INFLUENCE OF ELEVATED TEMPERATURE ON THE DYNAMICS OF PESTS AND DISEASES OF RICE

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Thesis submitted in part fulfillment of the requirements for the Degree of

MASTER OF SCIENCE IN AGRICULTURAL METEOROLOGY AND CLIMATOLOGY

to the Tamil Nadu Agricultural University, Coimbatore -641 003

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CERTIFICATE

This is to certify that the thesis entitled **"INFLUENCE OF ELEVATED TEMPERATURE ON THE DYNAMICS OF PEST AND DISEASE OF RICE"** submitted in partial fulfillment of the requirements for the Degree of **MASTER OF SCIENCE IN AGRICULTURAL METEOROLOGY AND CLIMATOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Ms. M. RAMYA** 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 or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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(M.RAMYA)

ABSTRACT

INFLUENCE OF ELEVATED TEMPERATURE ON THE DYNAMICS OF PESTS AND DISEASES OF RICE

By

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Degree : **Master of Science (Agriculture) in Agricultural Meteorology and Climatology**

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Investigations were carried out to study the influence of increasing temperature on the population dynamics of pests and diseases of rice (*Oryza sativa* L.) under laboratory and pot culture experiments. Experiments were conducted on the incidence of two paddy pathogens *viz*., blast (*Pyricularia grisea* Cooke) and sheath blight (*Rhizoctonia solani* Kuhn) and rice pests *viz*., brown planthopper (*Nilaparvata lugens*) and yellow stemborer (*Scirpophaga incertulas*) in relation with elevated temperatures.

The results of pathological study revealed that under elevated temperature the growth of both pathogens decreased under *in vitro* conditions. In this experiment maximum mycelial growth, dry mycelial weight and sporulation were recorded at 30°C in sheath blight and at 28°C in blast disease respectively. Under pot culture experiments maximum disease incidence in paddy sheath blight and blast was observed at 30°C and at 28°C respectively with the corresponding decrease in growth with increase in temperature and high relative humidity above 90 per cent. With increase in temperature the disease incidence showed a declined trend under reduced relative humidity. Defense related enzymes significantly increased upto 30°C and 28°C in sheath blight and blast disease respectively and decreased at higher temperature.

Investigations in the insect pests of rice revealed that there was an inverse correlation between temperature and total life span, developmental time and also fecundity.

However there was a positive correlation between temperature and net reproductive rate and development rate. In the same way survival of pests also had a negative correlation with temperature. In case of YSB and BPH, total life span at 38°C decreased significantly than at 30°C. Faster development rate of YSB and BPH was noticed at 38°C than 30°C. At higher temperature of 36°C the net reproductive rate was higher and the generation time was shorter compared to 30°C in YSB. In the case of BPH the NRR was significantly higher at 38°C and the generation time was shorter compared to 30°C.

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ABBREVATIONS USED

IPCC	: Inter Governmental Panel on Climate Change
ha	: hectare
%	: Per cent
ton	: tonnes
BPH	: Brown planthopper
YSB	: Yellow stem borer
CO_2	: Carbon dioxide
^{O}C	: Degree Celsius
CCC	: Climate Control Chamber
mm $year^{-1}$	: millimetre per year
ton ha^{-1}	: tonnes per hectare
GDP	: Gross domestic product
IARI	: Indian Agricultural Research Institute
lesion cm^{-2}	: Lesion per square centimetre
RH	: Relative humidity
Spores/ml	: spores per millilitre
POD	: polyphenol oxidase
PAL	: Phenylalanine ammonia lyase
PDA	: Potato dextrose agar
Conidia ml^{-1}	: conidia per millilitre
diam	: diameter
PDI	: Per cent disease intensity
ACRC	: Agro Climate Research Centre
TNAU	: Tamil Nadu Agricultural University

CHAPTER I

INTRODUCTION

Among the major food crops, rice (*Oryza sativa* L.) forms the stable food for more than half of the world's population. India has the largest paddy output in the world and is also the second largest exporter of rice in the world. India ranks first in area under rice (45 million ha.) and ranks second in production next to China. Rice occupies 23 per cent of the total cultivated area under cereals in the world, of which 89 per cent is in Asia (FAO, 2003). Asia produces 91 per cent of the world paddy production (Dubey, 2001), on which nearly half of the world's population depends for food and livelihood (Carriger and Vallee, 2007).

