar larvae was 6.5 and 4.5 days at 28.3^{o}C and 36^{o}C, respectively. Statistical tests indicated that the development time taken by second instar larva was significantly different between 28.3^{o}C and other temperature regimes. At the same time, the difference in development time taken at 30.6^{o}C, 32.7^{o}C and 34.3^{o}C was not statistically significant. However, there was a significant difference in the development time observed between 36^{o}C and all other temperature regimes.

Third instar larvae took 7.75 and 6.25 days to complete the stage at 28.3^{o}C and 36^{o}C, respectively. One way ANOVA test however indicated that there was no significant difference between the temperature regimes (F-2.29 p-0.107).

Table 3. Development time of Yellow Stem Borer at different temperature regimes

	Development time (days)													
Temperature regimes	Egg		I Instar		II Instar		III Instar		IV Instar		Pupa		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
28.3°C	8.50a	.577	7.25a	.500	6.50a	.577	7.75a	.957	7.25a	.500	7.50a	.577	44.8 a	1.3
30.6°C	7.75a	.500	6.75a	.957	5.50b	.577	7.50a	.577	7.00a	.816	7.25a	.957	41.8 b	1.0
32.7°C	6.75b	.500	6.50a	.577	5.50b	.577	7.00a	.816	6.50a	.577	6.75a	.957	39.0 c	1.4
34.3°C	6.25b	.500	5.00b	.816	5.00c	.816	6.75a	.500	6.25a	.500	6.25a	.500	35.5 d	1.3
36.0°C	5.75c	.500	5.25b	.500	4.50c	.577	6.25a	.957	5.50b	.577	5.00b	.816	32.2 e	1.0
	F –17.3 P<0.0001		F-8.05 p-0.001		F-5.12 p-0.008		F-2.29 p-0.107		F-5.44 p-0.007		F-6.91 p-0.002		F- 69.8 P< 0.001	

Mean followed by a different letter are significantly different at $P < 0.05$ in terms of mean development time (ANOVA followed by Duncan's new multiple range test).

The fourth instar larva took longer time to develop at 28.3°C and shorter time at 36°C. There was no significant difference in development time observed at the temperature regimes of 28.3°C, 30.6°C, 32.7°C. But the development time taken by fourth instar larva was significantly different between the above temperature regimes and 34.3°C, 36°C. But no significant difference in development time was observed between 34.3°C and 36°C.

As a whole the larvae took 28.75 days for its development at 28.3°C and 21.5 days at 36°C respectively. Statistical analysis indicated that there was a significant difference in development time taken by larval period at different temperature regimes (F-5.44; p-0.007).

The time taken by pupa to become adult was 7.5 days at 28.3°C, whereas it was only 5 days at 36°C. Statistical tests revealed that there was no significant difference in the pupal period observed at the temperature regimes of 28.3°C, 30.6°C, 32.7°C, 34.3°C. At the same time, significant difference (F-6.91; p-0.002) in length of the pupal period was observed between 36°C and other temperature regime (Table 3).

The development time taken for the total immature stage (Egg, Larva and Pupa) decreased with increasing temperature considerably as it took 44.8 days at 28.3°C and 32.2 days at 36°C. The difference in total immature development time taken at each temperature regime was statistically significant (F- 69.8 P< 0.001). In the case of rate of change in development, it revealed that there was no significant difference in the rate of change in development between different temperature regimes.

4.1.2.2. Brown Planthopper

The incubation period of BPH eggs decreased with increasing temperatures and difference was statistically significant (F-9.76; P<0.001) (Table 4). The eggs took 8.25 days to hatch into larvae at 28.3°C, whereas the incubation period was only 5.5 days for the eggs under 36°C. Statistical analysis revealed that there was no significant difference in the effect of temperature on incubation period from 28.3°C to 32.7°C as they formed a homogeneous group. But when the temperature increased to 34.3°C and 36°C, the difference in incubation period was significant.

There were five nymphal stages observed under all the temperature regimes and their duration varied under varying temperature regimes. The first nymphal stage took 4.75 days to complete the development at 28.3°C and 3.25 days at 36°C but the difference was statistically insignificant (F-2.99; p-0.053).

Table 4. Development time of Brown Planthopper at different temperature regimes

	Development time (days)													
Temperature regimes	Egg		Nymph I		Nymph II		Nymph III		Nymph IV		Nymph V		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
28.3^{o}C	8.25a	.500	4.75a	.957	4.25a	.500	3.25a	.957	2.75a	.500	3.25a	.500	26.5 a	0.6
30.6^{o}C	7.50a	.577	4.50a	.577	3.75a	.957	2.75a	.500	3.00a	.816	3.50a	.577	25.0 b	0.0
32.7^{o}C	7.25a	.957	3.75a	.957	3.75a	.500	2.50a	.577	2.50a	.577	3.50a	.577	23.2 c	1.3
34.3^{o}C	6.00b	.816	3.75a	.500	3.25a	.500	2.25a	.500	2.25a	.500	2.75a	.500	20.2 d	0.5
36.0^{o}C	5.50b	.577	3.25a	.500	2.75b	.500	2.25a	.500	1.75a	.500	2.50a	.577	18.0 e	1.2
	F-9.76		F-2.99		F-3.63		F-1.52		F-2.72		F-2.83		F-68.7	
	P<0.001		p-0.053		p-0.029		p-0.247		p-0.070		p-0.062		P<0.001	

Mean followed by a different letter are significantly different at $P < 0.05$ in terms of mean development time (ANOVA followed by Duncan's new multiple range test).

The development time taken by second nymphal stage was 4.25 days at 28.3°C but it was only 2.75 days at 36°C. Statistical tests showed that there was no significant difference in development time taken at the temperature regimes of 28.3°C, 30.6°C, 32.7°C and 34.3°C but significant difference was observed when the temperature was increased to 36°C (F-3.63; p-0.029). The development time taken by third, fourth and fifth nymphal stages were 3.25, 2.75 and 3.25 days respectively, at 28.3°C. At the same time, it took only 2.25, 1.75 and 2.25 days to complete the third, fourth and fifth nymphal stages respectively, at 36°C. But the differences in development time taken at third (F-1.52; p-0.247), fourth (F-2.72; p-0.070) and fifth (F-2.83; p-0.062) nymphal stages were not statistically significant

The total time taken by nymphal stage to complete the development was as more as 18.25 days at 28.3°C and as less as 12.5 days at 36°C. The total immature (Egg, Nymph) development time decreased with increasing temperatures and the difference was statistically significant (F-68.7; $P<0.001$) for all the temperature regimes. BPH took 26.5 days to complete the immature stage at 28.3°C, whereas it took only 18 days at 36°C.

4.1.2.3. Rice Leaffolder

The incubation period of RLF eggs generally decreased with increasing temperatures and the difference in incubation period was statistically significant (F-3.50; p-0.025). The incubation period of RLF eggs was 5.25 days at 28.3°C and the same was only 3.75 days at 36°C (Table 5). Statistical tests revealed that there was no significant difference in incubation period between 28.3°C and 30.6°C, whereas there was significant difference, when temperature increased to 32.7°C. The incubation periods at 32.7°C and 34.3°C were statistically similar and when the temperature increased to 36°C, significant difference was observed in incubation period when compared to all other temperature regimes.

Generally, five instars were observed under larval stage at all the temperature regimes. The first instar larvae took 2.5 days to complete the development at 28.3°C and 1.75 days at 36°C, and the difference was not statistically significant (F-1.10; p-0.432). The longest development time for second (3 days), third (4.25 days) and fourth (3.75 days) instar larvae were observed at 28.3°C. Whereas the shortest development time of 1.75, 3 and 3.25 days were observed for second, third, and fourth instar larvae, respectively at 36°C. But the difference in development time of second (F-3.40; p-0.036), third (F- 3.57; p-0.031) and fourth (F-1.96; p-0.152) instar larva was not statistically significant.

Table 5. Development time of Rice Leaffolder at different temperature regimes

	Development time (days)															
Temperature regimes	Egg		I Instar		II Instar		III Instar		IV Instar		V Instar		Pupa		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
28.3^{o}C	5.25a	.500	2.50a	.577	3.00a	.000	4.25a	.500	3.75a	.500	4.75a	.500	7.25a	.500	30.8 a	0.5
30.6^{o}C	5.00a	.816	2.25a	.500	2.50a	.577	4.25a	.500	3.75a	.500	4.50a	.577	6.25a	.500	28.5 a	1.3
32.7^{o}C	4.25b	.500	2.00a	.816	2.25a	.500	3.50a	.577	3.50a	.577	4.25b	.500	5.75b	.500	25.5 b	1.0
34.3^{o}C	4.00b	.816	2.00a	.000	2.25a	.500	3.25b	.500	3.00a	.000	3.25c	.500	5.25c	.500	23.0 c	0.8
36.0^{o}C	3.75c	.500	1.75a	.500	1.75b	.500	3.00b	.816	3.25a	.500	3.50c	.577	4.75c	.500	21.8 c	1.0
	F-3.50 p-0.025		F-1.10 p-0.432		F-3.40 p-0.036		F- 3.57 p-0.031		F-1.96 p-0.152		F-6.17 p- 0.004		F- 13.5 P<0.001		F-62.3 P<0.001	

Mean followed by a different letters are significantly different at $P < 0.05$ in terms of mean development time (ANOVA followed by Duncan’s new multiple range test).

The fifth instar larva took 4.75 days to complete the development at 28.3^{o}C and 3.5 days at 36^{o}C. The development time taken by fifth instar larva had significant difference between the temperature of regimes of 34.3^{o}C and 36^{o}C and all other temperature regimes (F-6.17; p- 0.004). At the same time the difference in development time observed between 28.3^{o}C and 30.6^{o}C was not statistically significant. In total the larval period took only 13.25 days to complete the development at 36^{o}C whereas it took as long as 18.25 days at 28.3^{o}C.

RLF pupa took 7.25 days to emerge into adult at 28.3^{o}C and it took 4.75 days at 36^{o}C and the difference was statistically significant (F- 13.5; P<0.001). Statistical analysis revealed that the temperature regimes can be grouped in to three homogenous sets based on its effect on the time taken by pupa to become adult. The temperature regimes of 28.3^{o}C and 30.6^{o}C can be grouped together, 34.3^{o}C and 36^{o}C can be grouped as another and 32.7^{o}C can be left separately as the effect of this temperature regime was different from other temperature regimes. The difference in total time taken for immature (Egg, Larva and Pupa) development at different temperature regime was statistically significant (F-62.3; P<0.001). RLF took 30.8 days to complete the immature development at 28.3^{o}C and it took only 21.8 days at 36^{o}C.

4.1.3. Longevity

The female YSB adults lived its life in 7.25 days at 28.3^{o}C and 5.75 days at 36^{o}C. Statistical tests revealed that the difference in time observed at 28.3^{o}C and 30.6^{o}C was not significant (Table 6). At the same time, there was difference in the longevity observed between 30.6^{o}C and 32.7^{o}C and the difference was statistically significant. However, the difference observed in longevity between 32.7^{o}C and 34.3^{o}C was not statistically significant. The difference observed in longevity between 36^{o}C and other temperature regimes was statistically significant (F-4.06; p-0.020). Similarly, YSB male lived its life in 5.25 days at 28.3^{o}C and 3.75 days at 36^{o}C and the difference was statistically significant (F-5.44; p-0.007). The difference observed in longevity between the temperature regimes of 28.3^{o}C, 30.6^{o}C and 32.7^{o}C was not statistically significant. But the difference was significant when the temperature increased to 34.3^{o}C and 36^{o}C. Generally females lived for longer duration than male adults.

Longevity of BPH adult female varied between 12.75 at 28.3^{o}C to 18.25 days at 36^{o}C and the difference was proved to be significant by statistical tests (F-70.57; P<0.0001). The difference observed in longevity at each temperature regime was statistically significant.

Table 6. Longevity of YBB, BPH and RLF adults at different temperature regimes

	Longevity (days)											
	YSB				BPH				RLF			
Temperature regimes	Female		Male		Female		Male		Female		Male	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
28.3^{o}C	7.25a	.957	5.25a	.500	18.25a	.500	13.25a	.500	8.25a	.500	4.25a	.500
30.6^{o}C	7.00a	.816	5.25a	.500	16.75b	.500	12.50a	.577	7.75a	.500	4.25a	.500
32.7^{o}C	6.25b	.500	4.75a	.500	14.75c	.500	10.75b	.500	7.25b	.500	3.75a	.500
34.3^{o}C	6.00b	.000	4.00b	.816	13.50d	.577	10.50b	.577	6.75b	.500	3.25b	.500
36.0^{o}C	5.75c	.500	3.75b	.500	12.75e	.500	8.50c	.577	6.00c	.816	3.25b	.500
ANOVA	F-4.06 p-0.020		F-5.44 p-0.007		F-70.57 P<0.0001		F-44.94 P<0.0001		F- 8.50 P<0.001		F-4.24 p-0.017	

Mean followed by a different letter are significantly different at P < 0.05 in terms of mean development time (ANOVA followed by Duncan’s new multiple range test).

The BPH male lived its life in 13.25 days at 28.3°C and 8.5 days at 36°C. The difference in longevity observed between 28.3°C and 30.6°C was not statistically significant. But when the temperature was increased to 32.7°C significant difference was found in the longevity. However, the longevity observed between 32.7°C and 34.3°C was statistically similar. The longevity observed at the temperature regime of 36°C was significantly different from the longevity observed at all other temperature regimes.

The longevity of RLF adult female was long (8.25) at 28.3°C and was short at 36°C. There was no significant difference in the longevity observed at 28.3°C and 30.6°C (Table 6). But significant difference in longevity was observed when the temperature increased to 32.7°C. No significant difference was observed between 32.7°C and 34.3°C and significant difference in longevity was observed when the temperature further increased to 36°C. The duration male adult was longer (4.25) at 28.3°C and shorter (3.25 days) at 36°C. No significant difference in the longevity observed at the temperature regimes of 28.3°C, 30.6°C, and 32.7°C. Significant difference in longevity was observed only when the temperature increased to 34.3°C or 36°C. The longevity of female was longer than male adult and generally longevity of both male and female adults decreased considerably with increasing temperature.

4.1.4. Age and stage specific life table

Data on vital schedules of survival, mortality and fecundity were collected for each pest at each temperature regime. The observations on fecundity and total number of females emerged were recorded from the experiment. By using the above said observations life and fecundity tables were constructed for each pest at different temperature regimes. The stage specific life table was constructed with the data derived from age specific life table and the results are described hereunder.

4.1.4.1. Yellow Stem Borer

The data on age specific life table at varying temperature regimes revealed that the total lifespan of *S. incertulus* extended to a maximum of 52 days at 28.3°C followed by 49 days at 30.6°C and 46 days at 32.7°C (Table 7-11). The longest development time of YSB was recorded at lowest temperature and shortest at higher temperature.

Table 7. Age specific life table of YSB at 28.3^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0								
5	1	1	0								
6	1	1	0								
7	1	1	0								
8	1	1	0.10			135.5	3123.5	23.05			
9	0.90	0.90	0.05			125	2988	23.90			
10	0.85	0.95	0.06			118.5	2863	24.16			
11	0.80	0.94	0.05			112	2744.5	24.50			
12	0.76	0.95	0.02			108	2632.5	24.38			
13	0.75	0.98	0.04			105	2524.5	24.04			
14	0.72	0.96	0.02			102	2419.5	23.72			
15	0.71	0.98	0.02			100	2317.5	23.18			
16	0.69	0.98	0.03			97.5	2217.5	22.74			
17	0.67	0.97	0.02			95	2120	22.32			
18	0.66	0.98	0.01			93.5	2025	21.66			
19	0.65	0.99	0.04			91	1931.5	21.23			
20	0.62	0.96	0.06			86.5	1840.5	21.28			
21	0.59	0.94	0.02			83	1754	21.13			
22	0.57	0.98	0.04			80.5	1671	20.76			
23	0.55	0.96	0.01			78.5	1590.5	20.26			
24	0.55	0.99	0.04			76.5	1512	19.76			
25	0.52	0.96	0.04			73.5	1435.5	19.53			
26	0.50	0.96	0.03			71	1362	19.18			
27	0.49	0.97	0.01			69.5	1291	18.58			

28	0.48	0.99	0.03			68	1221.5	17.96			
29	0.47	0.97	0.01			66.5	1153.5	17.35			
30	0.46	0.99	0.05			64.5	1087	16.85			
31	0.44	0.95	0.03			62	1022.5	16.49			
32	0.43	0.97	0.02			60.5	960.5	15.88			
33	0.42	0.98	0.02			59.5	900	15.13			
34	0.41	0.98	0.02			58.5	840.5	14.37			
35	0.41	0.98	0.03			57	782	13.72			
36	0.39	0.97	0.02			55.5	725	13.06			
37	0.38	0.98	0.02			54.5	669.5	12.28			
38	0.38	0.98	0.00			54	615	11.39			
39	0.38	1.00	0.00			54	561	10.39			
40	0.38	1.00	0.04			53	507	9.57			
41	0.36	0.96	0.02			51.5	454	8.82			
42	0.36	0.98	0.00			51	402.5	7.89			
43	0.36	1.00	0.00			51	351.5	6.89			
44	0.36	1.00	0.00			51	300.5	5.89			
45	0.36	1.00	0.04			50	249.5	4.99			
46	0.34	0.96	0.10	0	0	46.5	199.5	4.29	0	0	
47	0.31	0.90	0.14	0	0	41	153	3.73	0	0	
48	0.27	0.86	0.16	0	0	35	112	3.20	0	0	
49	0.22	0.84	0.16	980	30.63	29.5	77	2.61	6.85	335.80	0.06338
50	0.19	0.84	0.15	1121	41.52	25	47.5	1.90	7.84	391.96	0.06338
51	0.16	0.85	0.52	754	32.78	17	22.5	1.32	5.27	268.91	0.06338
52	0.08	0.48	1.00	600	54.55	5.5	5.5	1.00	4.20	218.18	0.06338
53	0.00	0.00									
Total					159.47				24.16	1214.9	0.06338

Table 8. Age specific life table of YSB at 30.6^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0								
5	1	1	0								
6	1	1	0								
7	1	1	0.09			132.5	3142.5	23.72			
8	0.91	0.91	0.02			124.5	3010	24.18			
9	0.88	0.98	0.03			121	2885.5	23.85			
10	0.86	0.97	0.02			118	2764.5	23.43			
11	0.84	0.98	0.03			115	2646.5	23.01			
12	0.81	0.97	0.04			110.5	2531.5	22.91			
13	0.78	0.96	0.02			107	2421	22.63			
14	0.76	0.98	0.03			104.5	2314	22.14			
15	0.74	0.97	0.03			101.5	2209.5	21.77			
16	0.72	0.97	0.02			99	2108	21.29			
17	0.71	0.98	0.02			97	2009	20.71			
18	0.69	0.98	0.04			94	1912	20.34			
19	0.66	0.96	0.03			90.5	1818	20.09			
20	0.64	0.97	0.03			87.5	1727.5	19.74			
21	0.62	0.97	0.03			84.5	1640	19.41			
22	0.60	0.97	0.04			81.5	1555.5	19.09			
23	0.58	0.96	0.04			78.5	1474	18.78			
24	0.55	0.96	0.01			76.5	1395.5	18.24			
25	0.55	0.99	0.03			75	1319	17.59			
26	0.53	0.97	0.04			72.5	1244	17.16			
27	0.51	0.96	0.03			70	1171.5	16.74			

28	0.50	0.97	0.01			68.5	1101.5	16.08			
29	0.49	0.99	0.03			67	1033	15.42			
30	0.47	0.97	0.02			65.5	966	14.75			
31	0.47	0.98	0.03			64	900.5	14.07			
32	0.45	0.97	0.02			62.5	836.5	13.38			
33	0.45	0.98	0.02			61.5	774	12.59			
34	0.44	0.98	0.02			60.5	712.5	11.78			
35	0.43	0.98	0.03			59	652	11.05			
36	0.42	0.97	0.02			57.5	593	10.31			
37	0.41	0.98	0.00			57	535.5	9.39			
38	0.41	1.00	0.00			57	478.5	8.39			
39	0.41	1.00	0.00			57	421.5	7.39			
40	0.41	1.00	0.00			57	364.5	6.39			
41	0.41	1.00	0.00			57	307.5	5.39			
42	0.41	1.00	0.05			55.5	250.5	4.51			
43	0.39	0.95	0.17	0	0	49.5	195	3.94	0.00	0.00	0
44	0.32	0.83	0.13	0	0	42	145.5	3.46	0.00	0.00	0
45	0.28	0.87	0.18	0	0	35.5	103.5	2.92	0.00	0.00	0
46	0.23	0.82	0.19	1210	37.81	29	68	2.34	8.71	400.43	0.07404
47	0.19	0.81	0.35	1389	53.42	21.5	39	1.81	9.99	469.66	0.07404
48	0.12	0.65	0.47	1112	65.41	13	17.5	1.35	8.00	384.00	0.07404
49	0.06	0.53	1.00	912	101.33	4.5	4.5	1.00	6.56	321.50	0.07404
50	0.00	0.00									
Total					257.98				33.26	1575.6	0.07404

Table 9. Age specific life table of YSB at 32.7^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1.00	1.00	0.00								
1	1.00	1.00	0.00								
2	1.00	1.00	0.00								
3	1.00	1.00	0.00								
4	1.00	1.00	0.00								
5	1.00	1.00	0.00								
6	1.00	1.00	0.14			138.5	3020.5	21.81			
7	0.86	0.86	0.05			124.5	2882	23.15			
8	0.81	0.95	0.03			119	2757.5	23.17			
9	0.79	0.97	0.04			114.5	2638.5	23.04			
10	0.75	0.96	0.03			110.5	2524	22.84			
11	0.73	0.97	0.02			108	2413.5	22.35			
12	0.72	0.98	0.03			105.5	2305.5	21.85			
13	0.70	0.97	0.02			103	2200	21.36			
14	0.68	0.98	0.03			100.5	2097	20.87			
15	0.66	0.97	0.04			97	1996.5	20.58			
16	0.64	0.96	0.03			93.5	1899.5	20.32			
17	0.62	0.97	0.02			91	1806	19.85			
18	0.60	0.98	0.01			89.5	1715	19.16			
19	0.60	0.99	0.03			87.5	1625.5	18.58			
20	0.58	0.97	0.03			84.5	1538	18.20			
21	0.56	0.97	0.01			82.5	1453.5	17.62			
22	0.55	0.99	0.05			80	1371	17.14			
23	0.52	0.95	0.01			77.5	1291	16.66			
24	0.52	0.99	0.01			76.5	1213.5	15.86			
25	0.51	0.99	0.04			74.5	1137	15.26			
26	0.49	0.96	0.01			72.5	1062.5	14.66			
27	0.48	0.99	0.04			70.5	990	14.04			

28	0.46	0.96	0.01			68.5	919.5	13.42			
29	0.46	0.99	0.03			67	851	12.70			
30	0.44	0.97	0.02			65.5	784	11.97			
31	0.44	0.98	0.03			64	718.5	11.23			
32	0.42	0.97	0.02			62.5	654.5	10.47			
33	0.42	0.98	0.05			60.5	592	9.79			
34	0.40	0.95	0.07			57	531.5	9.32			
35	0.37	0.93	0.00			55	474.5	8.63			
36	0.37	1.00	0.00			55	419.5	7.63			
37	0.37	1.00	0.00			55	364.5	6.63			
38	0.37	1.00	0.00			55	309.5	5.63			
39	0.37	1.00	0.00			55	254.5	4.63			
40	0.37	1.00	0.11			52	199.5	3.84			
41	0.33	0.89	0.20	0	0	44	147.5	3.35	0.00	0.00	
42	0.26	0.80	0.21	0	0	35	103.5	2.96	0.00	0.00	
43	0.21	0.79	0.16	1298	41.87	28.5	68.5	2.40	8.71	374.59	0.07692
44	0.17	0.84	0.27	1324	50.92	22.5	40	1.78	8.89	390.98	0.07692
45	0.13	0.73	0.58	1076	56.63	13.5	17.5	1.30	7.22	324.97	0.07692
46	0.05	0.42	1.00	786	98.25	4	4	1.00	5.28	242.66	0.07692
47	0.00	0.00									
Total					247.7				30.09	1333.2	0.07692

Table 10. Age specific life table of YSB at 34.3^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1.00	1.00	0.00								
1	1.00	1.00	0.00								
2	1.00	1.00	0.00								
3	1.00	1.00	0.00								
4	1.00	1.00	0.00								
5	1.00	1.00	0.29			143.5	1907	13.29			
6	0.71	0.71	0.07			115	1763.5	15.33			
7	0.66	0.93	0.08			106.5	1648.5	15.48			
8	0.61	0.92	0.07			98.5	1542	15.65			
9	0.57	0.93	0.03			93.5	1443.5	15.44			
10	0.55	0.97	0.05			89.5	1350	15.08			
11	0.52	0.95	0.08			83.5	1260.5	15.10			
12	0.48	0.92	0.05			78	1177	15.09			
13	0.45	0.95	0.09			72.5	1099	15.16			
14	0.41	0.91	0.03			68	1026.5	15.10			
15	0.40	0.97	0.06			65	958.5	14.75			
16	0.38	0.94	0.03			62	893.5	14.41			
17	0.36	0.97	0.03			60	831.5	13.86			
18	0.35	0.97	0.07			57	771.5	13.54			
19	0.33	0.93	0.04			54	714.5	13.23			
20	0.32	0.96	0.04			52	660.5	12.70			
21	0.30	0.96	0.06			49.5	608.5	12.29			
22	0.29	0.94	0.02			47.5	559	11.77			
23	0.28	0.98	0.02			46.5	511.5	11.00			
24	0.27	0.98	0.09			44	465	10.57			
25	0.25	0.91	0.02			41.5	421	10.14			
26	0.24	0.98	0.07			39.5	379.5	9.61			
27	0.23	0.93	0.03			37.5	340	9.07			

28	0.22	0.97	0.03			36.5	302.5	8.29			
29	0.21	0.97	0.11			34	266	7.82			
30	0.19	0.89	0.06			31	232	7.48			
31	0.18	0.94	0.03			29.5	201	6.81			
32	0.17	0.97	0.10			27.5	171.5	6.24			
33	0.15	0.90	0.04			25.5	144	5.65			
34	0.15	0.96	0.08			24	118.5	4.94			
35	0.14	0.92	0.09	0	0.00	22	94.5	4.30	0.00	0.00	
36	0.13	0.91	0.05	987	47.00	20.5	72.5	3.54	5.88	211.50	0.07796
37	0.12	0.95	0.20	878	43.90	18	52	2.89	5.23	193.37	0.07796
38	0.10	0.80	0.13	612	38.25	15	34	2.27	3.64	138.43	0.07795
39	0.08	0.88	0.14	456	32.57	13	19	1.46	2.71	105.86	0.07795
40	0.07	0.86	1.00	132	11.00	6	6	1.00	0.79	31.43	0.07795
41	0.00	0.00									
Total					172.72				18.24	680.6	0.07795

Table 11. Age specific life table of YSB at 36.0°C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1.00	1.00	0.00								
1	1.00	1.00	0.00								
2	1.00	1.00	0.00								
3	1.00	1.00	0.00								
4	1.00	1.00	0.00								
5	1.00	1.00	0.41			139.5	1381	9.90			
6	0.59	0.59	0.12			97	1241.5	12.80			
7	0.52	0.88	0.07			88	1144.5	13.01			
8	0.48	0.93	0.09			81	1056.5	13.04			
9	0.44	0.91	0.08			74	975.5	13.18			
10	0.40	0.92	0.08			68	901.5	13.26			
11	0.37	0.92	0.05			63.5	833.5	13.13			
12	0.35	0.95	0.06			60	770	12.83			
13	0.33	0.94	0.05			56.5	710	12.57			
14	0.31	0.95	0.07			53	653.5	12.33			
15	0.29	0.93	0.04			50	600.5	12.01			
16	0.28	0.96	0.08			47	550.5	11.71			
17	0.26	0.92	0.04			44	503.5	11.44			
18	0.24	0.96	0.02			42.5	459.5	10.81			
19	0.24	0.98	0.07			40.5	417	10.30			
20	0.22	0.93	0.03			38.5	376.5	9.78			
21	0.22	0.97	0.05			37	338	9.14			
22	0.20	0.95	0.08			34.5	301	8.72			
23	0.19	0.92	0.06			32	266.5	8.33			
24	0.18	0.94	0.10			29.5	234.5	7.95			
25	0.16	0.90	0.14			26	205	7.88			
26	0.14	0.86	0.04			23.5	179	7.62			
27	0.13	0.96	0.13			21.5	155.5	7.23			

28	0.11	0.87	0.10			19	134	7.05			
29	0.10	0.90	0.00			18	115	6.39			
30	0.10	1.00	0.00			18	97	5.39			
31	0.10	1.00	0.00			18	79	4.39			
32	0.10	1.00	0.39			14.5	61	4.21			
33	0.06	0.61	0.00	0	0	11	46.5	4.23			
34	0.06	1.00	0.09	369	33.55	10.5	35.5	3.38	2.10	71.28	0.05514
35	0.06	0.91	0.10	348	34.80	9.5	25	2.63	1.98	69.20	0.05514
36	0.05	0.90	0.33	286	31.78	7.5	15.5	2.07	1.63	58.50	0.05514
37	0.03	0.67	0.17	167	27.83	5.5	8	1.45	0.95	35.11	0.05514
38	0.03	0.83	1.00	64	12.80	2.5	2.5	1.00	0.36	13.82	0.05513
39	0.00	0.00									
Total					140.8	7.01	247.9				0.05513

4.1.4.1.1. Survivorship (l_x)

The survival exhibited by YSB indicated that it belongs to type III survivorship curve. In general, survival decreased with increasing temperatures. The curve indicated that the mortality during early stage of the pest was higher at higher temperature regimes (34.3°C and 36°C) (Figure 3). The 50 per cent mortality in YSB was recorded after 26.6 days of incubation at 28.3°C and however, it occurred as early as on 7.2 days at the temperature regime of 36°C followed by 11.5 days at 34.3°C, indicated that the higher temperature regimes were detrimental for YSB survival. Using the Doesn't Use Derivative (DUD) method, survivorship curves of different temperature were smoothened. Parameters (a and b) of the smoothened curves of different temperature regimes are given table 12.