However rapid population growth and climate change have greatly aggravated the food shortage problem. Since the world population is increasing at 1.17 per cent annually, an annual increase in rice production of 0.6–0.9 per cent is required until 2050 (Carriger and Vallee, 2007) to meet the anticipated demand. Rice productivity is affected by several biotic factors such as insect pests and diseases, and abiotic factors due to climate change.

Among various constrains in rice production, losses due to pest and diseases are major concern. Fungal diseases, which cause a drastic reduction in yield in rice include blast, sheath blight and brown spot. In India the percentage of loss in yield due to disease was estimated to be 16.8 to 48.4 per cent. Rice blast is one of the most destructive diseases of rice because of its wide distribution and destructiveness. In India, more than 2,66,000 tons of rice were lost, which was about 0.8 per cent of their total yield (Netam *et al.*, 2011). In Japan, the disease can infect about 8,65,000 ha of rice fields. In Philippines, many thousand hectares of rice fields suffer more than 50 per cent yield losses (IRRI, 2003). A 10 per cent neck rot causes yield loss of six per cent and five per cent increases in chalky kernels (Katsube and Koshimizu, 1970). Next to rice blast, sheath blight is an increasing concern for rice production especially in intensified production systems (IRRI, 2003). In Japan, the disease caused a yield loss of as high as 20 per cent and affected about 1,20,000-1,90,000 ha (Roy and Saikia, 1976). A yield loss of 25 per cent was reported if the flag leaves are infected. In the United States,

a yield loss of 50 per cent was reported when susceptible cultivars were planted (Prasad and Eizenga, 2008). Studies at IRRI showed that sheath blight causes a yield loss of six per cent in tropical Asia.

Puri (2000) reported that yellow stem borer, gall midge and brown planthopper were the key pests in rice causing 10 to 70 per cent, 15-60 per cent and 25-30 per cent losser, respectively. Paddy pests cause enormous grain yield losses, which may vary from 20-50 per cent if not protected, India losses 30 per cent yield in rice every year (Saravanan, 2008). At high population density of planthoppers, hopper burn or complete drying of the plants is observed. At this level, the crop loss may be 100 per cent. Under field conditions, plants nearing maturity developed hopper burns, if infested with about 400-500 brown planthopper (BPH) nymphs. In the 1970s and 1980s, BPH was considered a threat to rice production in Asia. BPH also transmit ragged stunt and grassy stunt viruses (Cabauatan and Hibino 1991). It was recorded that at a population density of more than 400-500 nymphs or 200 adults per plant, WBPH can cause complete loss of rice plants (Reissig *et al.*, 1986). The yellow stem borer is an important pest of irrigated rice in South and Southeast Asia. In the Philippines, it caused about 5 to 10 per cent yield loss (PhilRice, 1999). About one to 19 per cent yield loss in early planted rice crops and 38 per cent to 80 per cent yield in late-planted rice were reported in India.

In India, paddy is one of the major crops that is vulnerable to the climate change. Climate change is a result of global warming resulting in the increase of earth's average temperature. Intergovernmental Panel on Climate Change (IPCC) report gives detailed projections for the 21st century and these show that global warming will continue and accelerate. The best estimates indicate that the earth could warm by 3°C by 2100. Even if countries reduce their greenhouse gas emissions, the earth will continue to warm. Predictions by 2100 range from a minimum of 1.8°C to as much as 4°C rise in global average temperatures (UNFCC). Climate change has serious concern for food production and food security (Parry *et al*., 2004). Rise in temperature causes grain sterility. Heat stress, increased crop respiration and transpiration can ultimately reduce the paddy yield. Mathauda *et al*. (2000) reported that the temperature increase in decrease the rice yield. In 2004, other researchers found that rice yields in the Philippines were dropping by 10 per cent for every 1°C increase in night-time temperature.

Climate change produces warmer temperatures, increases CO_2 gases, rainfall and drought that enhance disease, pests and weeds. Climate factors play a major role in determining the impact of several pests and diseases on rice crop yields. Experts predict that these events will cause pests and diseases to spread further, covering more areas that increasingly become suitable for them, and to multiply faster in current areas.

Climate change could first affect disease directly by either decreasing or increasing the encounter rate between pathogen and host by changing rates of the two species. Disease severity should be positively correlated with increases in virulence and aggressiveness of pathogens. However, both of these effects on disease will be mediated by host resistance and encounter rates, which in turn are potentially affected by climate. Temperature has potential impacts on plant disease through both the host plant and the pathogen. Research has shown that host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; but some forage species become more resistant to fungi with increased temperature (Coakley *et al.*, 1999). Luo *et al.* (1998) reported that under humid tropics, daily temperature changes by -1°C and -3°C resulted in significantly more severe blast epidemics and temperature changes by +1°C and +3°C cause less severe blast.

Climate change resulting in increased temperature could impact crop insect pest populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects. Moreover insects are cold-blooded organisms and hence the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. 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). It has been estimated that with a 2°C temperature increase insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998).

In light of these in the background, it is imperative to have a knowledge about the dynamics of pests and disease at elevated temperature. So that pragmatic management strategies could be drawn when temperature rises up. Therefore the present study was undertaken with the following objectives

a. To study the biology of important disease such as sheath blight (*Rhizoctonia solani*) and blast (*Pyricularia grisea*) of rice at elevated temperatures

b. To study the dynamics of population growth of the important insect pests such as yellow stem borer (*Scirpophaga incertulas*) and brown planthopper (*Nilaparvata lugens*) of rice.

CHAPTER II

REVIEW OF LITERATURE

2.1. Climate change

Climate is the long-term average of a region's weather events, thus the phrase 'climate change' represents a change in these long-term weather patterns (Sudipmitra, 2007). Sea level rise has been observed to increase by 0.4-2 mm year^{-1} along the Gulf of Kutch and the coast of West Bengal (Kumar, 2006). The increasing green-house gases (GHG) resulted in global warming by 0.74°C over past 100 years and 11 of the 12 warmest years were recorded during 1995-2006. The Intergovernmental Panel for Climate Change (IPCC) projections on temperature predicts an increase of 1.8 to 4.0°C, by the end of this century. Some changes will affect agriculture through their direct and indirect effects on crops, soils, livestock, fisheries and pests.

2.2. Impact of climate change

Climate change impacts will lead to economic losses for various sectors. Scientists report a decrease in yield of crops as temperature increases in different parts of India. For example studies carried out by Sinha and Swaminathan (1991) and Aggarwal and Kalra (1994) showed that on a 2°C increase in mean air temperature, rice yields could decrease by about 0.75 ton ha^{-1} in the high yield areas. The major impacts of climate change will be on rainfed or unirrigated crops, which is cultivated in nearly 60 per cent of cropland area. In India it is the poorest, most vulnerable farmers who practice rainfed agriculture. A temperature rise by 0.5°C in winter temperature is projected to reduce rainfed wheat yield by 0.45 ton ha^{-1} in India (Lal *et al*., 1998). Wheat production for the country as a whole may decline after 2020 and rice production may be adversely impacted in the eastern states. Boundary changes in the growth of crops are also expected. Studies by the Indian Agricultural Research Institute (IARI) indicate the possibility of a loss of 4–5 million tonnes in annual wheat production with every 1°C rise in temperature even after considering the carbon fertilization effect (Kumar, 2006). Climate change has negative implications on gross domestic product (GDP). At the global level, GDP is expected to decrease by US$ 87 billion under a scenario of moderate climate change, which is equivalent to 0.09 percent of global GDP (Alvaro *et al.*, 2009).

2.2.1. Impact on pests and diseases

Climates continually change and there is evidence for the effect of recent accelerated warming on many biological systems (Parry *et al*., 2007). Gregory *et al.* (1999) revealed that the pests and pathogens have major effects in determining actual yields in practice and the effects of climate change on pests and pathogens have been evaluated in some experimental and modelling studies (Garrett *et al*., 2006).