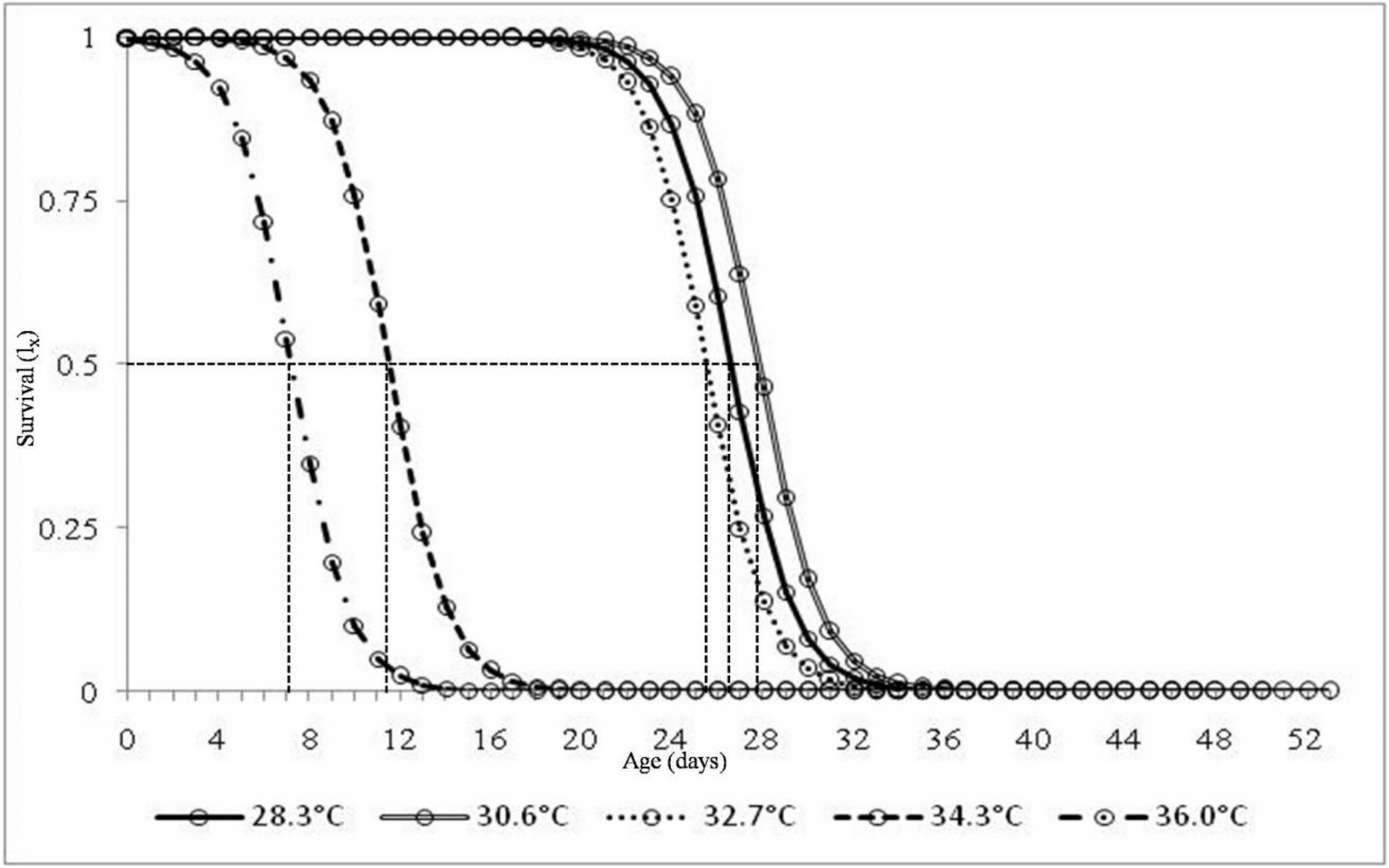
Table 12. Response of survival of YSB at different temperature regimes

Temperature regimes	'a' (50 % mortality)	'b' (Intercept)	r^2 Value
28.3°C	26.6	1.401	0.843
30.6°C	27.8	1.395	0.807
32.7°C	25.5	1.354	0.844
34.3°C	11.5	1.314	0.927
36.0°C	7.2	1.286	0.912

4.1.4.1.2. Survival proportion

In YSB, 89.5 per cent of eggs reached successfully to first instar and 37.8 per cent reached pupal stage at 28.3°C (Table 13-16). Around 62.8 per cent of insects died before reaching to the pupal stage at 28.3°C. Similar trend was noticed at 30.6°C, in which 58.3 per cent of insects died before reaching the pupal stage. At 36°C, only 11.4 per cent of eggs reached successfully to the pupal stage and remaining died in the process of development. In YSB, 38.8 per cent of eggs successfully became adults at 30.6°C followed by 34.3 and 31.5 per cent at 28.3°C and 32.7°C, respectively. But only 6.3 per cent of eggs became adult at 36°C.

Figure 3. Survivorship curves of YSB at different temperature regimes



4.1.4.1.3. Survival fraction (S_x)

Survival fraction (S_x) was found maximum (0.91) at 30.6^{o}C for egg stage and minimum (0.71) at 34.3^{o}C. This meant that, if 100 eggs were incubated, 91 eggs will successful emerge into larvae at 30.6^{o}C, whereas only 71 eggs will be successfully emerged into larvae. Among the larval stages, fourth instar seemed to be more successful at 30.6^{o}C as the S_x remained higher (0.85) and however, the rate of success was lower for second instar stage at 34.3^{o}C as the S_x was found lower (0.72) (Table 13-16). At pupal stage, the maximum S_x (0.93) was obtained at 30.6^{o}C in contrast to minimum (0.64) at 34.3^{o}C. The above results indicated that the successful completion of a particular stage reduced with increasing temperatures.

4.1.4.1.4. Apparent mortality

At egg stage the apparent mortality was more (29.17 %) at 34.3^{o}C and minimum (9.4%) at 30.6^{o}C. When the comparision was made between the larval instars, highest mortality (27.59 %) was observed at 34.3^{o}C for second instar, whereas minimum mortality (13.8 %) was observed at 28.3^{o}C for fourth instar. Similarly, mortality at pupal stage remained higher (36.11 %) at 34.3^{o}C and lower (6.9 %) at 30.6^{o}C (Table 13-16).

4.1.4.1.5. Mortality survivor ratio

Mortality survivor ratio (MSR) was calculated to understand the amount of population increase in particular stage, if, the mortality in the particular stage had not occurred. MSR was found maximum (0.41) at 34.3^{o}C and minimum (0.10) at 30.6^{o}C for egg stage. Among larval instars, maximum MSR (0.38) was observed at 34.3^{o}C for second instar. On the other hand, the minimum (0.17) MSR was obtained at 28.3^{o}C and 30.6^{o}C for fourth instar larvae. Furthermore, when the pupal stage was examined, the highest MSR (0.57) was observed at 34.3^{o}C and lowest was (0.07) at 30.6^{o}C (Table 13-16). The results revealed that the population increase would be more at higher temperature regimes, if the mortality doesn’t occurr.

Table 13. Stage specific life table of YSB at 28.3^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival Proportion	Survival fraction (S_x)	Apparent mortality	Morality survivor ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	143	15	100	0.90	10.5	0.12	5.7	0.0481
1st Instar	128	29	89.5	0.77	22.7	0.29	14.4	0.1116
2nd Instar	99	20	69.2	0.80	20.2	0.25	12.4	0.0980
3rd Instar	79	14	55.2	0.82	17.7	0.22	10.6	0.0847
4th Instar	65	9	45.5	0.83	13.8	0.17	8.2	0.0805
Pupa	54	5	37.8	0.91	9.3	0.10	5.0	0.0422
Adult	49	49	34.3	-	100.0	-	-	-
Average								0.0775

Table 14. Stage specific life table of YSB at 30.6^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival Proportion	Survival fraction (S_x)	Apparent mortality	Morality survivor ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	139	13	100	0.91	9.4	0.10	5.6	0.0426
1st Instar	126	23	90.6	0.82	18.3	0.22	12.1	0.0875
2nd Instar	103	17	74.1	0.83	16.5	0.20	10.7	0.0783
3rd Instar	86	18	61.9	0.79	20.9	0.26	14.3	0.1020
4th Instar	68	10	48.9	0.85	14.7	0.17	9.3	0.0691
Pupa	58	4	41.7	0.93	6.9	0.07	4.0	0.0310
Adult	54	54	38.8	-	100.0	-	-	-
Average								0.0684

Table 15. Stage specific life table of YSB at 32.7^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival Proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	149	21	100	0.86	14.09	0.16	7.71	0.0660
1st Instar	128	28	85.9	0.78	21.88	0.28	13.16	0.1072
2nd Instar	100	16	67.1	0.84	16.00	0.19	8.95	0.0757
3rd Instar	84	14	56.4	0.83	16.67	0.20	9.40	0.0792
4th Instar	70	14	47.0	0.80	20.00	0.25	11.75	0.0969
Pupa	56	9	37.6	0.84	16.07	0.19	9.00	0.0761
Adult	47	47	31.5	-	100.00	-	-	-
Average								0.0835

Table 16. Stage specific life table of YSB at 34.3^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival Proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	168	49	100	0.71	29.17	0.41	9.47	0.1498
1st Instar	119	32	70.8	0.73	26.89	0.37	8.46	0.1360
2nd Instar	87	24	51.8	0.72	27.59	0.38	8.76	0.1402
3rd Instar	63	16	37.5	0.75	25.40	0.34	7.83	0.1272
4th Instar	47	11	28.0	0.77	23.40	0.31	7.03	0.1158
Pupa	36	13	21.4	0.64	36.11	0.57	13.00	0.1946
Adult	23	23	13.7	-	100.00	-	-	-
Average								0.1439

4.1.4.1.6. Indispensable mortality

Indispensable mortality (IM) was recorded to understand the amount of mortality which can be avoided if the factor causing mortality is not allowed to operate. It was found that the IM was maximum (9.47) at 34.3°C and minimum (5.6) at 30.6°C for egg stage. The examination of larval instars revealed that the IM remained maximum (14.4) at 28.3°C for first instar, whereas the minimum value (7.03) was encountered at 34.3°C for fourth instar larva. Likewise, the IM for pupa was observed to be minimum (4.00) at 30.6°C, and maximum (13.00) at 34.3°C (Table 13-16).

4.1.4.1.7. K - values

At egg stage, the k-value was found maximum (0.2327) at 36°C and minimum (0.0426) at 30.6°C. Comparision of larval instars revealed that the highest 'K' value (0.2553) was recorded at 36°C for fourth instar and lowest (0.0691) at 30.6°C for the same. At pupal stage, K-value remained at its maximum (0.2596) at 36°C and minimum (0.0310) at 30.6°C. The total generation mortality was observed to be increasing with increasing temperatures. K - value was observed to be maximum (0.2007) at 36°C and minimum (0.0684) at 30.6°C (Table 13-16).

4.1.4.1.8. Life expectancy (e_x)

The life expectancy at different age class showed a decreasing trend at the initial period and then increased slightly at all the temperature regimes. After the increase the life expectancy started decreasing steadily at all the temperature regimes. The highest life expectancy was observed at 28.3°C. The life expectancy decreased with increasing temperatures. The life expectancy observed was 29.84 days at 28.3°C but was only 12.85 days at 36°C (Table 17).

4.1.4.1.9. Fecundity

Pre-oviposition period for YSB decreased with increasing temperatures. It was observed as 3 days at 28.3°C. Famale adults started egg laying after three days of emergence from pupa. The pre-oviposition period was only one day at 36°C (Table 7-11). It indicated that the adult starts laying the eggs early at higher temperature than at lower temperature. The oviposition period of YSB adult indicated that the period of egg laying increased with increasing temperatures. From 28.3°C to 32.7°C, oviposition period was 4 days, whereas it was five days at 34.3°C and 36°C (Table 17). It indicated that the oviposition starts early and continues for more number of days at higher temperature regime than at lower temperature regime. Age of first and last oviposition was observed to be 49th and 52nd day respectively, at 28.3°C. At 36°C, they were recorded on 34th and 38th day, respectively.

The total number of eggs laid by YSB increased with increasing temperature. Gross reproductive rate recorded was more (172) at 36°C and less (139) at 30.6°C (Figure 4). It was also noted that the 50 per cent fecundity in YSB was recorded on 49.7 days after incubation at 28.3°C, whereas it was observed as early as on 34.4 days when the YSB was reared at 36°C (Figure 5).

4.1.4.1.10. Net reproductive rate (R_o)

The Net reproductive rate of YSB was more at lower temperature regimes of 28.3°C and 30.6°C. The R_o observed to be decreased at the higher temperature regimes. The highest Net Reproductive Rate of 33.26 females/female was recorded at 30.6°C and lowest of 7.01females/female was recorded at 36°C (Table 17).

4.1.4.1.11. Intrinsic rate of natural increase (r_m)

The intrinsic rate of natural increase (r_m) increased with rise in temperature. It was 0.07795/day at 34.3°C, whereas it was 0.06338/day at 28.3°C. However, the increase in r_m has a turn around after 34.3°C and hence at 36°C it has been reduced to 0.05514/day (Table 17).

4.1.4.1.12. Finite rate of increase (λ)

Finite rate of increase (λ) also followed the same trend as intrinsic rate of natural increase. The Finite rate of increase (λ) increased with surging temperatures. It was 1.08107/day at 34.3°C, whereas it was 1.0654/day at 28.3°C. However, the increase in λ has a turn around after 34.3°C and hence at 36°C it has been reduced to 1.05669/day (Table 17).

4.1.4.1.13. Mean generation time (T)

The mean generation time of YSB was longer at lower temperature regimes and was shorter at higher temperature regimes. YSB took 50.25 days at 28.3°C to complete the generation which was longest of all temperature regimes (Table 17). But it took only 35.32 days at 36°C, which was shortest of all the temperature regimes.

4.1.4.1.14. Doubling time (t)

The doubling time (days) decreased with increasing temperatures. It was 8.89 days at 34.3°C, whereas it was 10.94 days at 28.3°C. However, the decrease in doubling time has a turn around after 34.3°C and hence at 36°C it has been increased to 12.57 days (Table 17).

Figure 4. Cumulative fecundity of YSB at different temperature regimes

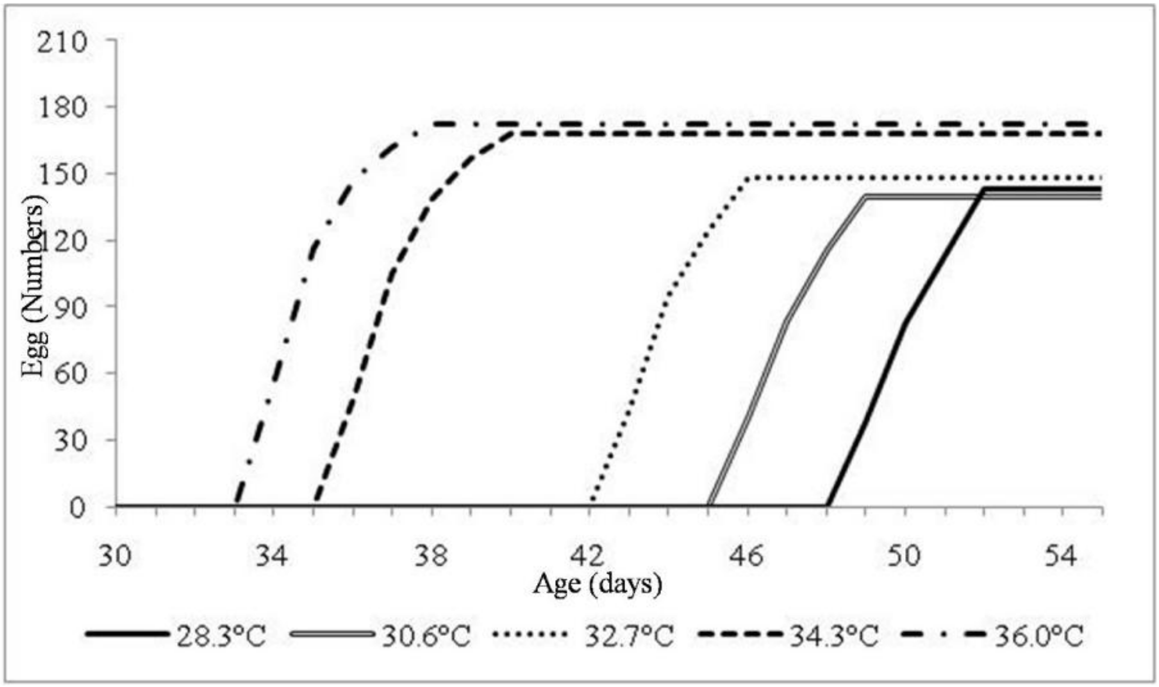


Figure 5. Per cent cumulative fecundity of YSB at different temperature regimes

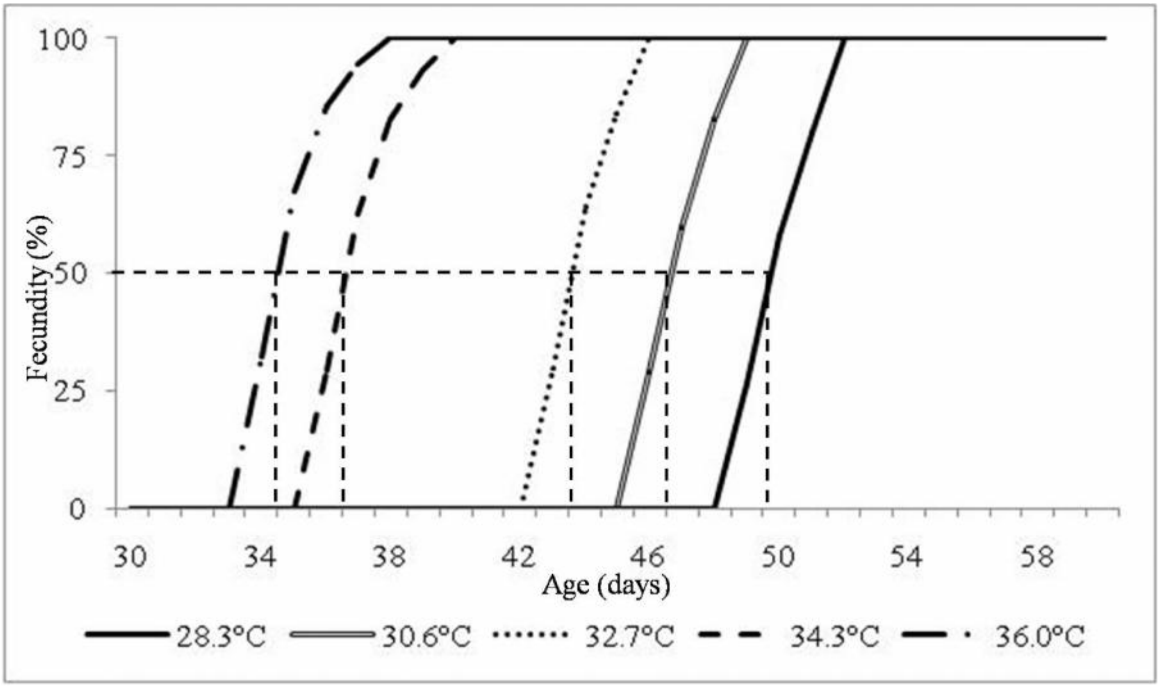


Table 17. Life table parameters of YSB at different temperature regimes

Parameter	**28.3°C**	**30.6°C**	**32.7°C**	**34.3°C**	**36.0°C**
Life expectancy (e_x) (days)	29.84	29.61	26.27	16.35	12.85
Age of first oviposition (day)	49	46	43	36	34
Age of 50 % oviposition (day)	49.7	46.5	43.6	36.5	34.4
Age of last oviposition (day)	52	49	46	40	38
Age of maximum oviposition (day)	50	47	44	37	35
Length Oviposition (days)	4	4	4	5	5
Net Reproductive rate (R_o) (females/female)	24.16	33.26	30.09	18.24	7.01
Intrinsic rate of natural increase (r_m) (day^{-1})	0.06338	0.07404	0.07692	0.07795	0.05514
Finite rate of increase (λ) (day^{-1})	1.0654	1.07685	1.07996	1.08107	1.05669
Mean generation time (T) (days)	50.25	47.33	44.26	37.25	35.32
Doubling time (t) (days)	10.94	9.36	9.01	8.89	12.57

4.1.4.2. Brown Planthopper

Age specific life table was constructed for *N. lugens* at various temperature regimes and it revealed that BPH took as long as 44 days to complete the generation at 28.3°C and as short as 32 days at 36°C (Table 18-22). The time taken for the development was inversely proportional to increasing temperatures.

4.1.4.2.1. Survivorship (l_x)

The graph constructed by using the age specific survival of BPH indicated that it belongs to type III survivorship curve (Figure 6). The data revealed that the number of survivors decreased with the progress of time. During the early stage of the insects the curve was observed to dip steeply at higher temperature regimes as the mortality during early stage of the insect was higher at higher temperature regimes. The 50 per cent mortality occurred on 20.1 days after incubation at 28.3°C, whereas it was observed as early as on 6.3 days at 36°C (Figure 4). This revealed that, BPH died earlier and faster at higher temperature regimes. Using the Doesn't Use Derivative (DUD) method, survivorship curves of different temperature were smoothened. Parameters (a and b) of the smoothened curves of different temperature regimes are given in Table 23.

Table 18. Age specific life table of BPH at 28.3°C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1.00	1	0								
1	1.00	1	0								
2	1.00	1	0								
3	1.00	1	0								
4	1.00	1	0								
5	1.00	1	0								
6	1.00	1	0								
7	1.00	1	0.09			206	3169	15.38			
8	0.91	0.91	0.06			190	2963	15.59			
9	0.85	0.94	0.05			179.5	2773	15.45			
10	0.81	0.95	0.02			173	2593.5	14.99			
11	0.79	0.98	0.02			169.5	2420.5	14.28			
12	0.78	0.98	0.02			166	2251	13.56			
13	0.76	0.98	0.04			160.5	2085	12.99			
14	0.73	0.96	0.05			153	1924.5	12.58			
15	0.69	0.95	0.05			145	1771.5	12.22			
16	0.65	0.95	0.06			137	1626.5	11.87			
17	0.62	0.94	0.07			128.5	1489.5	11.59			
18	0.57	0.93	0.06			120	1361	11.34			
19	0.54	0.94	0.06			112.5	1241	11.03			
20	0.50	0.94	0.11			103	1128.5	10.96			
21	0.45	0.89	0.09			92.5	1025.5	11.09			
22	0.41	0.91	0.07			85	933	10.98			
23	0.38	0.93	0.07			79	848	10.73			
24	0.35	0.93	0.09			72.5	769	10.61			
25	0.32	0.91	0.06			67	696.5	10.40			
26	0.30	0.94	0.06			63	629.5				
27	0.28	0.88	0.08	0	0	58.5	566.5	9.68	0	0	0

28	0.26	0.92	0.05	0	0	54.5	508	9.32	0	0	0
29	0.25	0.95	0.09	0	0	50.5	453.5	8.98	0	0	0
30	0.22	0.91	0.10	0	0	45.5	403	8.86	0	0	0
31	0.20	0.90	0.05	0	0	42	357.5	8.51	0	0	0
32	0.19	0.95	0.05	956	23.32	40	315.5	7.89	4.43	137.20	0.1042
33	0.18	0.95	0.03	1012	25.95	38.5	275.5	7.16	4.69	149.93	0.1042
34	0.18	0.97	0.05	1023	26.92	37	237	6.41	4.74	156.29	0.1041
35	0.17	0.95	0.14	987	27.41667	33.5	200	5.97	4.57	155.36	0.1041
36	0.14	0.86	0.06	848	27.35	30	166.5	5.55	3.93	137.41	0.1041
37	0.13	0.94	0.10	812	28.00	27.5	136.5	4.96	3.76	135.33	0.1040
38	0.12	0.90	0.08	656	25.23	25	109	4.36	3.04	112.37	0.1040
39	0.11	0.92	0.13	532	22.17	22.5	84	3.73	2.46	93.59	0.1040
40	0.10	0.88	0.10	365	17.38	20	61.5	3.08	1.69	65.90	0.1039
41	0.09	0.90	0.21	278	14.63	17	41.5	2.44	1.29	51.48	0.1039
42	0.07	0.79	0.27	189	12.60	13	24.5	1.88	0.88	35.88	0.1039
43	0.05	0.73	0.45	123	11.18	8.5	11.5	1.35	0.57	23.92	0.1039
44	0.03	0.55	1	0	0	3	3	1	0	0	0
Total					262.15				36.02	1290.7	

Table 19. Age specific life table of BPH at 30.6^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1.00	1	0								
1	1.00	1	0								
2	1.00	1	0								
3	1.00	1	0								
4	1.00	1	0								
5	1.00	1	0								
6	1.00	1	0								
7	1.00	1	0.12			217	3141.5	14.48			
8	0.88	0.88	0.06			197	2924.5	14.85			
9	0.83	0.94	0.05			186.5	2727.5	14.62			
10	0.79	0.95	0.04			178	2541	14.28			
11	0.75	0.96	0.02			172.5	2363	13.70			
12	0.74	0.98	0.01			170	2190.5	12.89			
13	0.73	0.99	0.05			165	2020.5	12.25			
14	0.70	0.95	0.03			158.5	1855.5	11.71			
15	0.68	0.97	0.03			154	1697	11.02			
16	0.66	0.97	0.04			149	1543	10.36			
17	0.63	0.96	0.08			140	1394	9.96			
18	0.58	0.92	0.08			128.5	1254	9.76			
19	0.53	0.92	0.07			118.5	1125.5	9.50			
20	0.49	0.93	0.13			106.5	1007	9.46			
21	0.43	0.87	0.13			92.5	900.5	9.74			
22	0.37	0.87	0.12			81	808	9.98			
23	0.33	0.88	0.11			72	727	10.10			
24	0.29	0.89	0.10			64.5	649	10.06			
25	0.26	0.90	0.10			58	590.5	10.18			
26	0.24	0.90	0.07			53	532.5	10.05			
27	0.22	0.93	0.06	0	0	49.5	479.5	9.69	0	0	

28	0.21	0.94	0.08	0	0	46	430	9.35	0	0	
29	0.19	0.92	0.05	0	0	43	384	8.93	0	0	
30	0.18	0.95	0.12	0	0	39.5	341	8.63	0	0	
31	0.16	0.88	0.11	1023	27.65	35	301.5	8.61	4.43	137.29	0.1064
32	0.14	0.89	0.03	1122	34.00	32.5	266.5	8.20	4.86	155.43	0.1064
33	0.14	0.97	0.09	1187	37.09	30.5	234	7.67	5.14	169.57	0.1063
34	0.13	0.91	0.00	1096	37.79	29	203.5	7.02	4.74	161.32	0.1063
35	0.13	1.00	0.07	976	33.66	28	174.5	6.23	4.23	147.88	0.1063
36	0.12	0.93	0.04	896	33.19	26.5	146.5	5.53	3.88	139.64	0.1062
37	0.11	0.96	0.08	775	29.81	25	120	4.80	3.35	124.13	0.1062
38	0.10	0.92	0.13	606	25.25	22.5	95	4.22	2.62	99.69	0.1062
39	0.09	0.88	0.10	478	22.76	20	72.5	3.63	2.07	80.70	0.1061
40	0.08	0.90	0.11	434	22.84	18	52.5	2.92	1.88	75.15	0.1061
41	0.07	0.89	0.18	389	22.88	15.5	34.5	2.23	1.68	69.04	0.1061
42	0.06	0.82	0.14	246	17.57	13	19	1.46	1.06	44.73	0.1060
43	0.05	0.86	1	0	0	6	6	1	0	0	0
44	0.0	0.0									
Total					344.5				39.9	1404.6	

Table 20. Age specific life table of BPH at 32.7^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0								
5	1	1	0								
6	1	1	0.19			204.5	2821	13.79			
7	0.81	0.81	0.06			177.5	2616.5	14.74			
8	0.76	0.94	0.05			168	2439	14.52			
9	0.73	0.95	0.04			161	2271	14.11			
10	0.70	0.96	0.02			156.5	2110	13.48			
11	0.69	0.98	0.03			153	1953.5	12.77			
12	0.67	0.97	0.03			149	1800.5	12.08			
13	0.65	0.97	0.03			145	1651.5	11.39			
14	0.63	0.97	0.03			140.5	1506.5	10.72			
15	0.61	0.97	0.08			132.5	1366	10.31			
16	0.56	0.92	0.09			121.5	1233.5	10.15			
17	0.51	0.91	0.06			112.5	1112	9.88			
18	0.48	0.94	0.11			103	999.5	9.70			
19	0.43	0.89	0.11			91.5	896.5	9.80			
20	0.38	0.89	0.09			82	805	9.82			
21	0.35	0.91	0.06			75.5	723	9.58			
22	0.32	0.94	0.08			70	647.5	9.25			
23	0.30	0.92	0.06			65	577.5	8.88			
24	0.28	0.94	0.06			61	512.5	8.40			
25	0.26	0.94	0.14	0	0	55	451.5	8.21	0	0	0
26	0.23	0.86	0.10	0	0	48.5	396.5	8.18	0	0	0
27	0.20	0.90	0.07	0	0	44.5	348	7.82	0	0	0

28	0.19	0.93	0.09	0	0	41	303.5	7.40	0	0	0
29	0.17	0.91	0.03	1089	27.92	38.5	262.5	6.82	4.82	139.74	0.1085
30	0.17	0.97	0.11	1125	29.61	36	224	6.22	4.98	149.34	0.1085
31	0.15	0.89	0.09	987	29.03	32.5	188	5.78	4.37	135.38	0.1084
32	0.14	0.91	0.06	976	31.48	30	155.5	5.18	4.32	138.19	0.1084
33	0.13	0.94	0.10	902	31.10	27.5	125.5	4.56	3.99	131.71	0.1084
34	0.12	0.90	0.15	613	23.58	24	98	4.08	2.71	92.22	0.1083
35	0.10	0.85	0.09	502	22.82	21	74	3.52	2.22	77.74	0.1083
36	0.09	0.91	0.20	423	21.15	18	53	2.94	1.87	67.38	0.1083
37	0.07	0.80	0.19	321	20.06	14.5	35	2.41	1.42	52.55	0.1082
38	0.06	0.81	0.31	198	15.23	11	20.5	1.86	0.88	33.29	0.1082
39	0.04	0.69	0.44	102	11.33	7	9.5	1.36	0.45	17.60	0.1082
40	0.02	0.56	1.00	0.0	0.0	2.5	2.5	1	0	0	0
41	0.0	0.0									
Total					263.3				32.02	1035.2	

Table 21. Age specific life table of BPH at 34.3^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0								
5	1	1	0.40			156.5	1431	9.1			
6	0.60	0.60	0.07			113	1274.5	11.3			
7	0.56	0.93	0.05			106.5	1161.5	10.9			
8	0.53	0.95	0.04			102	1055	10.3			
9	0.51	0.96	0.04			98	953	9.7			
10	0.49	0.96	0.06			93	855	9.2			
11	0.46	0.94	0.06			87.5	762	8.7			
12	0.43	0.94	0.04			83.5	674.5	8.1			
13	0.42	0.96	0.11			77.5	591	7.6			
14	0.37	0.89	0.11			69	513.5	7.4			
15	0.33	0.89	0.18			59	444.5	7.5			
16	0.27	0.82	0.17			48.5	385.5	7.9			
17	0.22	0.83	0.14			41	337	8.2			
18	0.19	0.86	0.13			35.5	296	8.3			
19	0.17	0.87	0.09			31.5	260.5	8.3			
20	0.15	0.91	0.03	0	0	29.5	229	7.8	0	0	0
21	0.15	0.97	0.10	0	0	27.5	199.5	7.3	0	0	0
22	0.13	0.90	0.04	0	0	25.5	172	6.7	0	0	0
23	0.13	0.96	0.08	543	21.72	24	146.5	6.1	2.77	63.72	0.1094
24	0.12	0.92	0.17	564	24.52	21	122.5	5.8	2.88	69.06	0.1093
25	0.10	0.83	0.05	512	26.95	18.5	101.5	5.5	2.61	65.31	0.1093
26	0.09	0.95	0.11	487	27.06	17	83	4.9	2.48	64.60	0.1092
27	0.08	0.89	0.19	412	25.75	14.5	66	4.6	2.10	56.76	0.1092

28	0.07	0.81	0.08	234	18.00	12.5	51.5	4.1	1.19	33.43	0.1091
29	0.06	0.92	0.17	165	13.75	11	39	3.5	0.84	24.41	0.1091
30	0.05	0.83	0.00	123	12.30	10	28	2.8	0.63	18.83	0.1091
31	0.05	1.00	0.20	76	7.60	9	18	2.0	0.39	12.02	0.1090
32	0.04	0.80	0.38	53	6.63	6.5	9	1.4	0.27	8.65	0.1090
33	0.03	0.63	1.00	32	6.40	2.5	2.5	1.0	0.16	5.39	0.1090
34	0.00	0.00									
Total					190.7				16.3	422.2	

Table 22. Age specific life table of BPH at 36.0^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0								
5	1	1	0.48			88	639	7.26			
6	0.52	0.52	0.10			57	551	9.67			
7	0.47	0.90	0.07			52	494	9.50			
8	0.43	0.93	0.06			48.5	442	9.11			
9	0.41	0.94	0.04			46	393.5	8.55			
10	0.39	0.96	0.02			44.5	347.5	7.81			
11	0.38	0.98	0.09			42	303	7.21			
12	0.34	0.91	0.15			37	261	7.05			
13	0.29	0.85	0.15			31.5	224	7.11			
14	0.25	0.85	0.14			27	192.5	7.13			
15	0.22	0.86	0.20			22.5	165.5	7.36			
16	0.17	0.80	0.10			19	143	7.53			
17	0.16	0.90	0.11			17	124	7.29			
18	0.14	0.89	0.19			14.5	107	7.38			
19	0.11	0.81	0.15	0	0	12	92.5	7.71	0	0	
20	0.09	0.85	0.00	0	0	11	80.5	7.32	0	0	
21	0.09	1.00	0.09	212	19.27	10.5	69.5	6.62	1.83	38.38	0.09371
22	0.09	0.91	0.00	202	20.20	10	59	5.90	1.74	38.31	0.09366
23	0.09	1.00	0.10	189	18.90	9.5	49	5.16	1.63	37.47	0.09362
24	0.08	0.90	0.11	165	18.33	8.5	39.5	4.65	1.42	34.14	0.09358
25	0.07	0.89	0.25	82	10.25	7	31	4.43	0.71	17.67	0.09355
26	0.05	0.75	0.00	59	9.83	6	24	4.00	0.51	13.22	0.09351
27	0.05	1.00	0.00	31	5.17	6	18	3.00	0.27	7.22	0.09348

28	0.05	1.00	0.33	29	4.83	5	12	2.40	0.25	7.00	0.09346
29	0.03	0.67	0.25	32	8.00	3.5	7	2.00	0.28	8.00	0.09343
30	0.03	0.75	0.33	15	5.00	2.5	3.5	1.40	0.13	3.88	0.09340
31	0.02	0.67	1.00	9	4.50	1	1	1.00	0.08	2.41	0.09338
32	0.00	0.00									
Total					124.3				8.83	207.7	

Table 23. Response of survival of BPH at different temperature regimes

Temperature regimes	'a' (50 % mortality)	'b' (Intercept)	r^2 Value
28.3^{o}C	20.1	1.510	0.831
30.6^{o}C	19/8	1.510	0.829
32.7^{o}C	17.5	1.456	0.866
34.3^{o}C	9.4	1.351	0.907
36.0^{o}C	6.3	1.325	0.893

4.1.4.2.2. Survival proportion

In the case of BPH, 90.7 per cent of eggs successfully emerged as nymphs and 28.2 per cent of eggs successfully became adult at 28.3^{o}C, whereas it was steeply decreased (15.3 per cent adults) at higher temperature regime of 34.3^{o}C. The next highest per cent of adults (26.1) was recorded at 32.7^{o}C. It was also observed that 71.8 per cent of insects died before reaching the adult stage at 28.3^{o}C and around 84.7 per cent at 34.3^{o}C (Table 24-27).

4.1.4.2.3. Survival fraction (S_x)

Survival fraction (S_x) was found maximum (0.91) for egg stage at 28.3^{o}C and minimum (0.60) at 34.3^{o}C which indicated that the egg stage was more successful at lower temperature regimes than at higher temperature regimes. Among the nymphal stages, S_x remained higher (0.89) at 32.7°C for second nymphal stage and lower (0.67) at 30.6^{o}C for fourth and fifth nymphal stage followed by 0.68 for the same stages at 34.3^{o}C (Table 24-27). This revealed that the success rates of fourth and fifth nymphal stages were reduced at both higher and lower temperature regimes.

4.1.4.2.4. Apparent mortality

The apparent mortality of BPH was minimum (9.26) at 28.3^{o}C and maximum (40.31) at 34.3^{o}C for egg stage. When the nymphal stages were examined, it was found that the highest mortality (32.31) was recorded at 34.3^{o}C for fourth nymphal stage and lowest (10.97) was recorded at 32.7°C for second nymphal stage (Table 24-27).

Figure 6. Survivorship curves of BPH at different temperature regimes

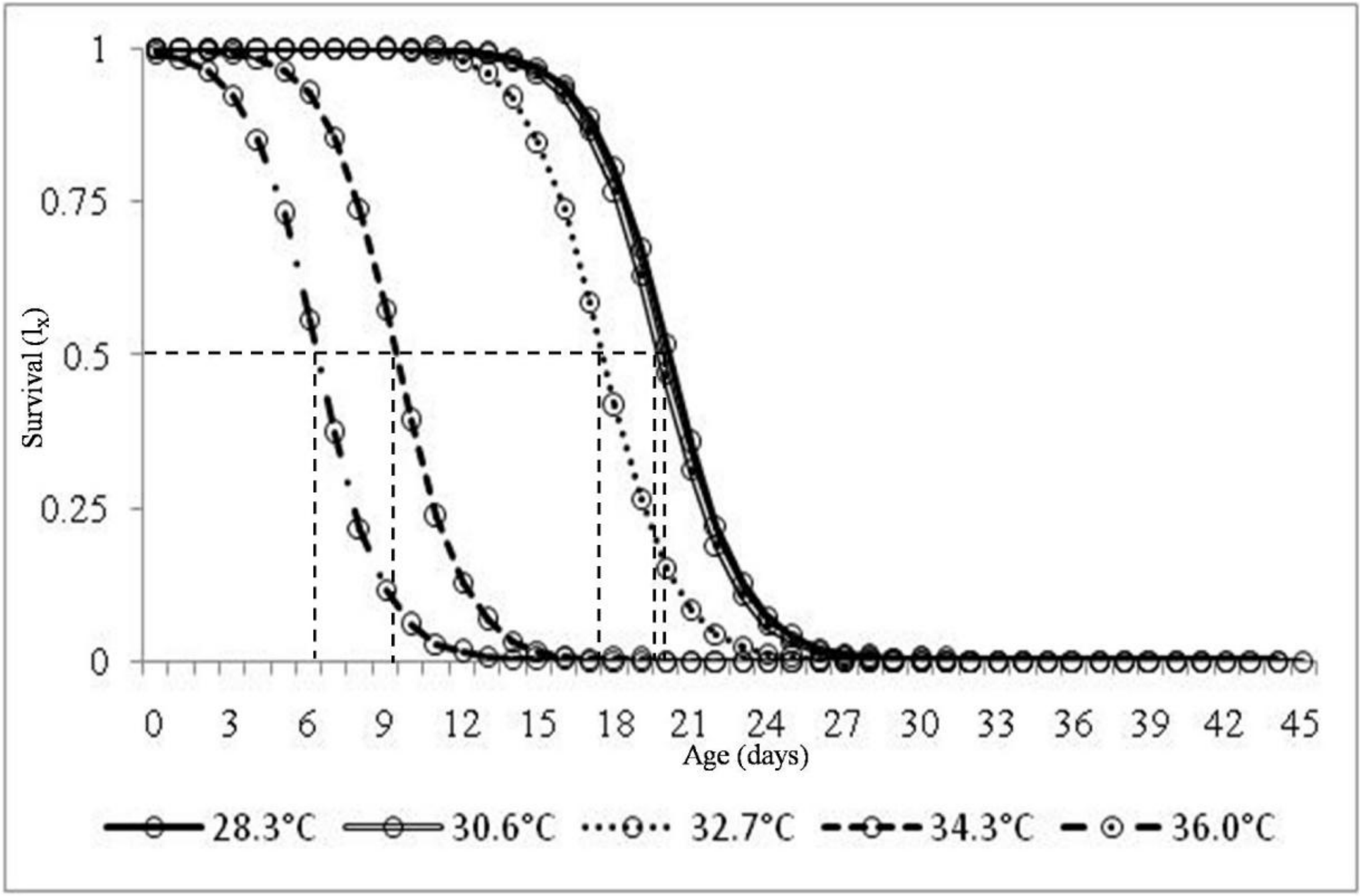


Table 24. Stage specific life table of BPH at 28.3^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	216	20	100	0.91	9.26	0.10	6.22	0.0422
Nymph I	196	32	90.7	0.84	16.33	0.20	11.90	0.0774
Nymph II	164	31	75.9	0.81	18.90	0.23	14.22	0.0910
Nymph III	133	24	61.6	0.82	18.05	0.22	13.43	0.0864
Nymph IV	109	27	50.5	0.75	24.77	0.33	20.09	0.1236
Nymph V	82	21	38.0	0.74	25.61	0.34	21.00	0.1285
Adult	61	61	28.2	-	100.00	-	-	-
Average								0.0915

Table 25. Stage specific life table of BPH at 30.6^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	231	28	100	0.88	12.12	0.14	7.03	0.0561
Nymph I	203	34	87.9	0.83	16.75	0.20	10.26	0.0796
Nymph II	169	23	73.2	0.86	13.61	0.16	8.03	0.0635
Nymph III	146	32	63.2	0.78	21.92	0.28	14.32	0.1075
Nymph IV	114	38	49.4	0.67	33.33	0.50	25.50	0.1761
Nymph V	76	25	32.9	0.67	32.89	0.49	25.00	0.1732
Adult	51	51	22.1	-	100.00	-	-	-
Average								0.1093

Table 26. Stage specific life table of BPH at 32.7^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	226	43	100	0.81	19.03	0.23	13.86	0.0917
Nymph I	183	28	81.0	0.85	15.30	0.18	10.66	0.0721
Nymph II	155	17	68.6	0.89	10.97	0.12	7.27	0.0505
Nymph III	138	29	61.1	0.79	21.01	0.27	15.70	0.1025
Nymph IV	109	31	48.2	0.72	28.44	0.40	23.45	0.1453
Nymph V	78	19	34.5	0.76	24.36	0.32	19.00	0.1212
Adult	59	59	26.1	-	100.00	-	-	-
Average								0.0972

Table 27. Stage specific life table of BPH at 34.3^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	196	79	100	0.60	40.31	0.68	20.26	0.2241
Nymph I	117	21	59.7	0.82	17.95	0.22	6.56	0.0859
Nymph II	96	14	49.0	0.85	14.58	0.17	5.12	0.0685
Nymph III	82	17	41.8	0.79	20.73	0.26	7.85	0.1009
Nymph IV	65	21	33.2	0.68	32.31	0.48	14.32	0.1695
Nymph V	44	14	22.4	0.68	31.82	0.47	14.00	0.1663
Adult	30	30	15.3	-	100.00	-	-	-
Average								0.1359

4.1.4.2.5. Mortality survivor ratio (MSR)

The mortality survivor ratio for egg stage was observed to be lowest (0.10) at 28.3^{o}C and highest (0.68) at 34.3^{o}C, which indicated that increase in population would be more at higher temperature regimes than at lower temperature regime (Table 24-27). Among all the nymphal stages, MSR was minimum (0.12) at 32.7°C for second nymphal stage and maximum (0.50) at 34.3^{o}C for fourth nymphal stage.

4.1.4.2.6. Indispensable mortality (IM)

For egg stage, the lowest (6.22) IM was recorded at 28.3^{o}C and highest (20.26) at 34.3^{o}C (Table 24-27). Examination of different nymphal stages revealed that the maximum IM (25.5) was recorded at 28.3^{o}C for fourth nymphal stage and minimum (5.12) was recorded at 34.3^{o}C for second nymphal stage. The results revealed that the amount of avoidable mortality can be more at higher temperature regimes.

4.1.4.2.7. K - values

The K value for egg stage was observed to be minimum (0.0422) at 28.3^{o}C and increased with increasing temperatures and reached its maximum (0.2863) at 36^{o}C. Examination of different nymphal stages revealed that the K value was minimum (0.0505) at 32.7°C for second nymphal stage and maximum (0.1871) at 36^{o}C for fifth nymphal stage (Table 24-27). The total generation mortality was minimum (0.0915) at 28.3^{o}C and maximum (0.1584) at 36^{o}C. Observations indicated that the K - values were inversely proportional to the temperature.

4.1.4.2.8. Life expectancy (e_x)

The data of life expectancy at different age class revealed that it decreased at the initial stage and then increased slightly at all the temperature regimes. The life expectancy started decreasing steadily with the progress of age. The life expectancy observed was 20.6 days at 30.6^{o}C and but was only 10.51 days at 36^{o}C (Table 28).

4.1.4.2.9. Fecundity

In BPH, the pre-oviposition period decreased considerably with increasing temperatures. It was observed to be five days at 28.3^{o}C, but only 2 days at 36^{o}C. There was a decrease in the oviposition period when the temperature increased. The oviposition period was 12 days at 28.3^{o}C and 30.6^{o}C and 11 days at the remaining temperature regimes. It indicated that the adults at higher temperature started laying their eggs earlier and completed the egg laying earlier, than the insects reared at lower temperature regimes (Table 19-23). Age of first and last oviposition was observed to be 32nd and 43rd day respectively, at 28.3°C. At 36°C, they were recorded on 21st and 31st day, respectively (Table 28). The Gross reproductive rate decreased at the higher temperature regimes. Total number of eggs recorded was more (233) at 30.6°C and less (116) at 36.0°C (Figure 7). It was also noted that the 50 per cent fecundity in BPH was recorded on 36th day after incubation at 28.3°C, whereas it was observed on 24.3 days itself when the BPH was reared at 36°C (Figure 8).

4.1.4.2.10. Net reproductive rate (R_o)

The net reproductive rate of BPH was observed to be higher at lower temperature regimes (28.3°C and 30.6°C) of the experiment and lesser at higher temperature regimes. The highest R_o of 39.95 females/female was recorded at 30.6°C followed by 36.02 females/female at 28.3°C and the lowest R_o of 8.84 female/female was recorded at 36°C followed by 16.33 females/female at 34.3°C (Table 28).

4.1.4.2.11. Intrinsic rate of natural increase (r_m)

The intrinsic rate of natural increase (r_m) increased with increasing temperatures. It was 0.1091/day at 34.3°C, whereas it was 0.1011/day at 28.3°C. However, the increase in r_m has a turnaround after 34.3°C and hence at 36°C, r_m has been reduced to 0.09353/day (Table 28).

4.1.4.2.12. Finite rate of increase (λ)

The finite rate of increase (λ) increased with increasing temperatures. It was 1.1153/day at 34.3°C, whereas it was 1.1064/day at 28.3°C. Even though, the **λ** was increased with increasing temperature, a turnaround was noticed in **λ** after 34.3°C and hence at 36°C **λ** has been reduced to 1.09804/day (Table 28).

4.1.4.2.13. Mean generation time (T)

The mean generation time was observed to be decreased with increasing temperatures. The BPH took 35.46 days to complete the generation at 28.3°C, whereas it took only 23.30 days at 36°C (Table 28).

4.1.4.2.14. Doubling time (t)

The doubling time required by BPH to double its population decreased with increasing temperatures. BPH took as long as 6.86 days for doubling the population at 28.3°C, whereas it took only 6.35 days at 34.3°C. However, the decrease in doubling time has a shift after 34.3°C and hence it has been increased to 7.41 days at 36°C (Table 28).

Figure 7. Cumulative fecundity of BPH at different temperature regimes

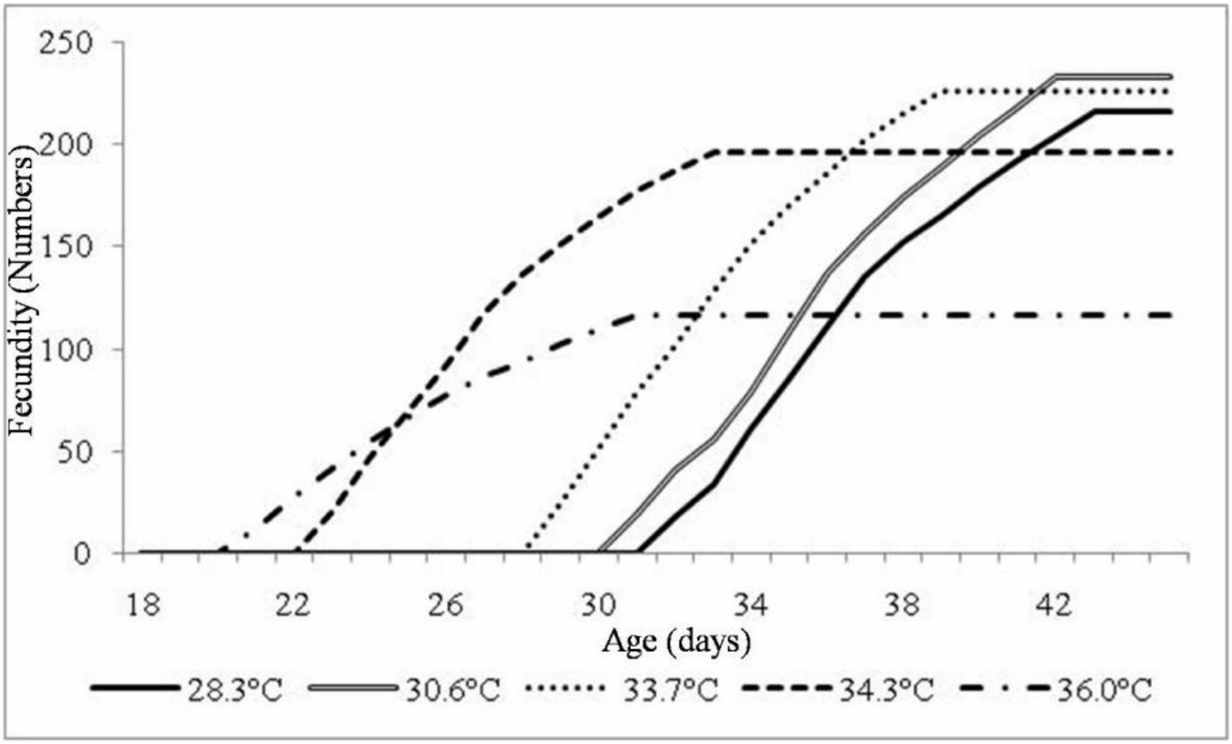


Figure 8. Per cent cumulative fecundity of BPH at different temperature regimes

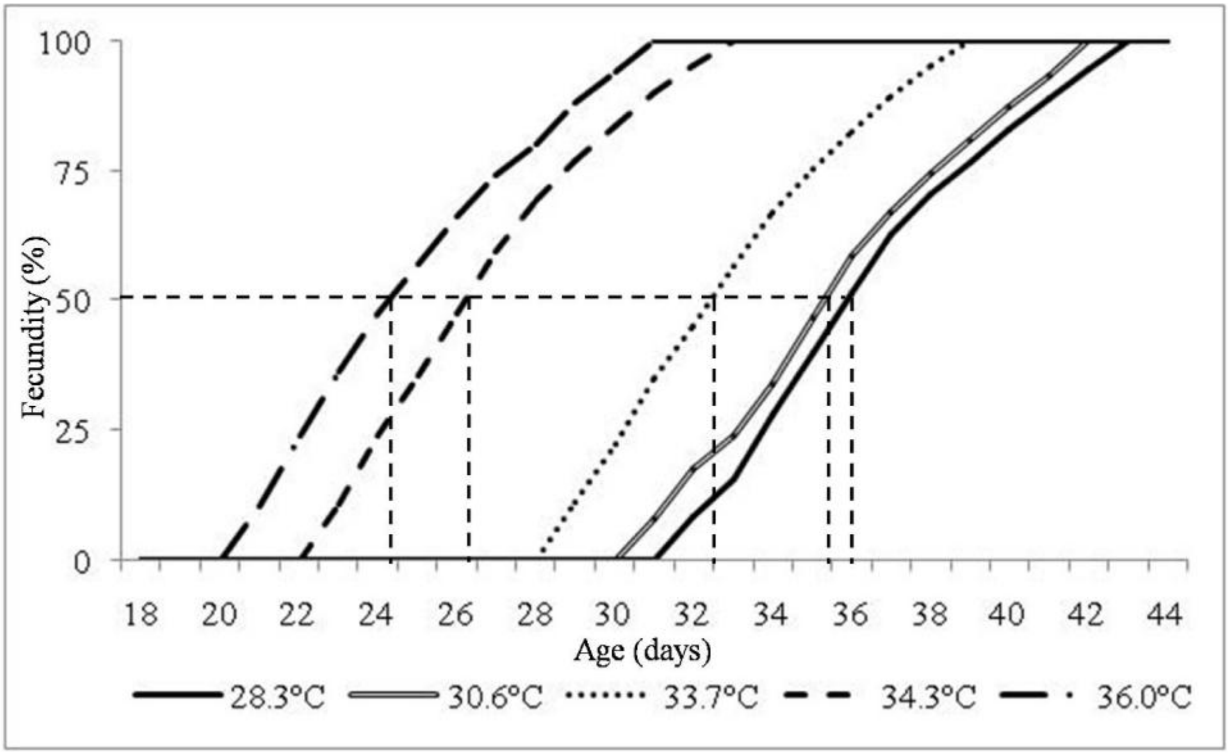


Table 28. Life table parameters of BPH at different temperature regimes

Parameter	**28.3°C**	**30.6°C**	**32.7°C**	**34.3°C**	**36.0°C**
Life expectancy (e_x) (days)	19.14	20.60	18.48	12.30	10.51
Age of first oviposition (day)	32	31	29	23	21
Age of 50 % oviposition (day)	36	35.4	32.5	26.3	24.3
Age of last oviposition (day)	43	42	39	33	31
Age of maximum oviposition (day)	35	35	31	24	22
Length Oviposition (days)	12	12	11	11	11
Net Reproductive rate (R_o) (females/female)	36.02	39.95	32.03	16.33	8.84
Intrinsic rate of natural increase (r_m) (day^{-1})	0.1011	0.1062	0.1083	0.1091	0.09353
Finite rate of increase (λ) (day^{-1})	1.1064	1.1121	1.1144	1.1153	1.09804
Mean generation time (T) (days)	35.46	34.72	32.00	25.59	23.30
Doubling time (t) (days)	6.86	6.53	6.40	6.35	7.41

4.1.4.3. Rice Leaffolder (RLF)

The constructed age specific life table of RLF revealed that, it took 36 days to complete the generation at 28.3°C, whereas it took only 27 days at 36°C (Table 29-33). Total time taken for completing the life cycle was decreased with increasing temperatures.

4.1.4.3.1. Survivorship (l_x)

The graphical relationship between of survival and age of RLF indicated that it belongs to type III survivorship curve (Figure 9). It was also understood that the number survivors decreased gradually with progress of time irrespective of the temperature regimes. The curve also revealed that the insects reared under higher temperature regimes subjected to higher mortality when compared to the lower temperature regimes as the survival curve dipped steeply at the start for the higher temperature regimes. The data on mortality revealed that 50 per cent mortality was observed on 15.4 days after incubation at 30.6°C, whereas the same was recorded as early as on 5.5 days after incubation at 36°C. Using the Doesn't Use Derivative (DUD) method, survivorship curves of different temperature were smoothened. Parameters (a and b) of the smoothened curves of different temperature regimes are given in Table 34.

Table 29. Age specific life table of RLF at 28.3°C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0.13			157	2387	15.20			
5	0.87	0.87	0.10			139	2230	16.04			
6	0.79	0.90	0.05			128.5	2091	16.27			
7	0.74	0.95	0.05			122	1962.5	16.09			
8	0.71	0.95	0.09			113.5	1840.5	16.22			
9	0.64	0.91	0.08			103.5	1727	16.69			
10	0.59	0.92	0.04			97	1623.5	16.74			
11	0.57	0.96	0.09			90.5	1526.5	16.87			
12	0.51	0.91	0.06			83.5	1436	17.20			
13	0.48	0.94	0.02			80	1352.5	16.91			
14	0.47	0.98	0.04			77.5	1272.5	16.42			
15	0.45	0.96	0.03			75	1195	15.93			
16	0.44	0.97	0.04			72.5	1120	15.45			
17	0.42	0.96	0.07			68.5	1047.5	15.29			
18	0.39	0.93	0.05			64.5	979	15.18			
19	0.38	0.95	0.05			61.5	914.5	14.87			
20	0.36	0.95	0.02			59.5	853	14.34			
21	0.35	0.98	0.03			58	793.5	13.68			
22	0.34	0.97	0.02			56.5	735.5	13.02			
23	0.33	0.98	0.02			55.5	679	12.23			
24	0.33	0.98	0.00			55	623.5	11.34			
25	0.33	1.00	0.00			55	568.5	10.34			
26	0.33	1.00	0.00			55	513.5	9.34			
27	0.33	1.00	0.00			55	458.5	8.34			

28	0.33	1.00	0.00			55	403.5	7.34			
29	0.33	1.00	0.00			55	348.5	6.34			
30	0.33	1.00	0.11			52	293.5	5.64			
31	0.29	0.89	0.14	0	0	45.5	241.5	5.31	0	0	
32	0.25	0.86	0.07	0	0	40.5	196	4.84	0	0	
33	0.23	0.93	0.05	0	0	38	155.5	4.09	0	0	
34	0.22	0.95	0.08	0	0	35.5	117.5	3.31	0	0	
35	0.20	0.92	0.09	1265	37.21	32.5	82	2.52	7.53	263.54	0.090161
36	0.18	0.91	0.26	1412	45.55	27	49.5	1.83	8.40	302.57	0.090158
37	0.14	0.74	0.52	1002	43.57	17	22.5	1.32	5.96	220.68	0.090154
38	0.07	0.48	1.00	721	65.55	5.5	5.5	1.00	4.29	163.08	0.090151
39	0.00	0.00									
Total					191.9				26.2	949.9	

Table 30. Age specific life table of RLF at 30.6^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0								
4	1	1	0.14			145	2306	15.90			
5	0.86	0.86	0.10			127.5	2161	16.95			
6	0.78	0.90	0.07			116.5	2033.5	17.45			
7	0.72	0.93	0.04			109.5	1917	17.51			
8	0.69	0.96	0.07			103	1807.5	17.55			
9	0.63	0.93	0.06			96	1704.5	17.76			
10	0.60	0.94	0.04			91	1608.5	17.68			
11	0.57	0.96	0.02			88	1517.5	17.24			
12	0.56	0.98	0.01			86.5	1429.5	16.53			
13	0.55	0.99	0.05			84	1343	15.99			
14	0.53	0.95	0.02			81	1259	15.54			
15	0.51	0.98	0.06			77.5	1178	15.20			
16	0.48	0.94	0.04			73.5	1100.5	14.97			
17	0.46	0.96	0.04			70.5	1027	14.57			
18	0.44	0.96	0.01			68.5	956.5	13.96			
19	0.44	0.99	0.00			68	888	13.06			
20	0.44	1.00	0.03			67	820	12.24			
21	0.42	0.97	0.03			65	753	11.58			
22	0.41	0.97	0.03			63	688	10.92			
23	0.40	0.97	0.00			62	625	10.08			
24	0.40	1.00	0.00			62	563	9.08			
25	0.40	1.00	0.00			62	501	8.08			
26	0.40	1.00	0.00			62	439	7.08			
27	0.40	1.00	0.00			62	377	6.08			

28	0.40	1.00	0.13			58	315	5.43			
29	0.35	0.87	0.09	0	0	51.5	257	4.99	0	0	
30	0.31	0.91	0.08	0	0	47	205.5	4.37	0	0	
31	0.29	0.92	0.09	0	0	43	158.5	3.69	0	0	
32	0.26	0.91	0.12	0	0	38.5	115.5	3.00	0	0	
33	0.23	0.88	0.19	1324	36.78	32.5	77	2.37	8.49	280.08	0.09848
34	0.19	0.81	0.28	1398	48.21	25	44.5	1.78	8.96	304.69	0.09847
35	0.13	0.72	0.57	1046	49.81	15	19.5	1.30	6.71	234.68	0.09847
36	0.06	0.43	1.00	768	85.33	4.5	4.5	1.00	4.92	177.23	0.09846
37	0.00	0.00									
Total					220.1				29.1	996.7	

Table 31. Age specific life table of RLF at 32.7^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0.26			150.5	1564.5	10.40			
4	0.74	0.74	0.12			120.5	1414	11.73			
5	0.65	0.88	0.10			107.5	1293.5	12.03			
6	0.59	0.90	0.14			95	1186	12.48			
7	0.51	0.86	0.10			83.5	1091	13.07			
8	0.46	0.90	0.10			75	1007.5	13.43			
9	0.41	0.90	0.03			70	932.5	13.32			
10	0.40	0.97	0.06			67	862.5	12.87			
11	0.38	0.94	0.08			62.5	795.5	12.73			
12	0.35	0.92	0.08			57.5	733	12.75			
13	0.32	0.92	0.04			54	675.5	12.51			
14	0.31	0.96	0.06			51.5	621.5	12.07			
15	0.29	0.94	0.08			48	570	11.88			
16	0.27	0.92	0.04			45	522	11.60			
17	0.25	0.96	0.07			42.5	477	11.22			
18	0.24	0.93	0.07			39.5	434.5	11.00			
19	0.22	0.93	0.03			37.5	395	10.53			
20	0.21	0.97	0.03			36.5	357.5	9.79			
21	0.21	0.97	0.06			35	321	9.17			
22	0.20	0.94	0.03			33.5	286	8.54			
23	0.19	0.97	0.03			32.5	252.5	7.77			
24	0.18	0.97	0.00			32	220	6.88			
25	0.18	1.00	0.03			31.5	188	5.97			
26	0.18	0.97	0.06	0	0	30	156.5	5.22	0	0	
27	0.17	0.94	0.03	0	0	28.5	126.5	4.44	0	0	

28	0.16	0.97	0.07	0	0	27	98	3.63	0	0	
29	0.15	0.93	0.08	998	38.38	25	71	2.84	5.77	167.29	0.09969
30	0.14	0.92	0.13	1002	41.75	22.5	46	2.04	5.79	173.76	0.09969
31	0.12	0.88	0.38	876	41.71	17	23.5	1.38	5.06	156.97	0.09968
32	0.08	0.62	1.00	665	51.15	6.5	6.5	1.00	3.84	123.01	0.09968
33	0.00	0.00									
Total					173				20.5	612.0	

Table 32. Age specific life table of RLF at 34.3°C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0.34			150	1241.5	8.28			
4	0.66	0.66	0.14			110.5	1091.5	9.88			
5	0.56	0.86	0.15			94.5	981	10.38			
6	0.48	0.85	0.15			80.5	886.5	11.01			
7	0.41	0.85	0.08			71	806	11.35			
8	0.38	0.92	0.07			65.5	735	11.22			
9	0.35	0.93	0.06			61	669.5	10.98			
10	0.33	0.94	0.03			58	608.5	10.49			
11	0.31	0.97	0.05			55.5	550.5	9.92			
12	0.30	0.95	0.04			53	495	9.34			
13	0.29	0.96	0.08			50	442	8.84			
14	0.27	0.92	0.13			45	392	8.71			
15	0.23	0.88	0.12			39.5	347	8.78			
16	0.20	0.88	0.08			35.5	307.5	8.66			
17	0.19	0.92	0.00			34	272	8.00			
18	0.19	1.00	0.00			34	238	7.00			
19	0.19	1.00	0.00			34	204	6.00			
20	0.19	1.00	0.00			34	170	5.00			
21	0.19	1.00	0.32			28.5	136	4.77			
22	0.13	0.68	0.09	0	0	22	107.5	4.89	0	0	
23	0.12	0.91	0.05	0	0	20.5	85.5	4.17	0	0	
24	0.11	0.95	0.10	687	34.35	19	65	3.42	3.80	91.09	0.1014
25	0.10	0.90	0.17	678	37.67	16.5	46	2.79	3.75	93.65	0.1014
26	0.08	0.83	0.07	543	36.20	14.5	29.5	2.03	3.00	78.00	0.1013
27	0.08	0.93	0.43	302	21.57	11	15	1.36	1.67	45.05	0.1013
28	0.04	0.57	1.00	143	17.88	4	4	1.00	0.79	22.12	0.1013
29	0.00	0.00									
Total					147.7				13.0	329.9	

Table 33. Age specific life table of RLF at 36.0^{o}C

x	l_x	s_x	q_x	mn_x	m_x	L_x	T_x	e_x	l_xm_x	xl_xm_x	r_m
0	1	1	0								
1	1	1	0								
2	1	1	0								
3	1	1	0.39			117.5	915	7.79			
4	0.61	0.61	0.12			83.5	797.5	9.55			
5	0.53	0.88	0.10			74	714	9.65			
6	0.48	0.90	0.09			67	640	9.55			
7	0.44	0.91	0.08			61.5	573	9.32			
8	0.40	0.92	0.07			57	511.5	8.97			
9	0.38	0.93	0.11			52	454.5	8.74			
10	0.34	0.89	0.06			47.5	402.5	8.47			
11	0.32	0.94	0.11			43.5	355	8.16			
12	0.28	0.89	0.15			38	311.5	8.20			
13	0.24	0.85	0.11			33	273.5	8.29			
14	0.21	0.89	0.13			29	240.5	8.29			
15	0.18	0.87	0.11			25.5	211.5	8.29			
16	0.16	0.89	0.08			23	186	8.09			
17	0.15	0.92	0.00			22	163	7.41			
18	0.15	1.00	0.00			22	141	6.41			
19	0.15	1.00	0.00			22	119	5.41			
20	0.15	1.00	0.00			22	97	4.41			
21	0.15	1.00	0.32			18.5	75	4.05			
22	0.10	0.68	0.07	0	0	14.5	56.5	3.90	0	0	
23	0.10	0.93	0.00	0	0	14	42	3.00	0	0	
24	0.10	1.00	0.21	269	19.21	12.5	28	2.24	1.84	44.22	0.07069
25	0.08	0.79	0.36	287	26.09	9	15.5	1.72	1.97	49.14	0.07069
26	0.05	0.64	0.57	210	30.00	5	6.5	1.30	1.44	37.40	0.07068
27	0.02	0.43	1.00	96	32.00	1.5	1.5	1.00	0.66	17.75	0.07068
28	0.00	0.00									
Total					107.3				5.9	148.5	

Table 34. Response of survival of RLF at different temperature regimes

Temperature regimes	'a' (50 % mortality)	'b' (Intercept)	r^2 Value
28.3°C	12.4	1.294	0.914
30.6°C	15.4	1.282	0.888
32.7°C	7.1	1.201	0.942
34.3°C	5.8	1.194	0.932
36.0°C	5.5	1.207	0.935

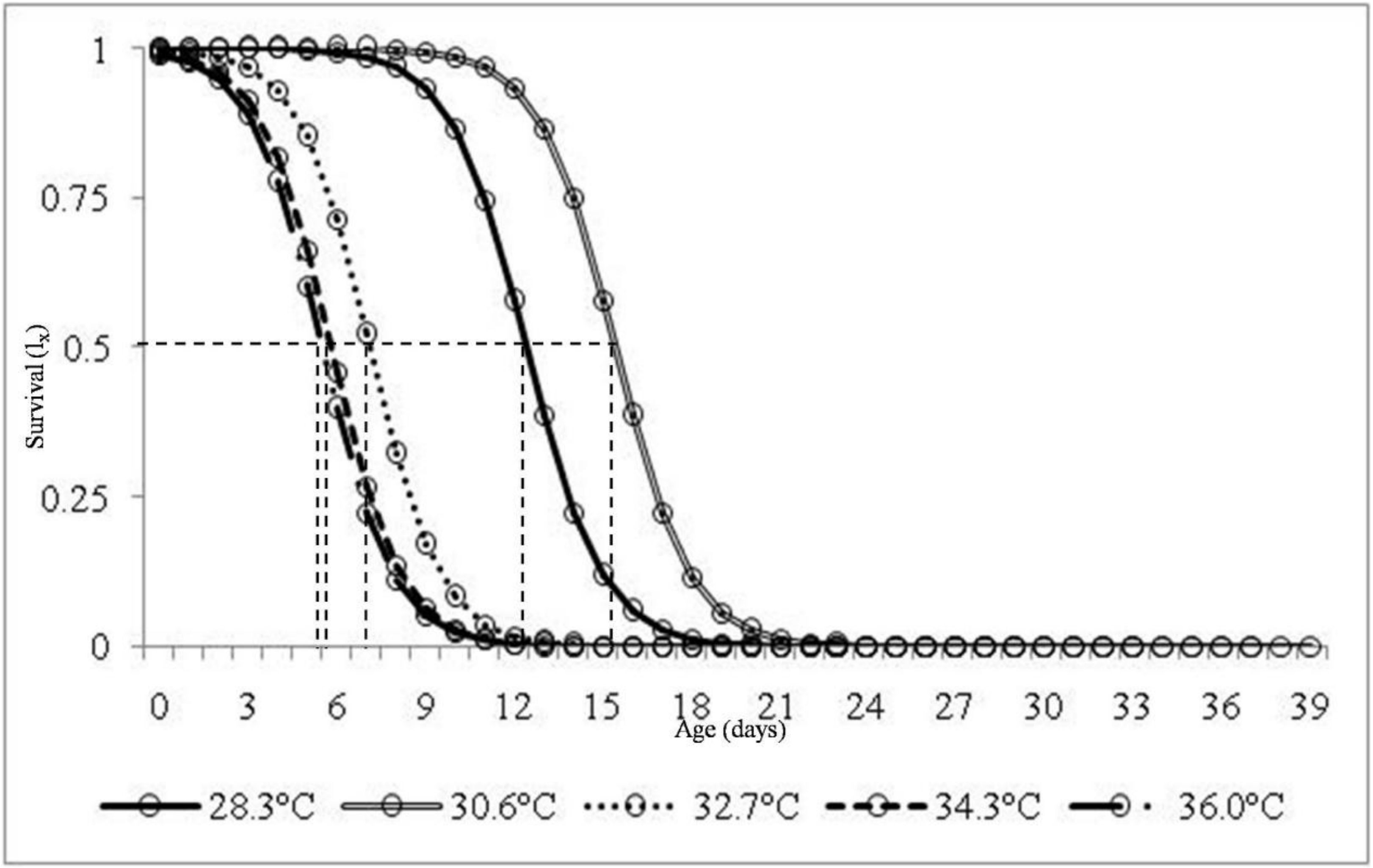
4.1.4.3.2. Survival proportion

In general, the number of newly emerged larvae from eggs decreased considerably with increasing temperature. At 28.3°C, 86.9 per cent of eggs entered into first instar stage, whereas it was only 65.7 per cent at 34.3°C (Table 35-38). It was observed that 39.7 and 18.8 per cent of eggs entered into pupal stage at 28.3°C and 34.3°C, respectively. The highest per cent of adults (34.6) was recorded at 30.6°C but at the same time only 12.7 per cent of eggs successfully became adults at 34.3°C. As a whole, the per cent of mortality was increased with increasing temperature.

4.1.4.3.3. Survival fraction (S_x)

Generally, the survival fraction was observed to be decreasing with increasing temperatures, which indicated that the more successful development was observed at lower temperature regimes. At egg stage, survival fraction was higher (0.87) at 28.3°C and lower (0.66) at 34.3°C (Table 35-38). Among the different larval instars, highest (0.90) survival fraction was recorded at 30.6°C for fifth instar and the lowest (0.71) was recorded at 34.3°C for fourth instar. At pupal stage, the highest (0.89) survival fraction was recorded at 28.3°C and lowest (0.68) was observed at 34.3°C.

Figure 9. Survivorship curves of RLF at different temperature regimes



4.1.4.3.4. Apparent mortality

The apparent mortality increased with increasing temperatures (Table 35-38). The lowest (13.10) apparent mortality for egg stage was observed at 28.3°C, whereas it was highest (34.25) at 36°C. When the comparison was made between larval instars, it showed that the lowest (10.14) apparent mortality was observed at 30.6°C for fifth instar larva and the highest (29.17) was recorded at 34.3°C for the same. The apparent mortality for pupal stage was observed to be lowest (10.91) at 28.3°C and highest (32.35) at 34.3°C.

4.1.4.3.5. Mortality survivor ratio (MSR)

MSR for egg stage was minimum (0.15) at 28.3°C and maximum (0.52) at 36°C. When the larval stages were examined, it revealed that the lowest (0.11) MSR was observed at 30.6°C for second instar and highest (0.41) at 34.3°C for fifth instar. At pupal stage, the lower (0.12) MSR ratio was observed at 28.3°C and highest (0.48) MSR was observed at 34.3°C (Table 35-38). The results revealed that the population increase would be more at higher temperature regimes as the MSR was remained higher at higher temperature regimes.

4.1.4.3.6. Indispensable mortality (IM)

IM at egg stage was lower (7.38) at 28.3°C and higher (11.38) at 34.3°C which indicated that the avoidable mortality was more at higher temperature, if the factor causing mortality was not allowed to operate. Among the larval stages, the IM was recorded lower (4.31) at 34.3°C for fourth instar and higher (12.38) at 28.3°C for second instar larva. The higher (11.00) IM was recorded for pupal stage at 34.3°C and lower (6.00) was recorded at both 28.3°C and 32.7°C (Table 35-38).

4.1.4.3.7..K-value

Generally, K - values increased with increasing temperature. The K value for egg stage was recorded lower (0.0610) at 28.3°C and higher (0.2150) at 36°C. During the larval instars, the lowest (0.0547) K value was recorded at 30.6°C for third instar and highest (0.1714) at 36°C for fourth instar. At pupal stage, higher (0.1698) K value was recorded at 34.3°C and lower (0.0502) was observed at 28.3°C (Table 35-38).

Table 35. Stage specific life table of RLF at 28.3°C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality / survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	168	22	100	0.87	13.10	0.15	7.38	0.0610
1st Instar	146	27	86.9	0.82	18.49	0.23	11.12	0.0888
2nd Instar	119	24	70.8	0.80	20.17	0.25	12.38	0.0978
3rd Instar	95	19	56.5	0.80	20.00	0.25	12.25	0.0969
4th Instar	76	13	45.2	0.83	17.11	0.21	10.11	0.0815
5th Instar	63	8	37.5	0.87	12.70	0.15	7.13	0.0590
Pupa	55	6	32.7	0.89	10.91	0.12	6.00	0.0502
Adult	49	49	29.2	-	100.00	-	-	-
Average								0.0764

Table 36. Stage specific life table of RLF at 30.6°C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality / survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	156	22	100	0.86	14.10	0.16	8.87	0.0660
1st Instar	134	22	85.9	0.84	16.42	0.20	10.61	0.0779
2nd Instar	112	19	71.8	0.83	16.96	0.20	11.03	0.0807
3rd Instar	93	11	59.6	0.88	11.83	0.13	7.24	0.0547
4th Instar	82	13	52.6	0.84	15.85	0.19	10.17	0.0750
5th Instar	69	7	44.2	0.90	10.14	0.11	6.10	0.0465
Pupa	62	8	39.7	0.87	12.90	0.15	8.00	0.0600
Adult	54	54	34.6		100.00			
Average								0.0658

Table 37. Stage specific life table of RLF at 32.7^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality / survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	173	45	100	0.74	26.01	0.35	10.90	0.1308
1st Instar	128	26	74.0	0.80	20.31	0.25	7.90	0.0986
2nd Instar	102	23	59.0	0.77	22.55	0.29	9.03	0.1110
3rd Instar	79	19	45.7	0.76	24.05	0.32	9.82	0.1195
4th Instar	60	14	34.7	0.77	23.33	0.30	9.43	0.1154
5th Instar	46	9	26.6	0.80	19.57	0.24	7.54	0.0946
Pupa	37	6	21.4	0.84	16.22	0.19	6.00	0.0768
Adult	31	31	17.9	-	100.00	-	-	-
Average								0.1067

Table 38. Stage specific life table of RLF at 34.3^{o}C

Stage	Number surviving at each stage (l_x)	Number dying at each stage (d_x)	Survival proportion	Survival fraction (S_x)	Apparent mortality	Morality / survival ratio (MSR)	Indispensable mortality (IM)	K - values
Egg	181	62	100	0.66	34.25	0.52	11.98	0.1821
1st Instar	119	32	65.7	0.73	26.89	0.37	8.46	0.1360
2nd Instar	87	19	48.1	0.78	21.84	0.28	6.43	0.1070
3rd Instar	68	11	37.6	0.84	16.18	0.19	4.44	0.0766
4th Instar	57	9	31.5	0.84	15.79	0.19	4.31	0.0746
5th Instar	48	14	26.5	0.71	29.17	0.41	9.47	0.1498
Pupa	34	11	18.8	0.68	32.35	0.48	11.00	0.1698
Adult	23	23	12.7	-	100.00	-	-	-
Average								0.1280

4.1.4.3.8. Life expectancy (e_x)

The life expectancy of RLF at different age class decreased in the initial period and then slightly increased at all the temperature regimes. After the slight increase, the life expectancy started decreasing steadily. The highest life expectancy of 18.78 days was observed at 30.6^{o}C, whereas the lowest life expectancy of 7.79 days was recorded at 36^{o}C (Table 39). Generally, the life expectancy of RLF was inversely proportional to the increasing temperatures.

4.1.4.3.9. Fecundity

Pre-oviposition period decreased considerably with increasing temperature. Pre-oviposition period was four days at 28.3^{o}C and it was decreased to two days at 36^{o}C (Table 29-33). It indicated that the RLF reared under higher temperature regimes started laying their eggs earlier and also completed the egg laying earlier than the insects reared at lower temperature regimes. The oviposition period was observed to be four days at all the temperature regimes, except 34.3^{o}C where it was observed to be five days (Table 39). The gross reproductive rate of RLF increased with increasing temperature. However, a shift in gross reproductive rate was noticed after 34.3^{o}C and hence it has been reduced to 146 eggs/insect at 36^{o}C (Figure 10). The highest number (181) of eggs per female was recorded at 34.3^{o}C. It was also noted that the 50 per cent fecundity in RLF was recorded on 35.9 days after incubation at 28.3^{o}C, whereas it was observed on 24.8 days itself when RLF was reared at 36^{o}C (Figure 11).

4.1.4.3.10. Net reproductive rate

The net reproductive rate of leaffolder was observed to be higher at the lower temperature regimes and lower when the insects were reared under higher temperature regimes. The highest net reproductive rate of 29.08 females/female was recorded at 30.6^{o}C whereas, the lowest rate of 5.90 females/female was recorded at 36^{o}C (Table 39).

4.1.4.3.11. Intrinsic rate of natural increase (r_m)

Intrinsic rate of natural increase (r_m) increased with increasing temperatures. It was 0.10135/day at 34.3°C, whereas it was only 0.09016/day at 28.3^{o}C. However, a turnaround in r_m was observed after 34.3°C and hence it has been reduced to 0.07069 at 36^{o}C (Table 39).

Figure 10. Cumulative fecundity of RLF at different temperature regimes

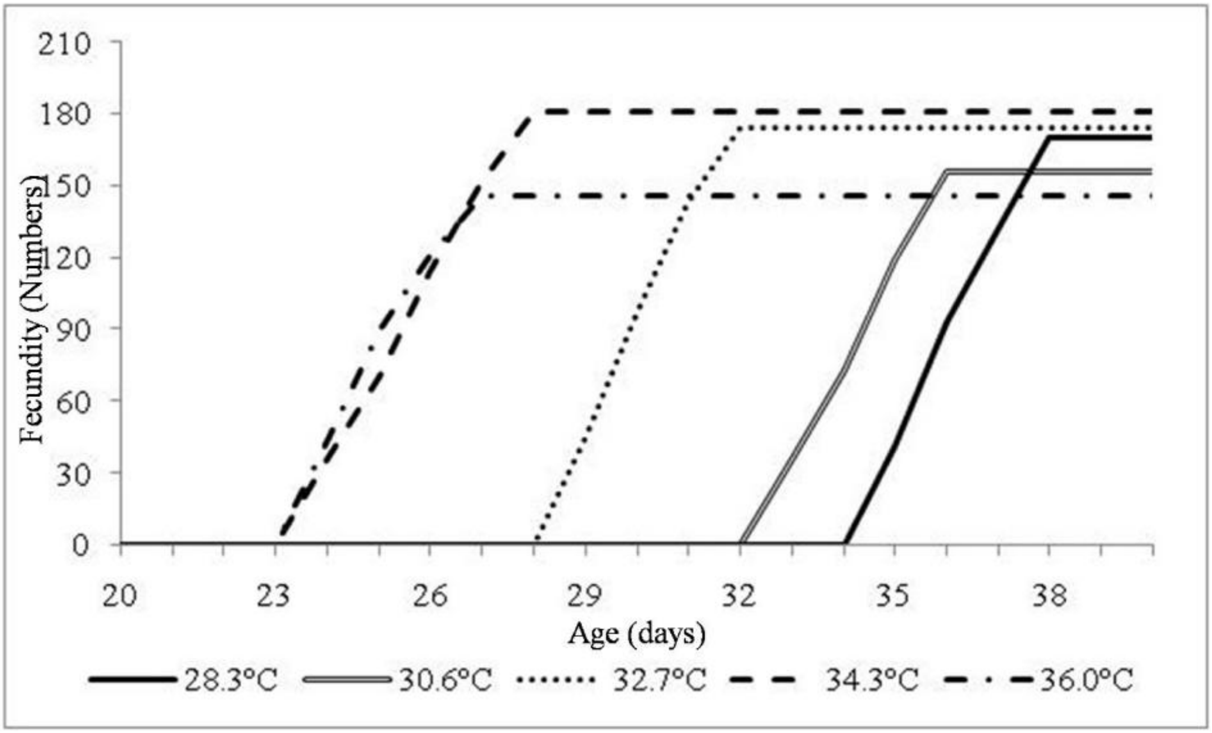
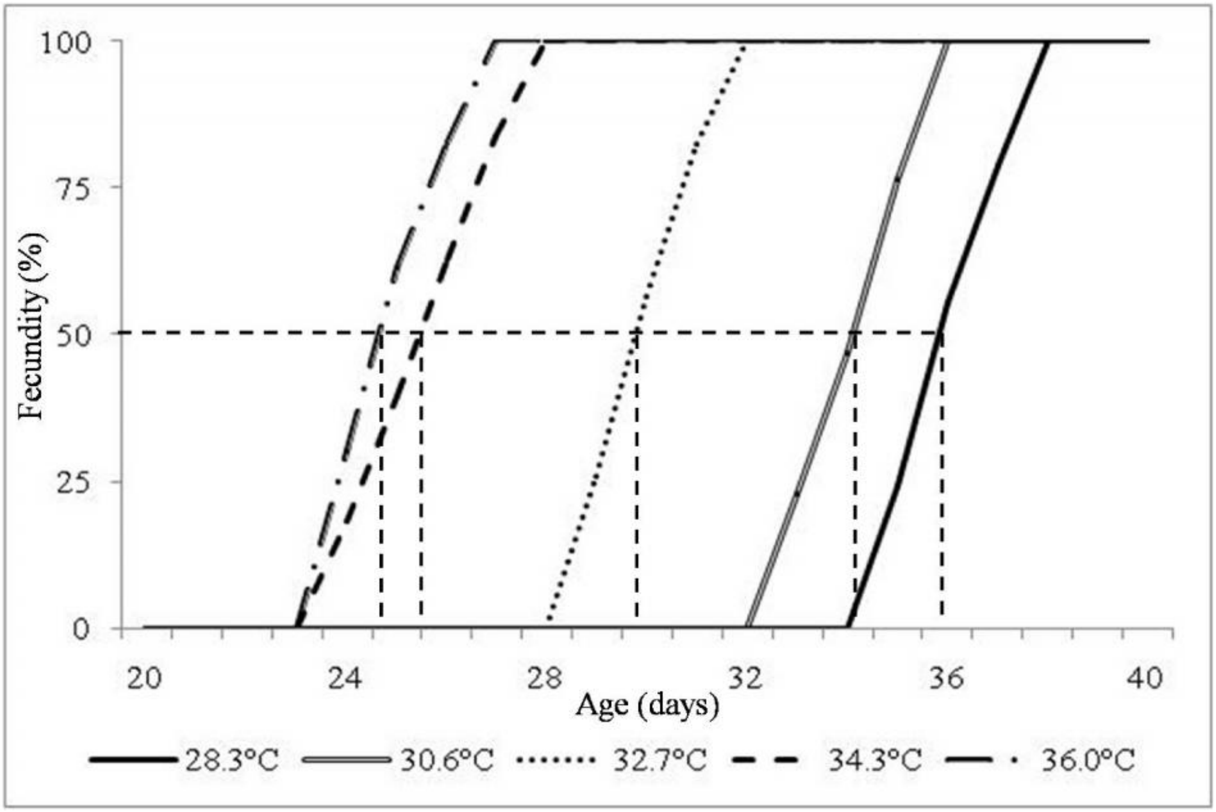


Figure 11. Per cent cumulative fecundity of RLF at different temperature regimes



4.1.4.3.12. Finite rate of increase (λ)

The finite rate of increase was observed to be increasing with increasing temperatures. The finite rate of increase reached its maximum value of 1.10666/day at 34.3^{o}C and it was only 1.09435/day at 28.3^{o}C. However, a shift in λ was observed after the temperature regime of 34.3^{o}C and the λ was reduced to 1.07324/day at 36^{o}C (Table 39).

Table 39. Life table parameters of RLF at different temperature regimes

Parameter	**28.3^{o}C**	**30.6^{o}C**	**32.7^{o}C**	**34.3^{o}C**	**36.0^{o}C**
Life expectancy (e_x) (days)	18.21	18.78	12.04	9.86	9.27
Age of first oviposition (day)	35	33	29	24	24
Age of 50 % oviposition (day)	35.9	34.3	29.8	25.5	24.8
Age of last oviposition (day)	38	36	32	28	27
Age of maximum oviposition (day)	36	35	30	26	25
Length Oviposition (days)	4	4	4	5	4
Net Reproductive rate (R_o) (females/female)	26.19	29.08	20.47	13.00	5.90
Intrinsic rate of natural increase (r_m) (day^{-1})	0.09016	0.09847	0.09969	0.10135	0.07069
Finite rate of increase (λ) (day^{-1})	1.09435	1.10348	1.10482	1.10666	1.07324
Mean generation time (T) (days)	36.22	34.22	30.28	25.31	25.12
Doubling time (t) (days)	7.69	7.04	6.95	6.84	9.81

4.1.4.3.13. Mean generation time (T)

The mean generation time required to complete the life cycle decreased with increasing temperature. The longest mean generation time of 36.22 days was recorded at 28.3^{o}C whereas, the shortest time of 25.12 was observed at 36^{o}C. Almost 11 days of difference in life cycle was observed between the lower and higher temperature regime (Table 39).

4.1.4.3.14. Doubling time (t)

The doubling time decreased with increasing temperatures (Table 39). RLF required only 6.84 days for doubling the population at 34.3°C, whereas it was 7.69 days at 36^{o}C. However, a turnaround was noticed in doubling time when the temperature increased from 34.3°C to 36^{o}C and the doubling time increased to 9.81 days at 36^{o}C.

4.2. Degree day accumulation

Experiments were conducted with different insect pests to determine the degree day requirement for different stages of the insect pests at various temperature regimes. The results of the experiments are described hereunder.

4.2.1. Yellow Stem Borer

The average degree day required to for eggs to emerge into adult was 136.3. The degree day requirement to complete the first, second, third and fourth instar larvae were 133.5, 119.7, 142.8 and 133.5, respectively at 28.3°C. In total, the larva of YSB required 529.6 degree days to complete the development at 28.3°C. At the same time, the requirement of degree days for first, second, third and fourth instar larva was 137.1, 117.5, 163.3 and 143.7, respectively at 36°C. In short, the larvae of YSB required only 561.6 degree days to complete the development at 36°C. Averagely it required 557.8 degree days to complete the larval stage. The pupal stage of the YSB required 151 degree days to emerge into adult at 28.3°C and it emerged as adult when it accumulated 139.2 degree days at 36°C. The average degree days required was 156.3 to complete the pupal stage. The female adult ended its life after the average accumulation of 142.8 degree days and male moth completed its life when it accumulated 101.4 degree days.

4.2.2. Brown Planthopper

BPH eggs required 117 degree days to hatch into larva at 28.3°C with an average of 123.3 degree days to hatch into nymph (Table 41). The average degree days required to complete the first, second, third, fourth and fifth stages of nymphs were 69, 61.2, 44.8, 42.1 and 51.9. In total, the nymphal stage must accumulate 269 degree days to become adult. The female adult of BPH died after accumulating 244.2 degree days and the male adult of BPH accumulated 178 degree days before ending its life.

4.2.3. Rice Leaffolder

RLF eggs required 96.1 degree days to hatch into larva at 28.3°C and average of 98.1 degree days to hatch into larva (Table 41). The average degree days required to complete the first, second, third, fourth and fifth larval instars were 46.3, 51.5, 80.4, 76.5 and 89.2. In total, the larval stage must accumulate 344 degree days to become adult. The female adult of RLF died after accumulating 159 degree days and the male adult accumulated 82.8 degree days before ending its life.

Table 40. Accumulated degree days for YSB at different temperature regimes

	Degree days (days)					
Stage	**28.3^{o}C**	**30.6^{o}C**	**32.7^{o}C**	**34.3^{o}C**	**36.0^{o}C**	**Average**
Egg	134.1	140.1	136.2	136.1	135.0	136.3
Larva						
1st Instar	133.5	139.9	148.3	122.1	137.1	136.2
2nd Instar	119.7	114.0	125.5	122.1	117.5	119.8
3rd Instar	142.8	155.4	159.7	164.8	163.3	157.2
4th Instar	133.5	145.0	148.3	152.6	143.7	144.6
Total Larval stage	529.6	554.3	581.9	561.7	561.6	557.8
Pupa	151.0	162.6	165.6	163.3	139.2	156.3
Adult Female	132.7	144.2	141.9	145.8	149.5	142.8
Adult Male	96.1	108.2	107.8	97.2	97.5	101.4

Table 41. Accumulated degree days for BPH at different temperature regimes

	Degree days (days)					
Stage	**28.3°C**	**30.6°C**	**32.7°C**	**34.3°C**	**36.0°C**	**Average**
Egg	117.0	123.6	134.7	121.1	120.3	123.3
Nymph						
Nymph I	64.3	71.3	67.3	73.3	69.0	69.0
Nymph II	57.5	59.4	67.3	63.5	58.4	61.2
Nymph III	44.0	43.6	44.9	44.0	47.8	44.8
Nymph IV	37.2	47.5	44.9	44.0	37.2	42.1
Nymph V	47.4	51.5	53.8	53.7	53.1	51.9
Total Nymphal stage	250.5	273.2	278.1	278.4	265.5	269.1
Female Adult	225.4	245.4	247.1	247.7	255.6	244.2
Male Adult	163.6	183.1	180.1	192.7	170.4	178.0

Table 42. Accumulated degree days for RLF at different temperature regimes

	Degree days (days)					
Stage	**28.3^{o}C**	**30.6^{o}C**	**32.7^{o}C**	**34.3^{o}C**	**36.0^{o}C**	**Average**
Egg	96.1	103.0	96.5	97.2	97.5	98.1
Larval stages						
1st Instar	45.8	46.4	45.4	48.6	45.5	46.3
2nd Instar	54.9	51.5	51.1	54.7	45.5	51.5
3rd Instar	77.8	87.6	79.5	79.0	78.0	80.4
4th Instar	68.6	77.3	79.5	72.9	84.5	76.5
5th Instar	86.9	92.7	96.5	79.0	91.0	89.2
Total Larval stage	334.0	355.4	351.9	334.1	344.5	344.0
Pupa	132.7	128.8	130.5	127.6	123.5	128.6
Female Adult	151.0	159.7	164.6	164.0	156.0	159.0
Male Adult	77.8	87.6	85.1	79.0	84.5	82.8

4.3. Weather pest relationships

Weekly surveillance data of YSB, BPH and RLF were collected for cauvery delta region from Directorate of Rice Research annual progress report for the period of 19 years from 1992 to 2010. The weekly data were examined for the quality and availability of the data. The examination revealed that there were extreme values (Table 43) in the data of all the three insects. However, the median of weekly surveillance data were only 70, 68 and 14 for YSB, BPH and RLF, respectively. After data quality check the extreme values were dispersed randomly in the weekly insect surveillance data and did not represent or hint a trend. The extreme values were defined as outliers or noise as it did not follow any trend.

Table 43. Basic statistics of weekly surveillance data

Insect	Available data (No. of weeks)	Number of insects captured		
		Minimum	Maximum	Median
YSB	562	0	27900	70
BPH	563	0	1582610	68
RLF	419	0	507	14

Based on the 95th percentile of the weighted mean weekly surveillance data was truncated in order to curtail noise the in data for all the three insects. The cut off for the number of captures was 900 and 140 for YSB and RLF, respectively (Table 44). Weekly surveillance data that has more number of captures than the ‘cut off’ figure was marked as missing. For BPH the cut off was determined to be mean +2SD upward and which happened to be 4200 per week. The data which was more than 4200 was removed from the surveillance data as it was considered as outliers.

Table 44. Percentiles of weekly surveillance data of YSB, BPH and RLF

Insects	**Insect capture percentiles**				
	25	**50**	**75**	**90**	**95**
YSB	27	58	142	416.6	918.25
BPH	6	56.5	261.75	1336.1	4256.75
RLF	1	14	43	88	143.5

As a result of the above statistical procedures, the number of observations removed from the weekly data was 28, 22 and 24 weeks in YSB, BPH and RLF surveillance data. The removed outliers were marked as missing and replaced with mean values from 10 values nearby so not to lose the quantity of data available for the statistical analysis. Thus, after truncation and missing value management the available surveillance data is presented in the following Table. 45.

Table 45. Availability of surveillance data after missing value management

Insect	Number of weeks available	Minimum	Maximum	Mean number of insects captured
YSB	564	0	859	119.3
BPH	419	0	135	24.5
RLF	564	0	4055	248.2

4.3.1. Effect of weather on insect surveillance data

A simple correlation between the weather parameters (maximum, minimum temperature, relative humidity, rainfall and sunshine hours of current week, one and two weeks before) and light trap catches of YSB, BPH and RLF. The results revealed that the light trap catches of YSB, BPH and RLF was significantly negatively correlated with the maximum and minimum temperature of current, one and two weeks before (Table 46). At the same time relative humidity of current, one and two weeks before had a significant positive correlation with light trap catches of YSB, BPH and RLF. Rainfall (current, one and two weeks before) also had the positive correlation with the light trap catches of all the pests except YSB, where current week of rainfall had negative relationship. But, relationship between rainfall and light trap catches were statistically insignificant.

In the case of sunshine hours, it was observed that the sunshine hours of current and one week before had a positive correlation with the light trap catches of YSB, whereas sunshine hours of two weeks before had a negative correlation with the light trap catches YSB. But the correlation was not significant. In the case of BPH, sunshine hours (current, one and two weeks before) had a negative relationship with the light trap catches. But, except the sunshine hours before two weeks, others are not significant. Sunshine hours of current week had a positive relationship with the light trap catches of RLF, whereas sunshine hours of one and two weeks before had a negative relationship. It was also noted that none of the relationship was significant (Table 46).

Table 46. Correlation coefficients of weather parameters and light trap catches of YSB, BPH and RLF

Weather parameters	Number of YSB captured		Number of RLF captured		Number of BPH captured	
	Pearson's r	p-value	Pearson's r	p-value	Pearson's r	p-value
Maximum Temperature	-0.277	<0.001	-0.297	<0.001	-0.293	<0.001
Minimum Temperature	-0.441	<0.001	-0.344	<0.001	-0.233	<0.001
Rainfall	-0.054	0.200	0.057	0.246	0.041	0.328
Humidity	0.342	<0.001	0.229	<0.001	0.243	<0.001
Sunshine hours	0.135	0.001	0.010	0.834	-0.084	0.046
Maximum Temperature past week	-0.346	<0.001	-0.326	<0.001	-0.297	<0.001
Minimum Temperature past week	-0.429	<0.001	-0.322	<0.001	-0.199	<0.001
Rainfall past week	0.013	0.759	0.035	0.480	0.065	0.122
Humidity past week	0.335	<0.001	0.215	<0.001	0.237	<0.001
Sunshine hours past week	0.064	0.133	-0.046	0.351	-0.104	0.014
Maximum Temperature 2 weeks back	-0.412	<0.001	-0.315	<0.001	-0.277	<0.001
Minimum Temperature 2 weeks back	-0.395	<0.001	-0.270	<0.001	-0.172	<0.001
Rainfall 2 weeks back	0.067	0.115	0.050	0.306	0.072	0.088
Humidity 2 weeks back	0.304	<0.001	0.203	<0.001	0.207	<0.001
Sunshine hours 2 weeks back	-0.038	0.376	-0.069	0.161	-0.113	<0.001

4.3.2. Principal component analysis

Principal component analysis was performed to understand the relationships between the weather parameters and with a purpose to reduce the number of variables that need to be regressed with the number of insects captured. Correlation matrix (Table 47) was established from the PCA to understand the relationship between the weather variables.

Table 47. Correlation matrix developed from Principal Component Analysis

Weather	Parameters	Max Temp	Max T1 W	Max T 2 W	Min T	Min T 1W	Min T 2 W	RF	RF 1 W	RF 2 W	RH	RH 1 W	RH 2 W	SSH	SSH 1 W	SSH 2 W
Max T	r value	1	0.877	0.799	0.688	0.599	0.493	-0.387	-0.346	-0.306	-0.658	-0.61	-0.54	0.464	0.387	0.348
	p value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Max T 1 W	r value	0.877	1	0.876	0.723	0.684	0.603	-0.207	-0.395	-0.326	-0.631	-0.656	-0.607	0.222	0.466	0.371
	p value	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Max 2 W	r value	0.799	0.876	1	0.767	0.72	0.687	-0.171	-0.215	-0.376	-0.645	-0.628	-0.655	0.113	0.219	0.454
	p value	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001
Min T	r value	0.688	0.723	0.767	1	0.869	0.811	-0.08	-0.106	-0.115	-0.664	-0.642	-0.618	-0.129	-0.031	0.03
	p value	<0.001	<0.001	<0.001		<0.001	<0.001	0.058	0.012	0.006	<0.001	<0.001	<0.001	0.002	0.47	0.482
Min T 1 W	r value	0.599	0.684	0.72	0.869	1	0.87	-0.04	-0.087	-0.09	-0.624	-0.66	-0.636	-0.12	-0.136	-0.05
	p value	<0.001	<0.001	<0.001	<0.001		<0.001	0.344	0.038	0.033	<0.001	<0.001	<0.001	0.004	0.001	0.242
Min T 2 W	r value	0.493	0.603	0.687	0.811	0.87	1	0.014	-0.047	-0.076	-0.584	-0.622	-0.658	-0.186	-0.126	-0.15
	p value	<0.001	<0.001	<0.001	<0.001	<0.001		0.734	0.27	0.07	<0.001	<0.001	<0.001	<0.001	0.003	<0.001
RF	r value	-0.387	-0.207	-0.171	-0.08	-0.04	0.014	1	0.142	0.153	0.276	0.15	0.149	-0.416	-0.236	-0.159
	p value	<0.001	<0.001	<0.001	0.058	0.344	0.734		0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RF 1 W	r value	-0.346	-0.395	-0.215	-0.106	-0.087	-0.047	0.142	1	0.138	0.191	0.279	0.153	-0.188	-0.417	-0.235
	p value	<0.001	<0.001	<0.001	0.012	0.038	0.27	0.001		0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RF 2 W	r value	-0.306	-0.326	-0.376	-0.115	-0.09	-0.076	0.153	0.138	1	0.168	0.182	0.272	-0.195	-0.188	-0.408
	p value	<0.001	<0.001	<0.001	0.006	0.033	0.07	<0.001	0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RH	r value	-0.658	-0.631	-0.645	-0.664	-0.624	-0.584	0.276	0.191	0.168	1	0.799	0.718	-0.113	-0.093	-0.109
	p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	0.007	0.028	0.01
RH 1 W	r value	-0.61	-0.656	-0.628	-0.642	-0.66	-0.622	0.15	0.279	0.182	0.799	1	0.797	-0.044	-0.112	-0.082
	p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	0.303	0.008	0.054
RH 2 W	r value	-0.54	-0.607	-0.655	-0.618	-0.636	-0.658	0.149	0.153	0.272	0.718	0.797	1	0.004	-0.041	-0.1
	p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		0.923	0.337	0.019
SSH	r value	0.464	0.222	0.113	-0.129	-0.12	-0.186	-0.416	-0.188	-0.195	-0.113	-0.044	0.004	1	0.411	0.306
	p value	<0.001	<0.001	0.007	0.002	0.004	<0.001	<0.001	<0.001	<0.001	0.007	0.303	0.923		<0.001	<0.001
SSH 1 W	r value	0.387	0.466	0.219	-0.031	-0.136	-0.126	-0.236	-0.417	-0.188	-0.093	-0.112	-0.041	0.411	1	0.408
	p value	<0.001	<0.001	<0.001	0.47	0.001	0.003	<0.001	<0.001	<0.001	0.028	0.008	0.337	<0.001		<0.001
SSH 2 W	r value	0.348	0.371	0.454	0.03	-0.05	-0.15	-0.159	-0.235	-0.408	-0.109	-0.082	-0.1	0.306	0.408	1
	p value	<0.001	<0.001	<0.001	0.482	0.242	<0.001	<0.001	<0.001	<0.001	0.01	0.054	0.019	<0.001	<0.001	

The correlation matrix revealed that there was strong correlation between weather variables such as temperature (maximum and minimum), relative humidity, rainfall and sunshine hours of current, one and two weeks before the occurrence of the pests. Based on the Eigen equation, 15 component factors were formed, which explained the variance in the relationship between the weather parameter. Rotation of the extracted matrix was done by Varimax method (An orthogonal rotation method that minimizes the number of variables that have high loadings on each factor). The factors which had eigen value more than two were selected for further analysis. Out of 15 there were only two factors which had eigen value more than two (Table 48).

Table 48. Component factors and their eigen value developed from PCA

Component	Initial eigen values			Extracted and rotated sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.77	45.14	45.14	6.25	41.67	41.67
2	2.73	18.17	63.31	3.25	21.64	63.31
3	1.12	7.46	70.77			
4	1.00	6.69	77.46			
5	0.78	5.21	82.68			
6	0.59	3.94	86.62			
7	0.55	3.68	90.30			
8	0.48	3.23	93.53			
9	0.29	1.91	95.45			
10	0.19	1.23	96.68			
11	0.17	1.12	97.81			
12	0.12	0.82	98.63			
13	0.11	0.70	99.33			
14	0.06	0.38	99.71			
15	0.04	0.29	100.00			

In the first factor weather variables such as temperature (maximum, minimum) and relative humidity of current, one and two weeks before the insect catches were included. In the second factor, rainfall of current, one and two weeks before was included. This grouping was done based on the inter relationship of weather parameters with each other (Table 49). Sunlight hours of the day was not included in the analysis as it was found to be statistically significantly ($p<0.001$, r-0.69) correlated with temperature. Two factors (eigen value more than 2.0) that were extracted explained 63.3 % of the total variance in the weather parameter data.

The first factor extracted had temperature and relative humidity parameters that were highly correlated between them. The factor could be labeled as 'temperature - humidity factor'. The second factor had the current and past rainfall variables and could be labeled as 'rainfall factor'.

Table 49. Varimax rotated components extracted by PCA

Weather Parameters	Factor 1	Factor 2
Minimum Temperature	0.871	
Minimum Temperature past week	0.849	
Minimum Temperature 2 weeks back	0.799	
Maximum Temperature	0.836	
Maximum Temperature past week	0.883	
Maximum Temperature 2 weeks back	0.891	
Relative Humidity	-0.821	
Relative Humidity past week	-0.835	
Relative Humidity 2 weeks back	-0.812	
Rainfall		0.603
Rainfall past week		0.555
Rainfall 2 weeks back		0.501

4.3.2.1. Component scores (by regression method)

It is a method for estimating factor score coefficients for the factors developed i.e. temperature – humidity factor and rainfall factor. The scores that were produced have a mean of zero and a variance equals to the squared multiple correlations between the estimated factor scores and the true factor values. The developed component scores of the two factors were stored as two variables. A value of 0 in the first component score implies 'average temperature and relative humidity'. A negative value denotes less than average temperature and relative humidity and a positive value denote more than average temperature and relative humidity. The same was also considered for the second factor 'rainfall'.

Thus 12 variables introduced in the PCA were reduced to two consolidated variables representing 'temperature and relative humidity' and 'rainfall'. These two variables were used as predictor variables to create a model that would explain the number of weekly insect capture.

4.3.3. Correlation between component score factors and light trap catches

Correlations were performed to understand the relationship between the component score factors of temperature-humidity, rainfall and number of light trap catches. The results of the study revealed that the temperature – humidity factor had a significant negative correlation (r=-0.452; p<0.001) with the number light trap catches of YSB. On the other hand, rainfall factor had insignificant negative relationship (r=-0.034; p=0.419) with the number of light trap catches of YSB. The above relationships indicated that, if the temperature – humidity and rainfall factors increased, then there will be a decrease in the number of light trap catches. The scatter plot diagram of light trap catches of YSB and temperature – humidity factor, rainfall clearly indicated the trend (Figures 12 and 13).

In the case of BPH, temperature – humidity factor had a significant negative correlation (r=-0.260; p<0.01) with the number of light trap catches, whereas rainfall factor had a significant positive correlation (r=0.127; p = 0.03) with the number of light trap catches. The scatter plot diagram of BPH with the temperature - humidity factor, rainfall factor showed that both were having opposite relationship with the light trap catches (Figures 14 and 15).

Figure 12. Weekly number light trap catches of YSB and temperature – humidity factor

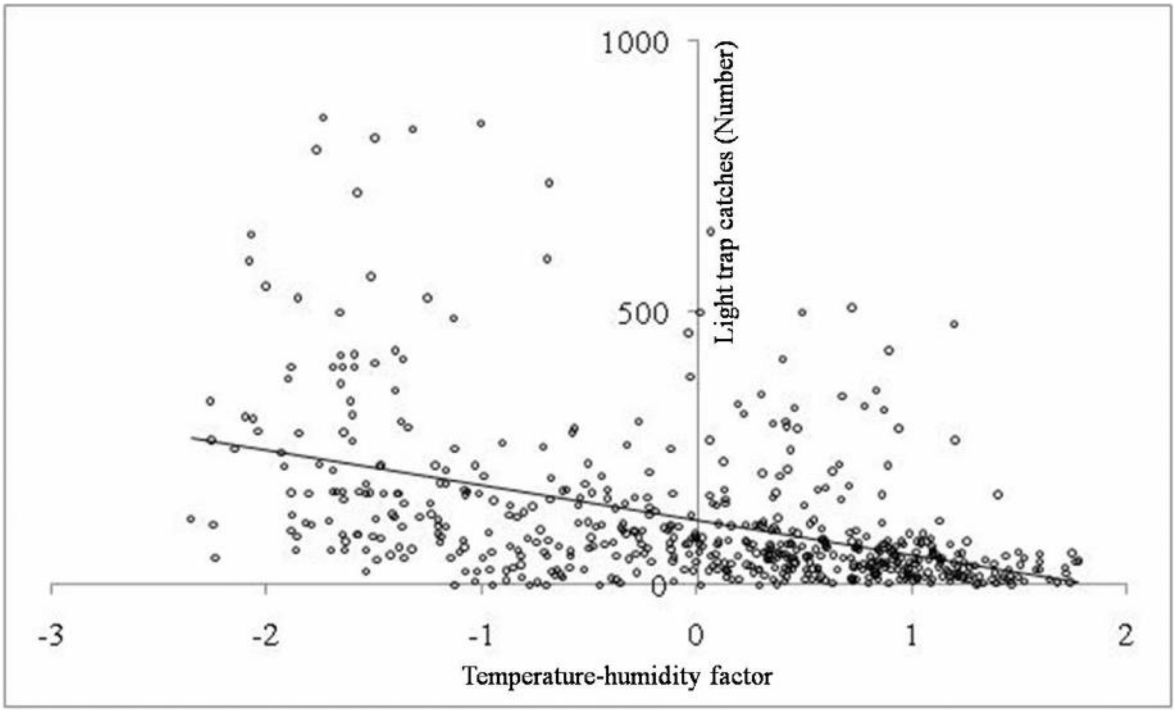


Figure 13. Weekly light trap catches of YSB and rainfall factor

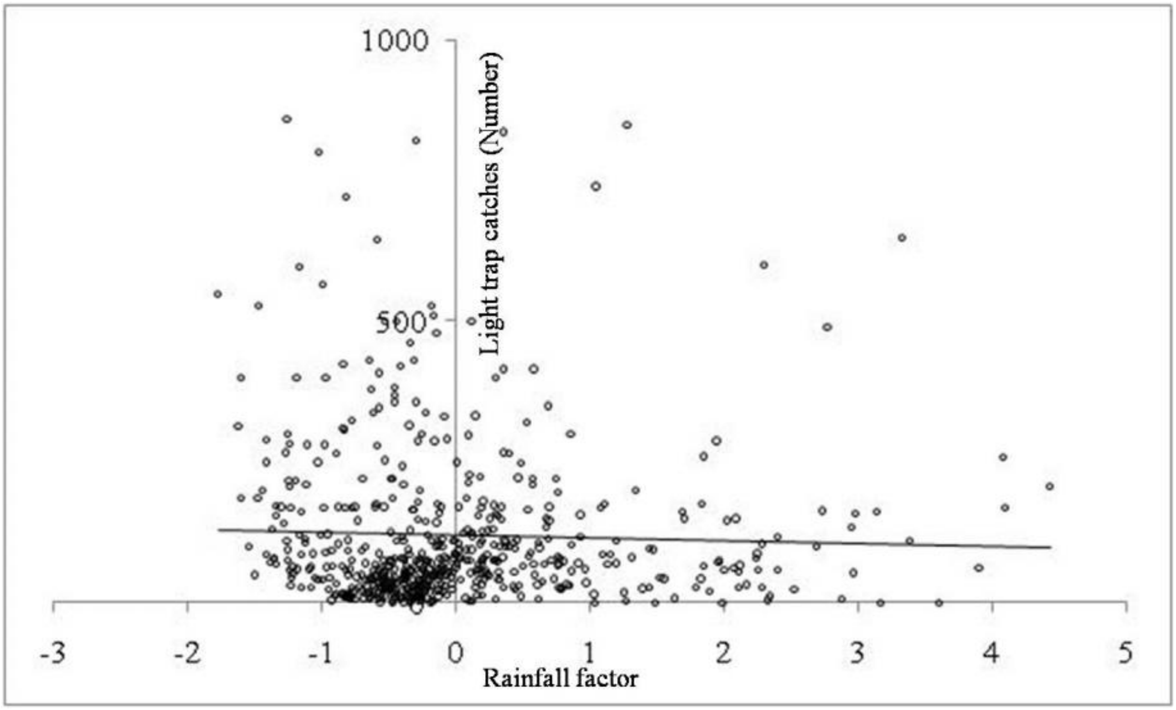


Figure 14. Weekly light trap catches of BPH and temperature – humidity factor

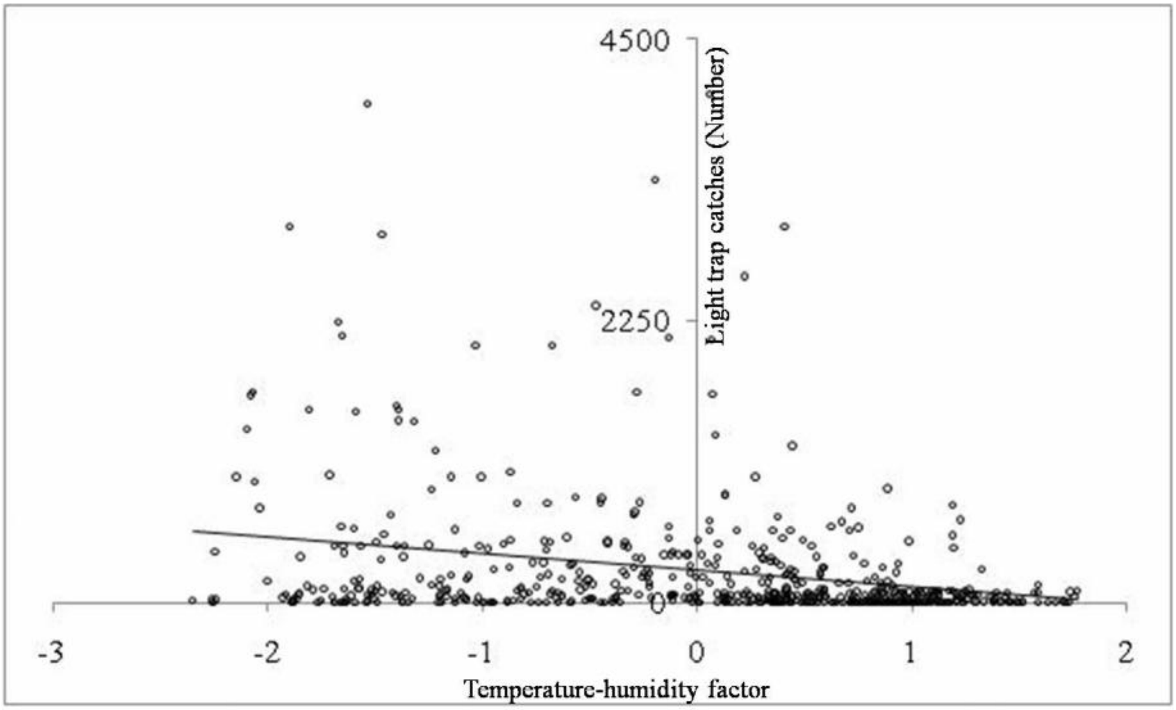


Figure 15. Weekly light trap catches of BPH and rainfall factor

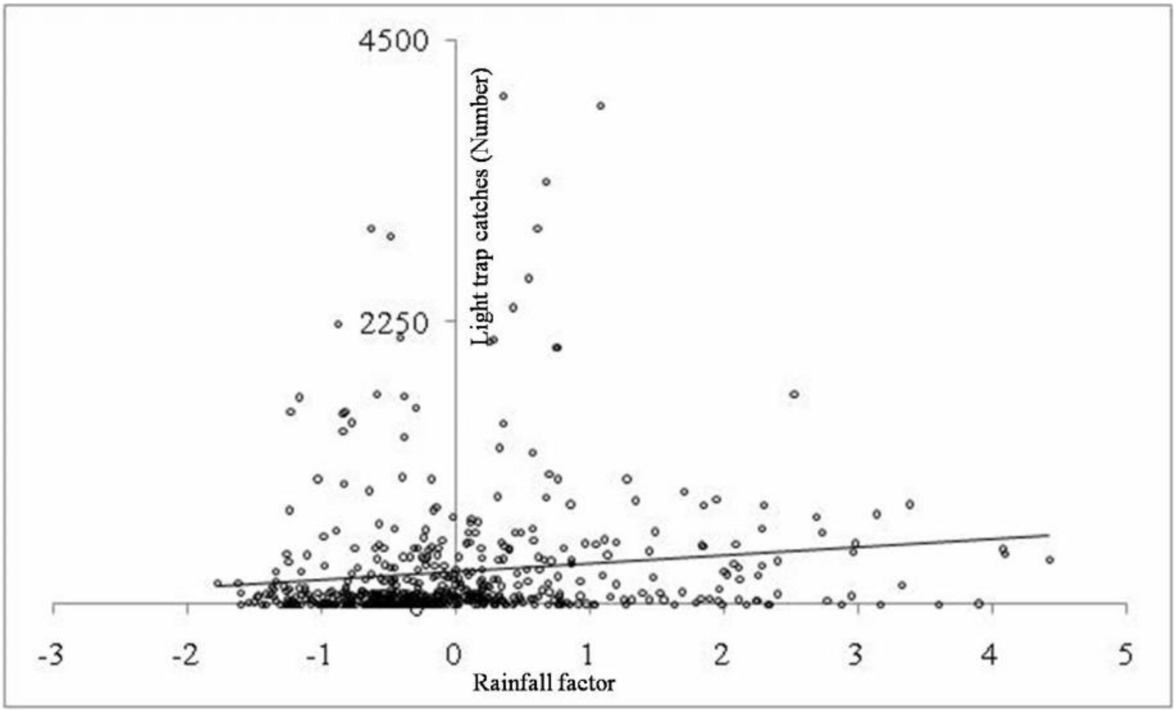


Figure 16. Weekly light trap catches of RLF and temperature – humidity factor

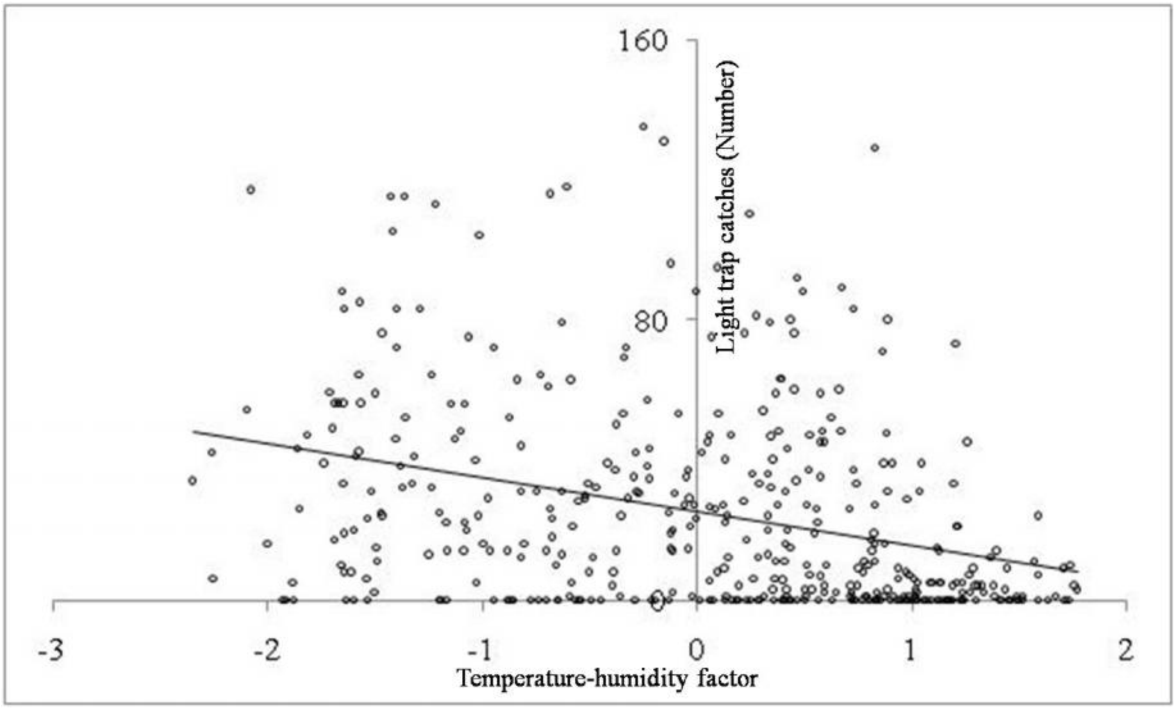
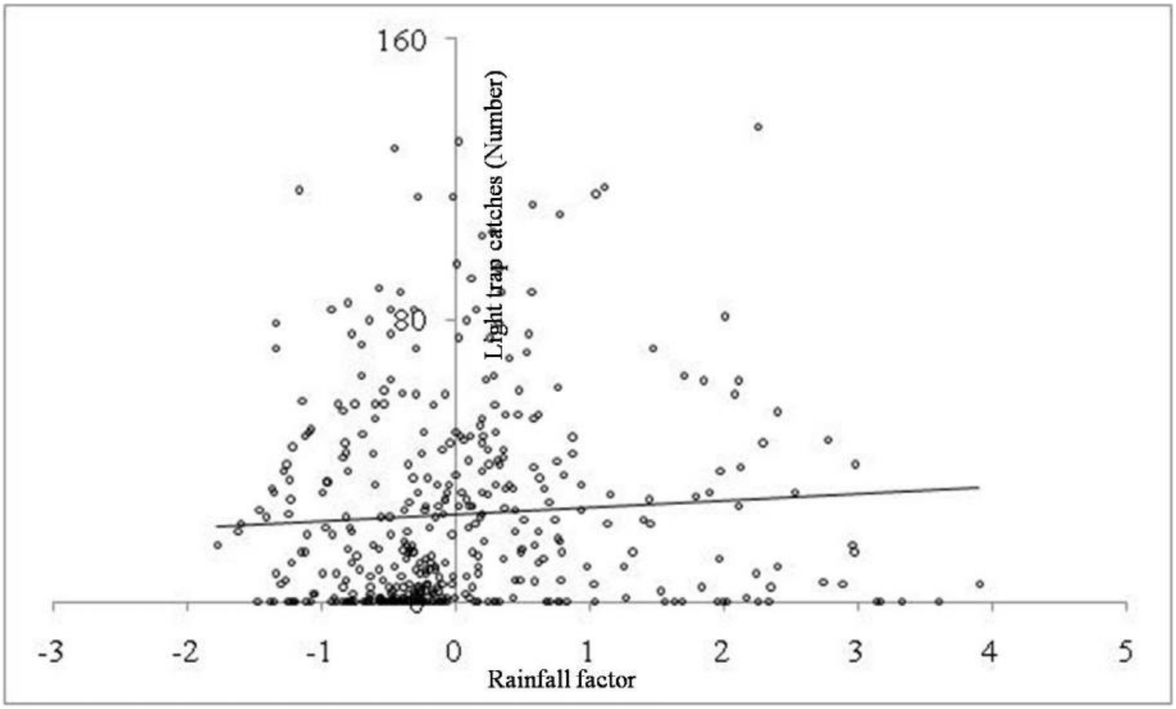


Figure 17. Weekly light trap catches of RLF and rainfall factor



Correlation studies in the light trap catches of RLF indicated that it had significant negative correlation (r=-0.334; p<0.001) with temperature – humidity factor whereas an insignificant positive relationship (r=0.064; p=0.195) with the rainfall factor. The figures 16 and 17 of the light trap catches of RLF and temperature – humidity, rainfall proved the above relationship.

4.3.4. Generalized Linear Model (GLiM)

The Generalized Linear Model is an extension of the General Linear Model to include response variables that follow any probability distribution in the exponential family of distributions. The exponential family includes such useful distributions as the Normal, Binomial, Poisson, Multinomial, Gamma, Negative Binomial, and others. Hypothesis tests applied to the Generalized Linear Model do not require normality of the response variable, nor do they require

homogeneity of variances. Hence, Generalized Linear Models can be used when response variables follow distributions other than the Normal distribution, and when variances are not constant. Hence, our insect capture count data would be appropriately analyzed as a Poisson random variable within the context of the Generalized Linear Model.

The non-normal data was subject to Generalized Linear Multivariate Model (GLiM) with number of light trap catches data as the dependent variable and the two principal component score variables (Temperature and relative humidity and Rainfall) as continuous predictor variables. A poisson loglinear regression model was fit for the count data.

The results of the generalized linear model for YSB, BPH and RLF are given in the table (Table 50, 51 and 52).

Table 50. Parameters of the generalized linear model of YSB

Parameter	β	Std. Error	p-value
(Constant)	4.65	0.043	<0.001
Temperature - humidity	-0.525	0.038	<0.001
Rainfall	0.006	0.036	0.869

Table 51. Parameters of the generalized linear model of BPH

Parameter	β	Std. Error	p-value
(Constant)	5.33	0.072	<0.001
Temperature - humidity	-0.554	0.063	<0.001
Rainfall	0.235	0.048	<0.001

Table 52. Parameters of the generalized linear model of RLF

Parameter	β	Std. Error	p-value
(Constant)	3.137	0.059	<0.001
Temperature - humidity	-0.37	0.057	<0.001
Rainfall	0.079	0.052	0.127

The equations which were used to predict the light trap catches of YSB, BPH and RLF were developed from the results of the generalized linear model by using the link function and predictor values of the two factors; temperature and relative humidity factor and rainfall factor.

Insect	Model	Equation
YSB	Log linear poison regression model	Log E(y) = -0.525 (Temperature-humidity factor) + 0.006 (rainfall) + 4.65. (Chi-square – 198.8; $p<0.01$)
BPH	Log linear poison regression model	Log E(y) = -0.554 (Temperature-humidity factor) + 0.235 (rainfall) + 5.33 (Chi-square – 44.5; $p<0.01$)
RLF	Log linear poison regression model	Log E(y) = -0.37(Temperature-humidity factor) + 0.079(rainfall)+3.137 (Chi-square – 95.9; $p<0.01$)

4.3.4.1. Aptness of the model

One of the main objectives of model development is that to check how best it predicts a dependent variable. The last and perhaps most important step in model development is to carry out a thorough evaluation of the selected model. Based on the equations developed, insect catches were predicted for all the pests under study for a year which had been observed from light trap catches.

The results of the above evaluation indicated that there was difference in observed and predicted number of light trap catches for all the insects under study. However, rising and decreasing trend was observed to be coinciding at most of the points. The predicted and observed light trap catches of YSB was observed to be following the same trend from March to September and for November (Figure 18). The highest number of insect catches was originally observed during the month of January, whereas the highest insect catches were predicted to occur during the month of February. In the case of BPH, it was noted that there was large difference in observed and predicted number of light trap catches of insects. The highest number of light trap catches was occurred during December in both observed and predicted values (Figure 19). The trend between observed and predicted was same for the light trap catches of RLF from January to March. The highest insect catches were predicted to occur during December whereas, it was originally observed during the month of October (Figure 20).

Figure 18. Observed and predicted light trap catches of YSB

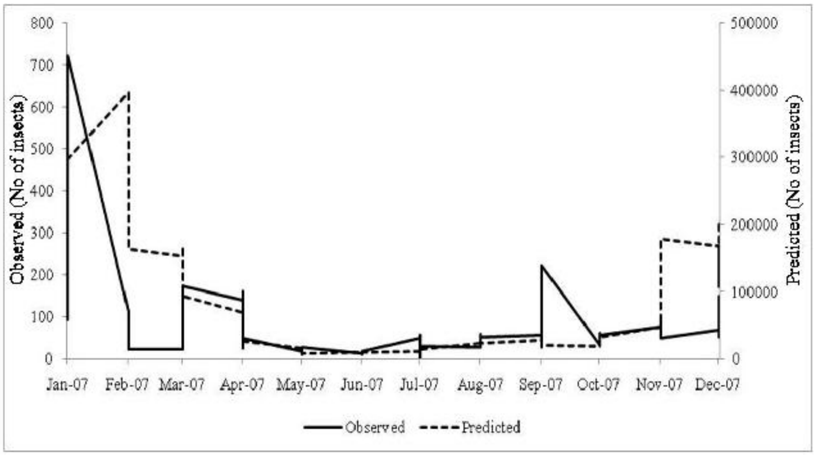


Figure 19. Observed and predicted light trap catches of BPH

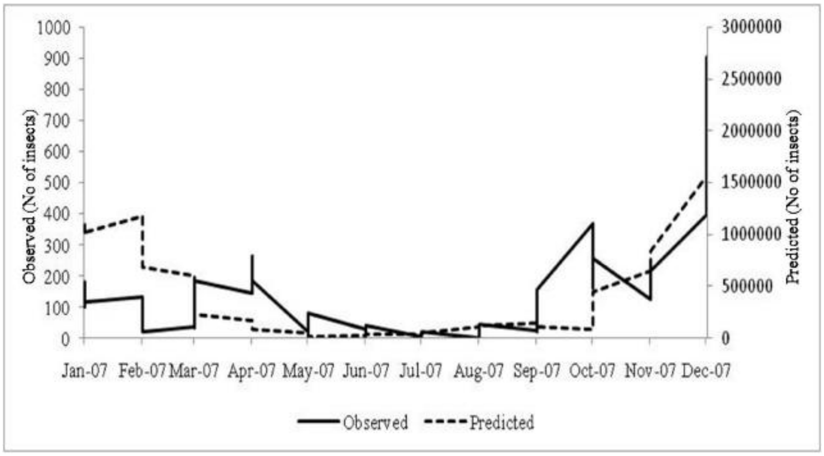
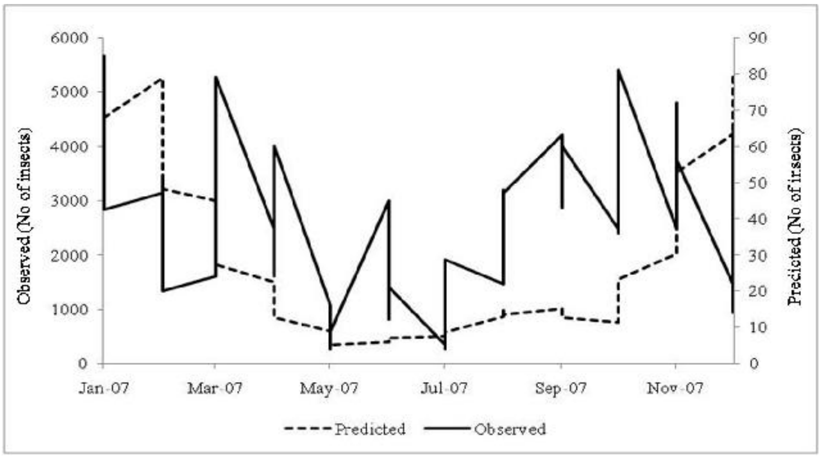


Figure 20. Observed and predicted light trap catches of RLF



Discussion

CHAPTER V

DISCUSSION

The present investigation was taken up with an aim to understand the effect of elevated temperature on demography of the important pests of rice such as YSB, BPH and RLF and the corresponding thermal requirement for their growth and development. To predict the pest occurrence of these pests, weather based pest forewarning models were developed. The results of the aforesaid studies are discussed here under.

5.1. Effect of elevated temperature on bionomics of major pests of rice

5.1.1. Oviposition

The number eggs laid by YSB increased with increasing temperature (Figure 21). Increase in egg laying at elevated temperature might be the result of more feeding and increased reproductive effort by the insects (Adamo and Lovett, 2011). Insect populations from environments with higher temperatures may have higher fecundity and shorter growth stage to increase fitness. Experiments of Karlsson and Johansson (2008) were in line with our results as they have reported that the number of eggs laid by pierid butterfly increased with increasing temperatures. In case of BPH, the number of eggs and hatching was observed to be lowest at higher temperature regimes. Hence, higher temperature regimes of 34.3^{o}C and 36^{o}C were not suitable for egg laying and egg growth and development by BPH adults as it reduces fertility and viability of eggs. Xiaoping *et al.,* (1992) reported that the number of eggs laid by BPH decreased rapidly as the temperature increased. Eggs laid by rice leaffolder increased with increasing temperatures. However, the number of eggs laid by RLF has a turnaround after reaching 34.3^{o}C and hence the number eggs were decreased at 36^{o}C. Riordan (1957) suggested that high temperatures might cause temporary or permanent sterility or deactivation of the sperms stored in the spermatheca resulting in a reduced fertility. This might be a reason for low fecundity at higher temperatures.

The egg hatching (%) decreased considerably with increasing temperatures for all the three insect pests (Figure 22). Same trend was noticed in *Willowsia jacobsoni* (Borner) in which hatching decreased dramatically as the temperature increased beyond the optimal level. Inability to complete the hatching process was attributed to either the shell did not break completely or the larva died attempting to leave the egg (Mutt *et al.,* 1984). It is also reported by Khan *et al.* (1991) that, although embryonic development of YSB eggs could be completed at higher temperature regimes, the larvae succumb within the chorion and results in less or minimal hatching of eggs. As a whole, it was observed that the temperature range of 28.3^{o}C to 30.6^{o}C was favorable for laying, growth and development of YSB, BPH and RLF eggs. Even though YSB and RLF laid more number of eggs at higher temperature regimes, hatching (%) was considerably reduced.

Figure 21. Total number of eggs laid by YSB, BPH and RLF and different temperature regimes

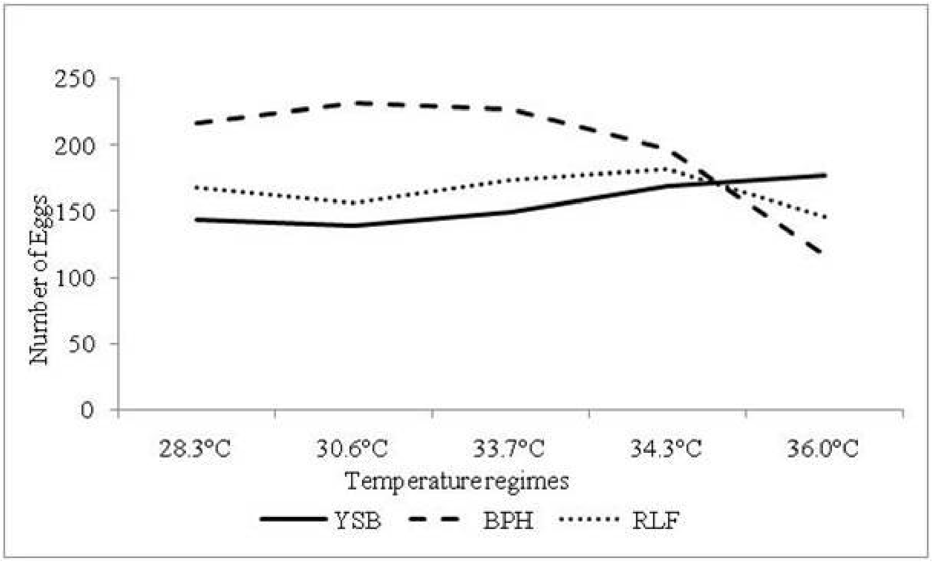
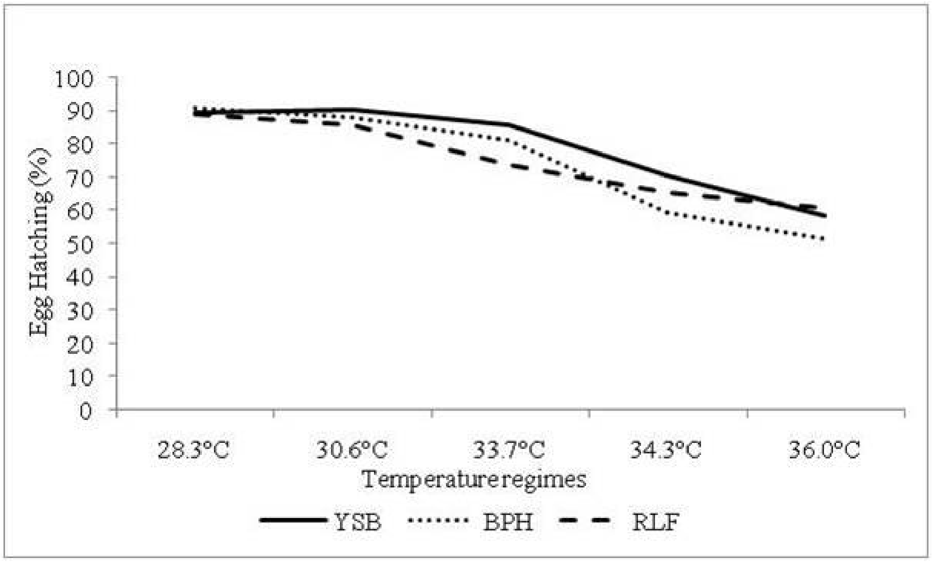


Figure 22. Percentage of hatching of YSB, BPH and RLF and different temperature regimes



5.1.2. Development time

Although insects do not live in a stable environment without temperature fluctuations, the results of studies under constant temperatures are still very useful in understanding the population dynamics (Summers *et al.*, 1984). The immature stages of YSB, BPH and RLF took more time to complete the development at lower temperature regimes, whereas it took less time at higher temperature regimes. It was observed that the YSB adult emerged 12.5 days earlier (Figure 23) at higher temperature regime (36^{o}C) when compared to the lower temperature regime (28.3^{o}C). In the same way BPH (Figure 24) and RLF (Figure 25) adults emerged 8.5 and 9 days earlier at higher temperature regime (36^{o}C) when compared to lower temperature regime (28.3^{o}C). It was also observed that (Figure 26) development time of YSB life cycle exhibited more linear growth pattern when compared to BPH and RLF. As a whole, the female YSB took as long as 52 days to complete the life cycle at lower temperature regime and as short as 32 days at higher temperature regimes. In the case of BPH and RLF it took 44.75 and 39 days respectively, to complete the life cycle at lower temperature regime (28.3^{o}C). At the same time, BPH and RLF took 30.75 and 27.75 days respectively, at higher temperature regime (36^{o}C). It is reported that the incubation period of YSB decreased with increasing temperature and the rate of larval development was positively correlated with temperature between 17 and 35 °C (Pathak and khan, 1994). Similarly, the green peach aphid developed significantly faster at warmer temperatures than at cooler temperatures (Satar *et al.*, 2008). Studies by many other authors (Komazaki, 1982; Hirano *et al*,. 1996; Wang and Tsai, 2001) also revealed that the development time decreases with increase in temperature.

Temperature is an important factor, which exerts a profound influence on the development of insects. Development time is mostly dependant on the metabolic rate of the insects. The metabolic rate of insects depends on their body temperature. The temperature inside the insect's body achieves equal or close values to the ambient temperature. Hence, the metabolic rate of insects increases linearly with ambient temperature and results in faster development at higher temperature (Grodzicki and Walentynowicz, 2011). The effects of temperature on insect development may vary among species, but lower temperatures typically result in a decrease in the rate of development and increase in the duration of the time spent in each developmental stage (Ju *et al.*, 2011).

Figure 23. Development time taken by YSB at different temperature regimes

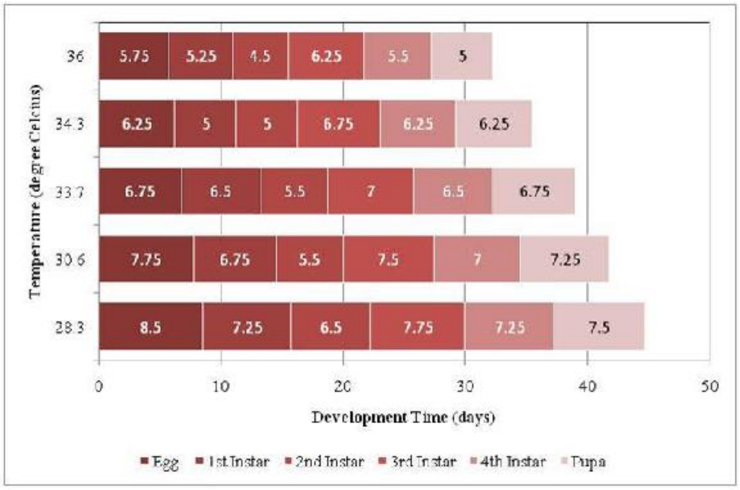


Figure 24. Development time taken by BPH at different temperature regimes

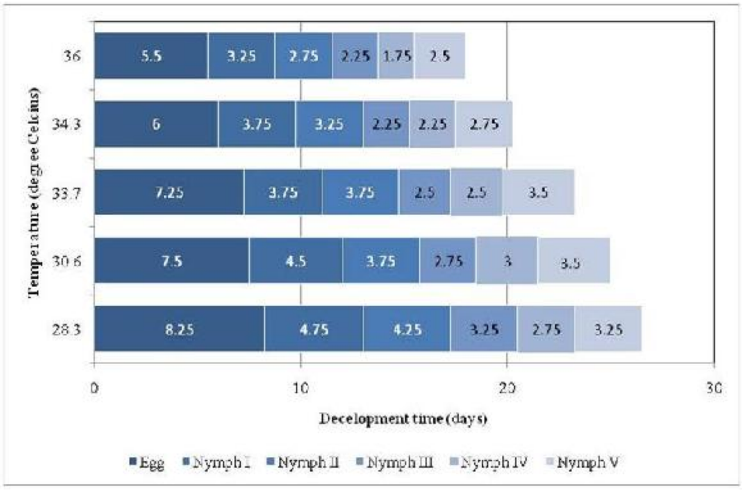


Figure 25. Development time taken by RLF at different temperature regimes

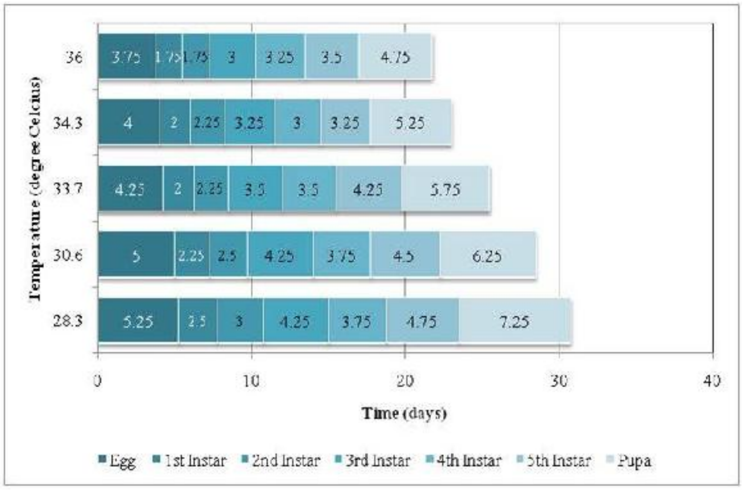
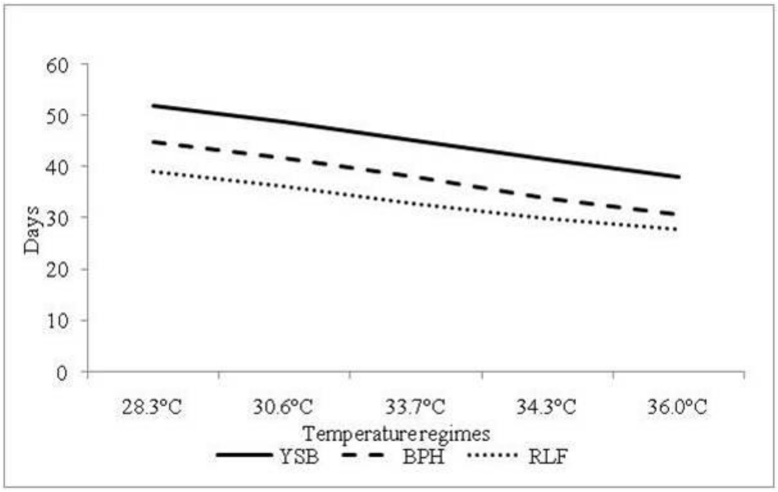


Figure 26. Generation time taken by RLF at different temperature regimes



5.1.3. Longevity

Generally, female lived longer than male adults at all the temperature regimes. This was in line with the results of the experiment conducted by Hugar *et al.* (2009) who reported that YSB female lived longer than male adults. The longevity of YSB female at higher temperature regime (36^{o}C) was 1.5 days shorter when compared to the lower temperature regime (28.3^{o}C). Similar trend was also noticed in BPH and RLF females as they lived out in 5.5, 2.25 days earlier at higher temperature regime, when compared to lower temperature regime. Generally, it was observed that irrespective of the type of insect species, longevity decreased with increasing temperatures. It was reported by Sarma (1984) that, O_2 consumption increases corresponding to the increase of temperature. Higher O_2 consumption means greater metabolic activity. In higher temperature regimes death of insects takes place early because of increased metabolism. O_2 consumption is very low in lower temperatures. Hence longer duration in of longevity in lower temperature can thus be explained as resulting from reduced activity confirmed by lower O_2 consumption. It was also reported that very high temperatures reduce insect longevity (Das *et al.*, 2011). In the same way, longevity of females of sycamore lace bug was found to be the shortest, 17.7 days at 33°C and the longest, 58.9 days at 16°C (Ju *et al.*, 2011).

5.2. Life and fertility table

Data from our study indicated that temperature had a profound effect on life table parameters such as survival, longevity, and fecundity of YSB, BPH and RLF. It is difficult, however, to know how well the parameters estimated under the laboratory conditions at constant temperatures could be applied in the field (Omer *et al.*, 1996) because under natural conditions, insects are never exposed to constant temperatures (Infante, 2000). Nevertheless, laboratory studies at different temperatures can provide useful information on the development, survival, and reproduction of insects (Wang *et al.*, 1997) that is essential to developing an effective IPM programs. Life tables are powerful tools for analyzing and understanding the impact that an external factor has upon the growth, survival, reproduction, and growth rate of an insect population (Bellows *et al.*, 1992). In addition, the classical life table is primarily used to understand the age dynamics of adult populations studied under controlled laboratory conditions (Aysal and Kıvan, 2008).

5.2.1. Survivorship

Results indicated that the age specific survivorship decreased with the progress of age at all the temperatures irrespective of the insect pests. It was important to find out the age at which 50 per cent mortality occurred, as it indicated the ability of the insect to survive under different temperature regimes. In YSB, the 50 per cent of mortality was observed on 26.6 days after incubation at 28.3^{o}C, whereas at this stage almost 84 per cent of populations died, when YSB happened to live at 36^{o}C. The 50 per cent mortality was observed just on 7.2 days after incubation at 36^{o}C. In the case of BPH, number of days to reach 50 per cent mortality was more (20.1 days) at 28.3^{o}C, but it was only 6.3 days at 36^{o}C. The 50 per cent mortality in RLF was observed on 15.4 days at 28.3^{o}C and was observed just on 5.5 days after incubation 36^{o}C. Same results were also reported by many authors, which support the results of the above experiments. YSB experiences high mortality above a temperature of 34°C (Catling and Islam 1995). Experiments conducted Pathak and Khan (1994) revealed that the survival of BPH nymphs at 31, 35, and 38°C was significantly lower than that at 26°C.

The time taken for 50 per cent mortality decreased with increasing temperatures. It indicated that the most of the insects reared under higher temperature regimes died faster and earlier as they were not able to tolerate the higher temperature. When the insects happened to live in higher temperature regimes, respiration increases up to a critical upper limit. After this upper limit, respiration decreases. Adequate supply of oxygen is essential for insects to survive heat stress (Whitting *et al.*, 1991). Hence, higher mortality in insects reared under higher temperature thus explained as the result of decreased respiration when the temperature increased. Yamaguchi *et al.* (2001) reported that the potential rate of insect population is strongly dependent on temperature, and their survival is impaired at temperature extremes. It was also reported by Kuo *et al.*, (2006) that only 12.5 % of nymphs survived when the temperature increased from 10^{o}C to 35^{o}C in *Tetraneura nigriabdominalis.*

Survival proportion calculated from the stage specific life table indicated that the proportion of survivors to the original population decreased with increasing temperatures for the insect species under study. In YSB, 90.6 per cent successfully emerged into larvae and 38.8 per cent of the eggs became adults at 28.3^{o}C, whereas 70.8 per cent emerged into larvae and only 21.4 per cent of the eggs became adult at 34.3^{o}C. Same trend was noticed in BPH also where, 90.7 and 59.7 per cent of eggs emerged into nymphal stage at 28.3^{o}C and 34.3^{o}C, respectively. Results showed that 28.2 per cent of eggs became adult at 28.3^{o}C, but it was only 15.3 per cent at 36.0^{o}C. In the case of RLF, 86.9 per cent of eggs entered into first instar stage at 28.3^{o}C, whereas it was only 65.7 per cent at 36^{o}C. The highest per cent of adults (34.6) was recorded at 30.6^{o}C but at the same time only 12.7 per cent of eggs successfully became adults at 34.3^{o}C. The above results revealed that the survival proportion of insects which happened to live at higher temperature regime of 34.3^{o}C has been drastically reduced as this temperature regime was unfavourable for the survival of YSB, BPH and RLF. It was also reported that the survival of the different stages of the RLF was greatly affected at 35°C. The upper temperature threshold for survival of this species appears to lie between 30 and 35 °C (Heong *et al.*, 1995). A temperature of 33°C is lethal to freshly hatched BPH nymphs and greatly reduces the life span of the adults (Pathak and Khan, 1994).

5.2.2. Survival fraction

The results of the survival fraction of the insects indicated that it decreased with increasing temperatures. For all the insects tested under different temperature regimes, the survival fraction remained higher for all the stages at lower temperature regimes (28.3^{o}C and 30.6^{o}C) and drastically reduced at higher temperature regime of 34.3^{o}C (Figure27, 28 and 29). The results reported were in line with the results of Katsarou *et al.* (2005); Ali and Rizvi, (2010); Aziz *et al.* (2013) who reported that the survivor fraction decreased with increasing temperature.

Figure 27. Survival fraction of YSB at different temperature regimes

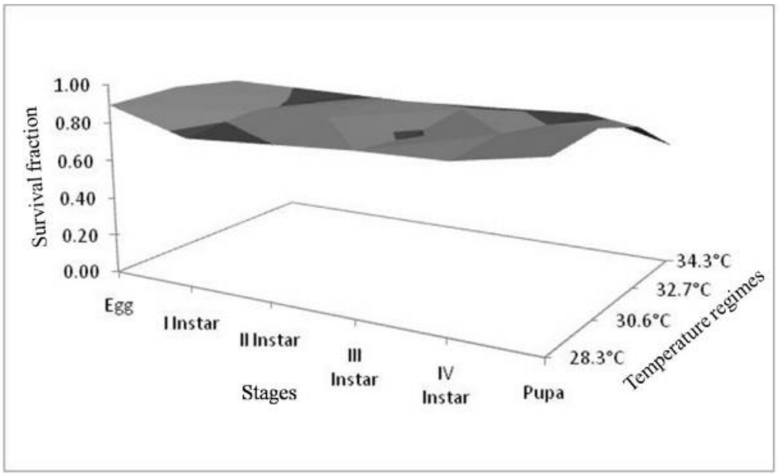


Figure 28. Survival fraction of BPH at different temperature regimes

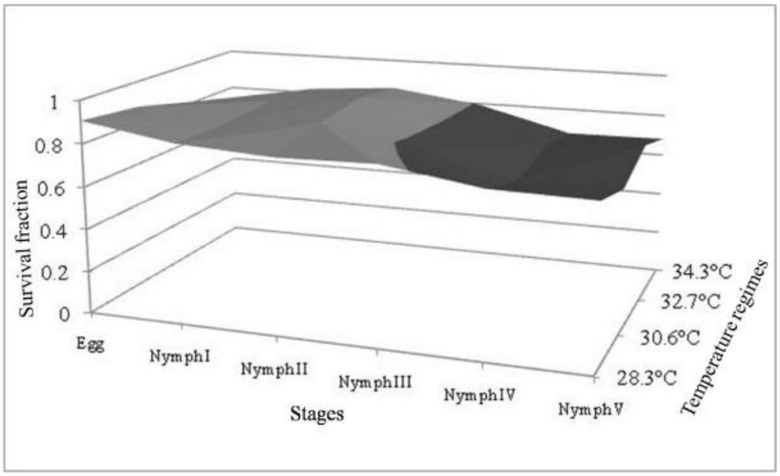
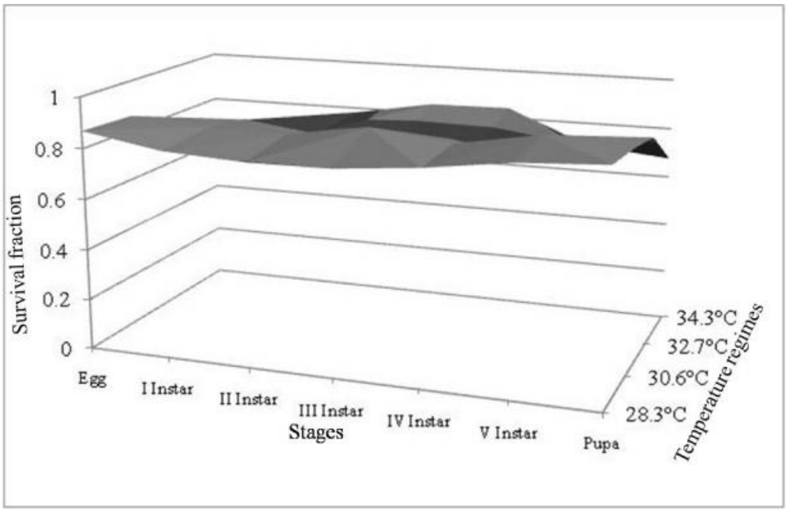


Figure 29. Survival fraction of RLF at different temperature regimes



5.2.3. Apparent mortality

Apparent mortality indicated the percentage insects died to the total number of insects entered at each stage. The calculated apparent mortality indicated that, the percentage of insect died, increased with increasing temperatures and reached its peak at 34.3°C, irrespective of the stage of insects and type of insect species. The observed apparent mortality in YSB also revealed that, among the larval instars the mortality remained higher for first and fourth instar larvae when compared to the others (Figure 30). It was understood that the later nymphal stages (Nymph V and IV) of BPH were observed to be more susceptible as the apparent mortality was more at these stages (Figure 31). In the case of RLF, clear distinction between different larval stages was not noted down, as the mortality was irregular between the stages at all the temperature regimes (Figure 32). Generally, apparent mortality increased towards the higher temperature regimes, indicating the less tolerance of insects to higher temperature regimes. Similar results were also reported by Katsarou *et al.* (2005); Ali and Rizvi, (2010); Aziz *et al.* (2013).

5.2.4. Mortality survivor ratio

Mortality survivor ratio (MSR) is used to understand the increase in the population of insects at each stage if the mortality in the stage had not occurred. The results showed that the MSR was observed to be increasing with increasing temperatures for all the stages irrespective of the insect pest under study (Figure 33, 34 and 35). The increase in the MSR with increasing temperatures was attributed to the decrease in the survival (l_x) with increasing temperature, as the MSR was the function of the l_x. Similar results were reported by Butler (1982); Rai *et al.* (2002); Aziz *et al.* (2013).

5.2.5. Indispensable mortality

The indispensable mortality (IM) was used to understand the amount of mortality, which would not be there if the factor causing mortality was not allowed to operate. As expected, the value of IM was observed to be decreasing with increasing temperatures (Figure 36, 37 and 38). As the number of adults emerged was less under higher temperature regimes, naturally the IM was lesser under higher temperature regimes as it was the function of the number of adults emerged. It was also observed that the IM was remained higher for egg stage at higher temperature regimes (34.3°C) irrespective of the insect species. This might be due to the higher MSR for egg stage for all the pests at higher temperature regimes. The above results were in line with the studies conducted by Katsarou *et al.* (2005); Ali and Rizvi, (2010); Aziz *et al.* (2013); who reported that the IM was lower for the insects which were happened to live under the higher temperature regimes.

5.2.6. K - values

Irrespective of the insect species, the generation mortality was increased with increasing temperatures for all the stages. It revealed that the insects which happened to live under higher temperature regimes were reproduction oriented as the most of the energy was spent in reproduction rather than spending the energy for living for longer time. Similar results were obtained by Omkar and Pervez (2004); Ali and Rizvi, (2009); (2010); Aziz *et al.* (2013). Generally YSB, BPH and RLF tend to be K favoring at higher temperature from being r favoring at lower temperature. The tradeoff between survival and reproduction is yet to be explored full.

5.2.7. Life Expectancy

Life expectancy of the tested insects revealed that it decreased with increasing temperatures. The life expectancy of YSB was 29.8 days at 28.3^{o}C but was only 12.85 days at 36^{o}C. In the case of BPH it was observed to be 20.6 and 10.5 days at 30.6^{o}C and 36^{o}C, respectively. RLF also followed the same trend of YSB and BPH as the life expectancy was observed to be 18.8 and 7.8 days at 30.6^{o}C and 36^{o}C, respectively. As the life expectancy is the function of the number survivors and development time, it happened to decrease with increasing temperature. Total number of survivors living at a point at higher temperature regimes was lesser when compared to that of lower temperature regimes. Thus, the lower life expectancy at higher temperature was the result of the lesser survivors and faster development at the higher temperature regimes. Similar results were obtained by Amiri *et al.* (2010), who reported that the life expectancies of *P. corylifoliella* reared under different constant temperature indicated that it decreased with increasing temperature. Ali and Rizvi (2010) also stressed the role of temperature in the life expectancy. They reported that the life expectancy of insect pests decreased considerably with increasing temperatures.

Figure 30. Apparent mortality of YSB at different temperature regimes

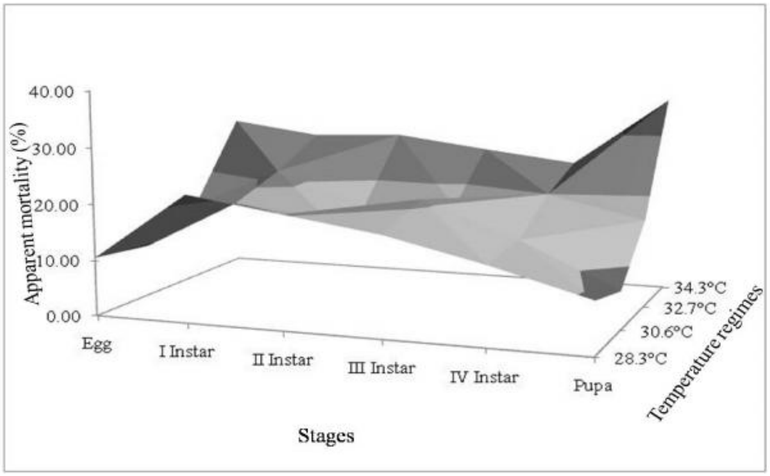


Figure 31. Apparent mortality of BPH at different temperature regimes

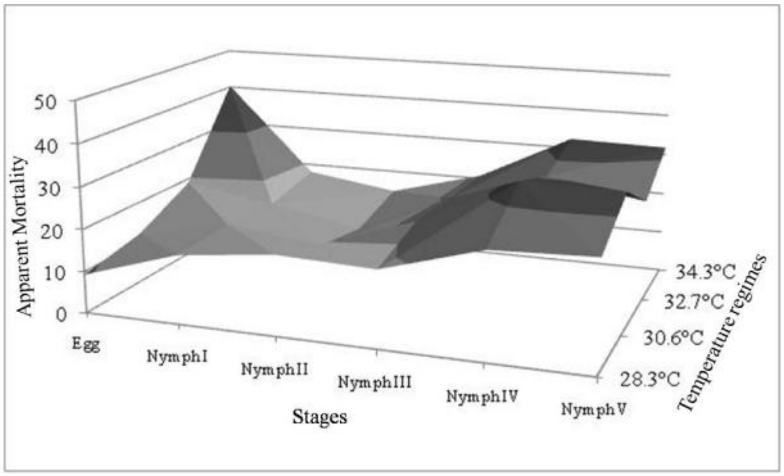


Figure 32. Apparent mortality of RLF at different temperature regimes

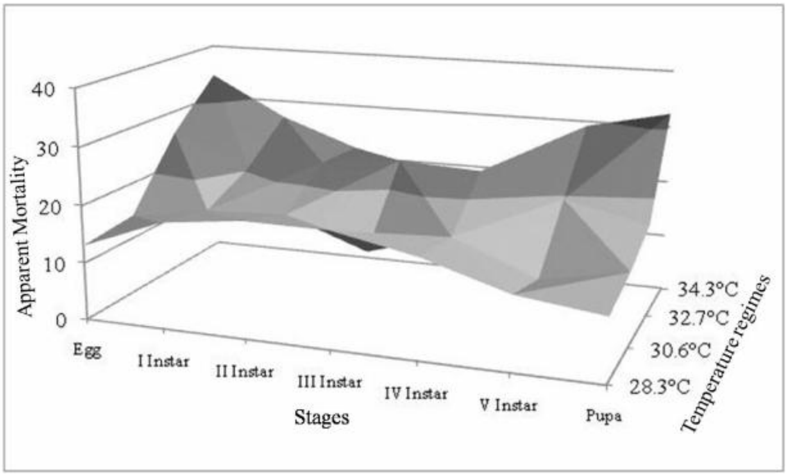


Figure 33. Mortality Survival Ratio of YSB at different temperature regimes

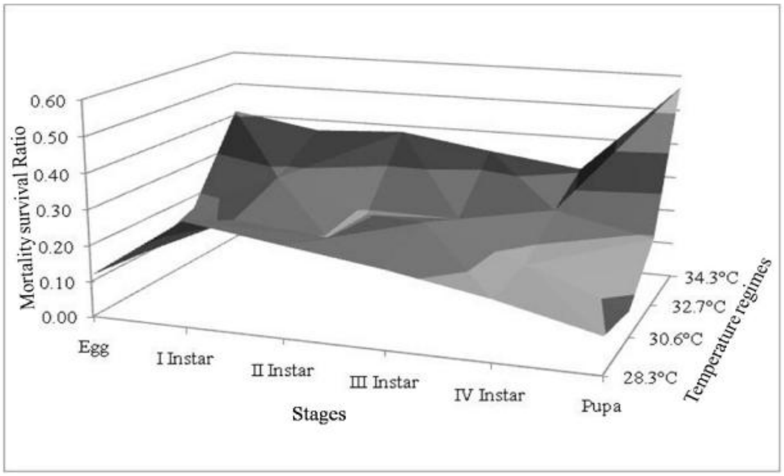


Figure 34. Mortality Survivor Ratio of BPH at different temperature regimes

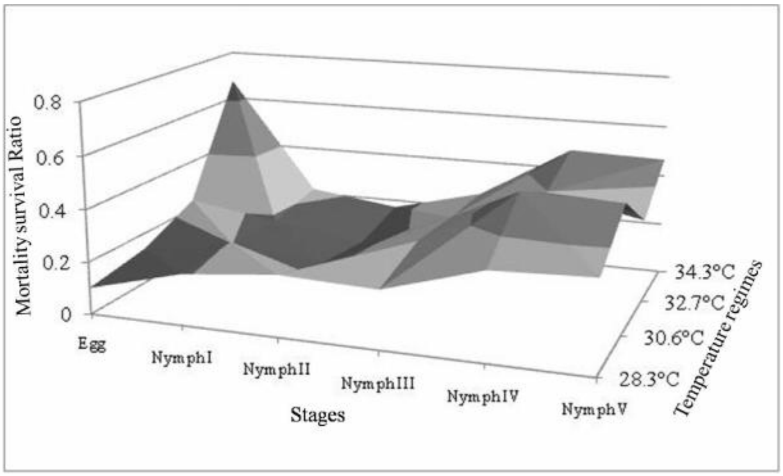


Figure 35. Mortality Survivor Ration of RLF at different temperature regimes

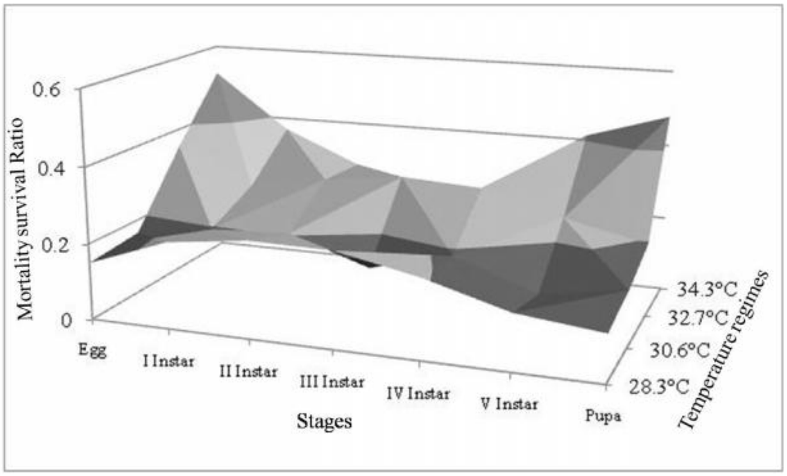


Figure 36. Indispensable Mortality of YSB at different temperature regimes

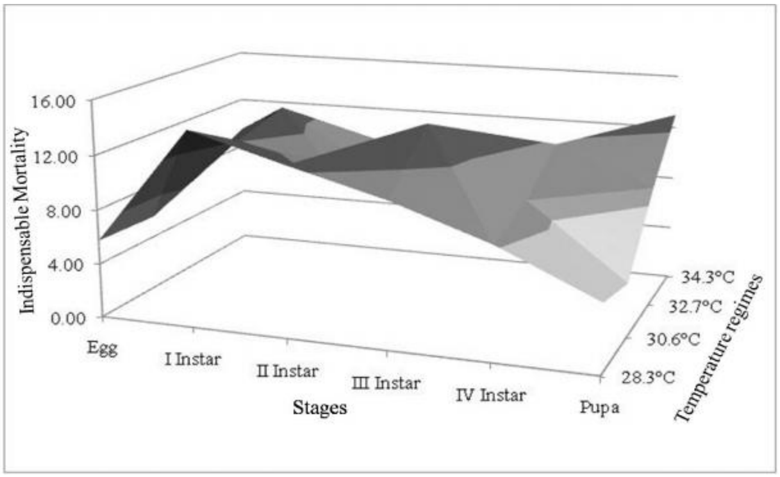


Figure 37. Indispensable Mortality of BPH at different temperature regimes

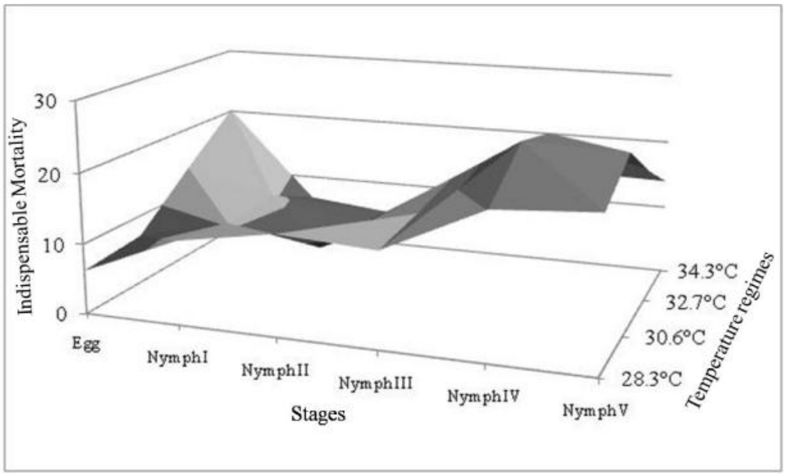
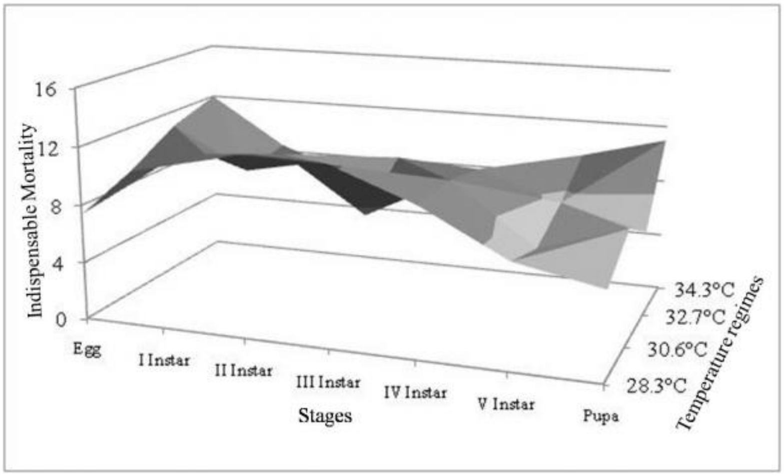


Figure 38. Indispensable Mortality of RLF at different temperature regimes



5.2.8. Fecundity

The results of the experiments conducted revealed that the pre-oviposition period of insects decreased with increasing temperatures. In YSB the pre-oviposition period ranges between one to three days, the lowest being at the higher temperature regime (36^{o}C). In BPH, the pre-oviposition period was observed to be five days at 28.3^{o}C but it was reduced to just two days when the insects happened to live at 36^{o}C. Similarly, the pre-oviposition period was reduced from four to two days when the temperature increased from 28.3^{o}C to 36^{o}C. The longer pre-oviposition period at lower temperature may be attributed to the lower metabolic activity at lower temperature regimes (Didonet *et al.,* 1996). Insects need to accumulate more energy to maintain the vital functions. Hence, at lower temperature pre-oviposition period was observed to be more. However, the pre-oviposition period decreased when the insects happened to live at higher temperature regimes as the metabolic rate increased. Similar results were reported by Heong *et al.* (1995), Son and Lewis, (2005) and Ju *et al.* (2011).

The length of oviposition period was observed to be decreasing with increasing temperatures in BPH, whereas, there was slight increase in length oviposition for YSB and RLF. In YSB, the length of oviposition was four days when the insects happened to live at the temperature regimes 28.3^{o}C, 30.6^{o}C and 32.7^{o}C and the same was observed to be five days when the insects were reared at 34.3^{o}C and 36.0^{o}C. In RLF, the length of oviposition period was observed to be four days at all the temperature regimes except 34.3^{o}C where it was five days. The oviposition period of BPH was observed to be 12 days at the temperature regimes of 28.3^{o}C, 30.6^{o}C and 11 days at the remaining temperature regimes.

The total number of eggs recorded generally increased with increasing temperature. Experiments conducted by Ju *et al.,* (2011) revealed that the preoviposition period had a strong influence on the total number of eggs laid by the insects. Generally pre-oviposition period decreased with increasing temperature for all the insects and resulted in higher number of eggs at higher temperature regimes. In contrast, it was also observed that the number of eggs decreased at the highest temperature regimes in RLF and BPH and it has been already discussed in the chapter 5.1.1.

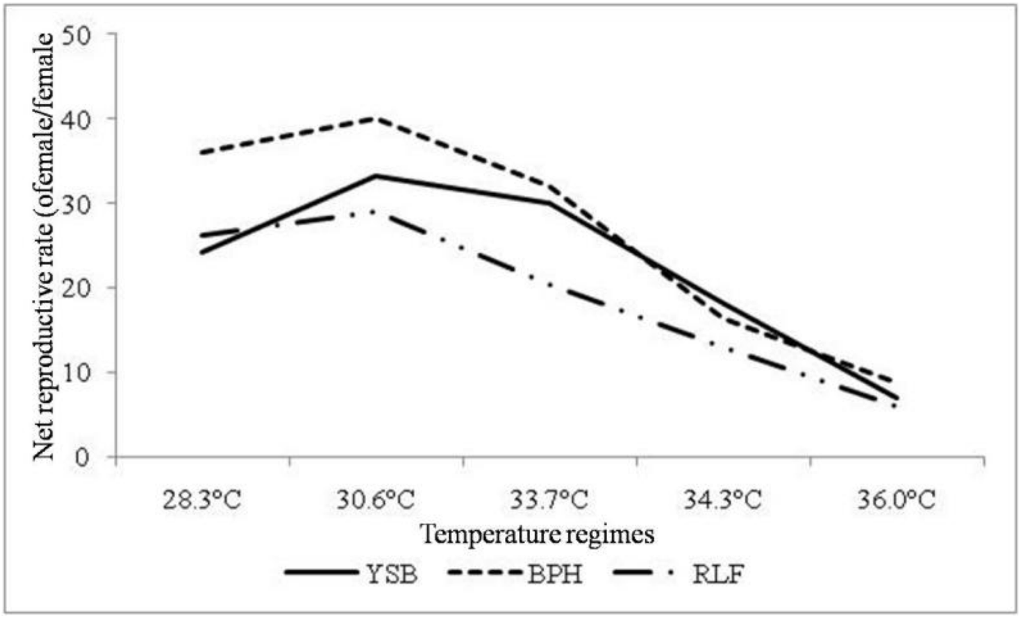
5.2.9. Net reproductive rate

The net reproductive rate was observed to be higher at the lower temperature regimes and lower at higher temperature regimes of the experiment. The net reproductive rate of YSB was highest at 30.6^{o}C (33.26 females/female) followed by 32.7^{o}C (30.09 females/female). In contrast, net reproductive rate largely reduced (7.01 females/female) at 36.0^{o}C (Figure 39). The net reproductive rate of BPH was 39.95 females/female at 30.6^{o}C, whereas it was only

8.84 females/female at 36.0°C. In the case of RLF, it was observed to be 29.08 females/female at 30.6°C but only 5.9 females/female. If one assumes that all the births are concentrate at one moment, two consecutive generations of YSB will be separated by 47.33 days (Andrewartha and Birch, 1954) or the population increases 33.26 times in 47.33 days. The above results indicated that the net reproductive rate was higher at 30.6°C irrespective of the type of the insects. At the same time it was also revealed that the temperature regimes of 34.3°C and 36.0°C were more detrimental to the insect pests as the net reproductive rate at these regimes was largely reduced.

Similar results were reported by Satar *et al.* (2008) in cotton aphids. The results revealed that the reproduction rates of the green peach aphid were in general higher at temperatures between 20.0 and 27.5°C (79.29 – 85.33 aphids aphid^{-1}) and decreased with an increase in temperature to 5.00 aphids aphid^{-1} at 30.0°C. The lowest R_o value at higher temperature could be explained due to the heavy mortality of the immature life stages and also adults between emergence and peak oviposition (Amiri *et al.*, 2010).

Figure 39. Net reproductive rate of YSB, BPH and RLF at different temperature regimes



5.2.10. Mean generation time

Mean generation time decreased with increasing temperatures irrespective of the insect species. It was indicated that the insects happened to live under higher temperature regimes develop and complete its life cycle faster by means of accelerated metabolic activities. Similar results were also reported by Kuo *et al.* (2006); Yang and Chi (2006); Amiri *et al.* (2010); Iranipour *et al.* (2010); Ali and Rizvi, (2010); Ju *et al.* (2011).

5.2.11. Population growth parameters

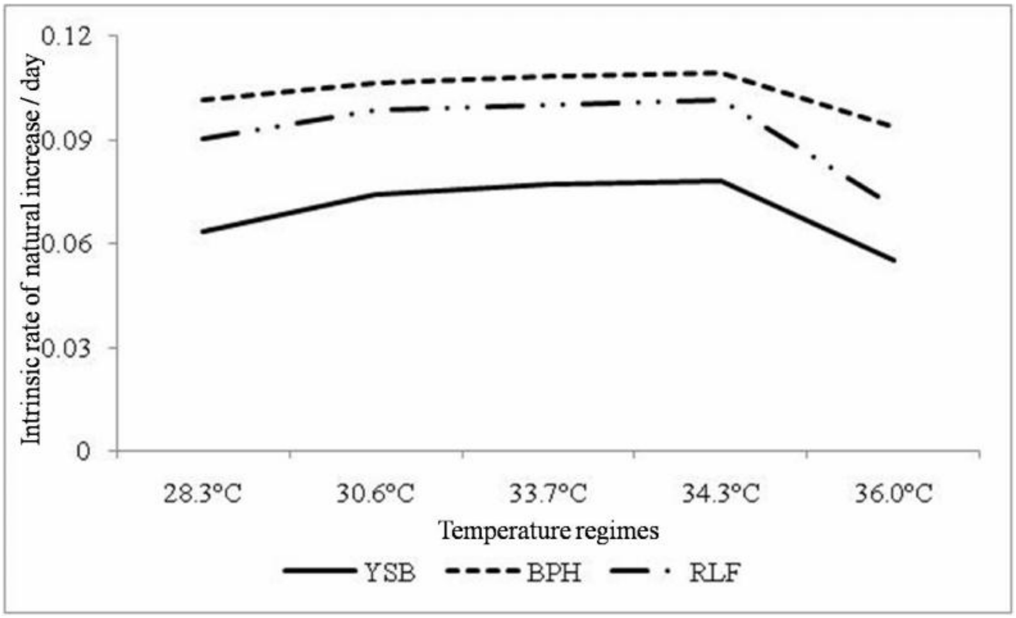
Capacity for increase, intrinsic rate of natural increase, finite rate of increase and doubling time are considered as population growth parameters. Population demographic parameters are important in measurement of population growth capacity of a insect under specified conditions. These parameters are also used as indices of a population responding to selected conditions and as bioclimatic indices in assessing the potential of a pest population growth in a new area. They also reflect the carrying capacity of a population to next generation (Southwood and Henderson, 2000). Among the population growth parameters, r_m is an important value, because it indicates the temperature at which the growth of a population is most favorable, and this reflects overall effects of temperature on development, reproduction, and survival (Southwood and Henderson, 2000). The finite rate of increase also depends on intrinsic rate of natural increase as the former value was calculated by using the later.

Temperature had a significantly influence on the various population demographic parameters. The results of the experiments revealed that the all the population growth parameters increased with increasing temperatures. However, the increase had a turnaround after a threshold temperature (34.3^{o}C) of the experiment and hence it has been reduced at 36.0^{o}C. The value of r_m started increasing from 28.3^{o}C and reached its peak at 34.3^{o}C. The higher intrinsic rate of natural increase of 0.07795 day^{-1}, 0.1091^{-1} and 0.10135^{-1} were recorded for YSB, BPH and RLF respectively, at 34.3^{o}C (Figure 40). The value of r_m followed the order of 34.3^{o}C > 32.7^{o}C > 30.6^{o}C > 28.3^{o}C > 36.0^{o}C.

Iranipour *et al.* (2003) reported that, developmental time decreased as temperature increased. This is the primary reason why the intrinsic rate of natural increase was observed to increase with temperature in the present study. As pointed out by Lewontin (1965) and Dent and Walton (1997), r_m is affected more by age of first reproduction than by fecundity. Delayed development causes a delay in onset of reproduction and a parallel increase in generation time.

Earlier the eggs are produced, more will be their contribution to the value of r_m (Birch, 1948). Thus, the highest r_m value might be attributed to the earlier oviposition at higher temperature regimes for all the pests. However, the experiment results also revealed that the increase in r_m was not continuous as it reduced at 36.0^{o}C. Similar results were also reported by Kuo *et al.* (2006); De conti *et al.* (2010). The lowest r_m value at 36.0^{o}C could be explained to the heavy mortality at the highest temperature regime (Vojdani, 1961).

Figure 40. Intrinsic rate of natural increase in YSB, BPH and RLF at different temperature regimes



5.3. Degree day accumulation

The growth and development of insects are dependent on weather especially temperature. Degree-days (DD) are measurement units that combines temperature and time. In other words, temperature and time work together such that the time for development of the organism's life cycle, or any stage or portion of the life cycle, decreases as the temperature increases (Ascerno, 1991). The key point is that the heat units (degree days) required to complete development of insect pest will be approximately same at different temperatures. This is termed as the physiological time for development of the organism. Although temperatures and days to maturity may vary, the organism's physiological time (Degree days) remains relatively constant (Herms, 2004). Hence, degree days (DD) are used in pest management because they allow a simple way of predicting development of cold blooded organisms (Murray, 2008).

Many pests and some beneficial species have a known degree-day requirement for a generation to develop to maturity based on their individual lower threshold temperature. In order to track this development, a starting date is crucial. This starting date is termed as the biofix. Biofix points are usually based on planting dates, first trap catch or first occurrence of the pest. Once the biofix point is established, then tracking and accumulating degree-days can begin.

The average degree days required to complete the development of YSB egg, larva and pupa were 136.3, 557.8 and 156.3, respectively. The female adult lived out its life after the accumulation of 142.8 degree days and male moth completed its life when it accumulated 101.4 degree days. BPH eggs required an average of 123.3 degree days to hatch into nymph and the nymphal stage must accumulate 269 degree days to become adult. The female adult of BPH died after accumulating 244.2 degree days and the male adult of BPH accumulated 178 degree days before ending its life. RLF eggs required an average of 98.1 degree days to hatch into larva and the larval stage must accumulate 344 degree days to become adult. The female adult of RLF died after accumulating 159 degree days and the male adult accumulated 82.8 degree days before ending its life. Similar results of were reported by Davidson (1944); Campbell and Machauer, (1975); Nasr *et al.* (1980); Fetoh *et al.* (2006).

Using degree-days allows for predicting pest occurrence. Hence, by using the above degree day values, predictions on the occurrence of different stages can be made. Using degree-days can be an aid for scheduling sprays and beneficial insect releases at the optimum time to insure the best results (Murray, 2008). In the case of YSB, spray can be scheduled after the accumulation of 136.3 degree days to effectively control the larval stage of the insect. The YSB adults emerged from the pupa after accumulating 850.4 from the egg stage. Effective scouting of the insects can be planned after accumulating 850.4 degree days. In the case of BPH, spray can be planned after the accumulation of 123.3 degree days to effectively control the insects at initial nymphal stage. Likewise, for RLF a spray can be planned after the accumulation of 98.1 degree days.

5.4. Weather pest relationships

Weekly light trap catches of YSB, BPH and RLF and corresponding weather data for cauvery delta zone (Aduthurai) were collected from the Directorate of Rice Research, Hyderabad. Different statistical methods were engaged in order understand the relationship between light trap catches and weather and to develop a prediction model to predict the pest population at a particular time. The results of the above experiment are discussed here.

5.4.1. Effect of weather on light trap catches of insects

Results of the correlation studies indicated that temperature (maximum and minimum) of all the periods had a significant negative relationship with the number of light trap catches of all the insects, whereas relative humidity had a significant positive relationship. In the case of sunshine hours it exhibited different relationships with YSB, BPH and RLF. Rainfall (current, one and two weeks before) had the positive correlation with the light trap catches of all the pests except YSB where current week of rainfall had negative relationship. But, none of the rainfall relationships were statistically significant.

Similar results were reported by many authors. Experiments conducted by Nandihalli *et al.,* (1990) revealed that there is a negative correlation between trap catches of leaffolder and average temperature and a positive correlation with average morning relative humidity. Kim (1969) found a positive correlation between the population densities of *Laodelphax striatellus* and relative humidity in May in Orea. Correlation between weather factors and leaffolder population indicated that the maximum temperature, minimum temperature, rainfall and sunshine hours have significant negative relationship while morning relative humidity and evening relative humidity exhibited positive relationship (Padmavathi *et al.*, 2008). Abiotic conditions such as minimum temperature, temperature gradient, maximum relative humidity and average relative humidity had significant positive influence on *C. medinalis* population. In case of minimum relative humidity and sunshine hours a negative influence was observed. In addition, other factors such as maximum temperature, relative humidity gradient, average relative humidity, number of rainy days and rainfall imparted insignificant positive effect on population development (Chakraborty and Deb, 2011).

Principal component analysis was carried out to reduce the number of weather parameters which were carried to the model development as large number of variables would affect the model prediction. The results of the correlation between temperature – humidity factor had negative relationship with the light trap catches of all the insects. Rainfall factor had significant positive relationship with the light trap catches of BPH and RLF and negative relationship with YSB. Upadhyay and Sharma (2004) also used PCA to find out the factors which play important roles in the population build up of yellow stem borer and rice gundhi bug. They reported that rainfall and relative humidity played a significant role in the population build up of yellow stem borer and in case of the population of rice gundhi bug no meteorological variables were found to be significant. According to Mishra *et al.,* (2005), stem borer damage had a positive significant correlation with maximum, minimum temperature and a negative correlation with relative humidity. From the above studies we could understand that effect weather variables on the light trap catches varied with different locations. Hence, it was understood that effect of weather variables on the insect catches were location specific, as the relationship between weather variables and insect population were not the same at all places.

5.4.2. Generalized linear model

Most the literature which is devoted to forecasting of insect pests based on weather contains only simple forecasting models on the base of the time series methods or linear regression methods. Here we have used generalized linear model, which generalizes the linear regression. Generalized linear model was used over other linear models as it returns predictions on the scale of the response and the response variable need not be of normal distribution. The use of the link functions avoids the need for prior transformation of the response for back-transformation of predictions.

Chi square test was carried out on the equations developed to check its goodness fit. The results of chi square test revealed that, there were differences between observed and predicted values of number of light trap catches for all the three insects. It indicated that, there are many other factors which affect the number of light trap catches of the insects apart from weather parameter. Statistical models used to predict pest population rely heavily only on approximated weather. The reliability of predictions based on weather is less because there are variables that are either not calculated in prediction or they are ruled out of the prediction. For example in order to predict pest occurrence, a simulator would need to have all the current factors affecting pest occurrence, such as cultivar, management practices, etc,. The predictability of the equation can be increased if the weather factors are combined with the other factors (variety, soil, fertilizer application, etc.,) in developing the model.

Summary and Conclusion

CHAPTER VI

SUMMARY AND CONCLUSION

Rice is one of the most important and extensively grown foods in the tropical and subtropical regions of the world. Several improvements have been made to boost up productivity but insect pests still continue to be major limiting factor (Saxena and Shrivastava, 1992). Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming as temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Over the past 150 years, global average surface temperature has increased 0.76°C. Heat units are methods of quantifying a biological organism's thermal environment. Hence the GDD accumulation for each of the pest can be used to predict the pest occurrence. In addition, meteorological factors like temperature, relative humidity, rainfall and sunshine hours play an important role in seasonal abundance, distribution and population build up of insect pests.

In the light of the above, experiments were undertaken to study the behaviour of the major rice pests under different temperature regimes and corresponding thermal accumulation for growth and development and to develop a weather based forewarning model to forecast the pest population at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore.

Experiments were carried out in Climate Control Chamber where the required levels temperature was controlled by giving commands through the control panel. For this investigation five different constant temperatures (28.3°C, 30.6°C, 32.7°C, 34.3°C and 36°C) were maintained and major insects such as, Yellow Stem Borer (YSB), Brown Planthopper (BPH) and Rice Leaffolder (RLF) were considered for the study. Observations on demographic parameters of insects and thermal requirement were recorded at different temperature regimes. Apart from this, data on weekly light trap catches of insects were collected from the progress report of Directorate of Rice Research, Hyderabad for Cauvery delta region and a weather based forewarning model had been developed. The important inferences derived from the experiments and conclusion and recommendation of the experiments are given hereunder.

Summary

Demography

- The number eggs laid by YSB increased with increasing temperatures. In case of BPH, the number of eggs and hatching was observed to be lowest at higher temperature regimes. Eggs laid by RLF increased with increasing temperatures. However, the number of eggs laid by RLF has a turnaround after reaching 34.3°C and hence the number eggs were decreased at 36°C.
- The immature stages of YSB, BPH and RLF took more time to complete the development at lower temperature regimes, whereas it took less time at higher temperature regimes.
- The development time of YSB life cycle exhibited more linear growth pattern when compared to BPH and RLF.
- Generally, female lived longer than male adults at all the temperature regimes irrespective of the insect species.
- The longevity of YSB, BPH and RLF female at higher temperature regime (36°C) was 1.5, 5.5 and 2.25 days shorter when compared to the lower temperature regime (28.3°C).
- The total lifespan of YSB extended to a maximum of 52 days at 28.3°C whereas, it was only 38 days at 36°C. BPH took as long as 44 days to complete the generation at 28.3°C and as short as 32 days at 36°C. RLF took 36 days to complete the generation at 28.3°C, whereas it took only 27 days at 36°C.
- The age specific survivorship decreased with the progress of age at all the temperatures irrespective of the insect pests.
- In YSB, the 50 per cent of mortality was observed on 26.6 days after incubation at 28.3°C, whereas it was observed just on 7.2 days after incubation at 36°C. In the case of BPH, it was more (20.1 days) at 28.3°C, but only 6.3 days at 36°C. In RLF, 50 per cent of mortality was observed on 15.4 days at 36°C and was observed just on 5.5 days after incubation.
- The survival fraction remained higher for all the stages at lower temperature regimes (28.3°C and 30.6°C) and drastically reduced at higher temperature regime of 34.3°C for all the insects.
- The apparent mortality increased with increasing temperatures and reached its peak at 34.3°C, irrespective of the stage of insects and type of insect species.

- Mortality Survivor Ration (MSR) was observed to be increasing with increasing temperatures for all the stages irrespective of the insect pest under study.
- The Indispensable Mortality was observed to be decreasing with increasing temperatures for all the insects
- Generally YSB, BPH and RLF tend to be K favoring at higher temperature from being r favoring at lower temperature.
- Life expectancy of the tested insects revealed that it decreased with increasing temperatures.
- The results of the experiments conducted revealed that the pre-oviposition period of insects decreased with increasing temperatures.
- The net reproductive rate was observed to be higher at the lower temperature regimes and lower at higher temperature regimes of the experiment.
- All the population growth parameters (Finite rate of increase, Intrinsic rate of natural increase and doubling time) increased with increasing temperatures. However, the increase had a turnaround after a threshold temperature (34.3^{o}C) of the experiment and hence it has been reduced at 36.0^{o}C.

Thermal requirement

- The average degree days required to complete the development of YSB egg, larva and pupa were 136.3, 557.8 and 156.3, respectively. The female adult lived out its life after the accumulation of 142.8 degree days and male moth completed its life when it accumulated 101.4 degree days.
- BPH eggs required an average of 123.3 degree days to hatch into nymph and the nymphal stage must accumulate 269 degree days to become adult. The female adult of BPH died after accumulating 244.2 degree days and the male adult of BPH accumulated 178 degree days before ending its life.
- RLF eggs required an average of 98.1 degree days to hatch into larva and the larval stage must accumulate 344 degree days to become adult. The female adult of RLF died after accumulating 159 degree days and the male adult accumulated 82.8 degree days before ending its life.

Weather based pest forewarning model

- Temperature (maximum and minimum of current, one and two weeks before the light trap catches) had a significant negative relationship with the number of light trap catches of all the insects, whereas relative humidity had a significant positive relationship.

- Rainfall (current, one and two weeks before the light trap catches) had the positive correlation with the light trap catches of all the pests except YSB where current week of rainfall had negative relationship. But, none of the rainfall relationships were statistically significant.
- Weather based pest forewarning models for YSB, BPH and RLF were developed by using Generalized Linear Model. Chi square test revealed that, there were differences between observed and predicted values of number of light trap catches for all the three insects.

Recommendations

- The timing of the control measures like chemical spray to control the insects could be planned based on the thermal accumulation (degree days) of the insects which will reduce the cost of spray and improve the efficiency
- Weather based forewarning models developed for each insect could be used to forewarn the pest population at particular time which will be useful in planning the control strategies.

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ANNEXTURE I

Abbreviations

YSB – Yellow Stem Borer

BPH – Brown Plant Hopper

RLF – Rice Leaffolder

x – Age class

l_x – Survival rate at age x to the beginning of age of x

s_x – Survival rate at age class x

q_x – Age specific mortality rate

mn_x – Total number of females produced at age x

m_x – Total number of females/female at age x

L_x – Average number of individuals alive during age interval x to x + 1

T_x – Total days lived into the future by individuals of age class x in population

e_x – Life expectancy

r_m – Intrinsic rate of natural increase