Climatic factors such as temperature and rainfall and relative humidity have known to greatly influence the insect population change (Muhamad and Chung, 1993; Way and Heong, 1994; Zhu, 1999; Heong *et al*., 2007; Siswanto *et al*., 2008). Porter *et al.* (1991) listed the effects of temperature on insects which limit their range, overwintering, population growth rate, number of generations per annum, length of growing season, crop-pest synchronization, intraspecific interaction, dispersal, migration and availability of host plants and refugia. CO_2 increase may not only influence the plant selection, but also alters plant-insect population. Impact of CO_2 on a wide range of phytophagous insect is an aspect which needs more intensive studies and available information points to the low insect abundance to elevated CO_2 levels in respect of insects such as *Empoasca sp, Trialeurodes vaporiorum* in different tomato cultivars. In *Myzus persica,* increase of mean temperature by 1°C advances the time of progeny migration by two weeks, also well evident in *Acyrthosiphon, Rhopalosiphum, Sitobion* (Ananthakrishnan, 2007).

Many pathosystems, it seems the cereal rusts in particular, are affected by temperature. At times about half of the wheat cultivars on the UK Recommended List (HGCA, 2003) showed differential resistance expression when tested against isolates of brown rust (*Puccinia triticina*), either effective at 10°C and not at 25°C or vice versa (Jones and Clifford, 2002; Jones, 2007). These differential responses to disease expression at different temperatures were also found against other rusts such as oat stem rust (Martens *et al*., 1967) and stripe rust (Gerechter-Amitai *et al*., 1984). In wheat stem rust the classical temperature sensitivity of the *Sr6* gene was extensively reported by Harder *et al*. (1979). The effect was not necessarily attributable simply to resistance gene expression response to temperature as isolates too showed differential temperature responses independent of resistance responses, and other authors reported similar effects

(Dyck and Johnson, 1983; Browder and Eversmeyer, 1986). However this condition not unique to rusts on cereals, but extend to other pathosystems involving monocot and dicot hosts and very different pathogens (Gregory *et al*., 2009). In rice some resistance genes, such as *Xa*7 effective against some *Xanthomonas oryzae* pv. *oryzae* races, are more effective at high temperatures than low, whereas other resistance genes are less effective (Webb *et al*., 2010).

2.3. Increasing temperature effects on pathogens

Plant pathogen interactions are known to be affected by environmental factors including temperature. Yi *et al.* (2009) reported that a moderate increase in temperature resulted in inhibition of (R) gene - mediated defence response to bacterial pathogen *Pseudomonas syringe.* Each pathogen has an optimum temperature for growth in addition, different growth stages of the fungus such as production of spores, their germination and the growth of the mycelium may have different optimum temperatures.

2.3.1. Impact of temperature on mycelial growth of pathogen and disease incidence

Mishra and Singh (1963) reported that the optimum temperature for infection and development of the *Helminthosporium turcicum* is 32°C. Below and above this temperature the infection progressively decreases and there is almost negligible infection at 16.1°C. At humidity levels lower than 90 per cent, no disease developed. The foot rot disease of coriander is favoured by a low temperature range (19°C and 24°C); higher temperatures (29°C and 34°C) tend to depress it (Gupta, 1963).

Suzuki (1969) reported that the temperature was the most important single determinant of disease. An epidemic of blast develops during prolonged periods when the average daily temperatures range between 19 and 28°C and minimum daily temperatures range between 17 and 23°C. Incubation of inoculated seedlings in alternating day/night temperature regimes of 32/24°C or 28/20°C reduced the rate of disease development compared with that at 28°C in *Colletotrichum gloeosporioides* f. sp. *aeschynomene*. (Te Beest *et al.*, 1978).

Chang and Shizuo (1986) reported that the typical leaf blast lesions produced more in 29/21°C -23/15°C plot than in other temperature but total number of typical lesions decreased as the length of duration became longer. On the contrary, total number

of typical lesions increased by the longer duration in 23/15°C -29/21°C plot. The constant exposure of leaves to 20°C or 24°C temperature and high relative humidity for at least 12 hour in six day period were favourable for infection of peanut by *Cercosporidium personatum* (Shew *et al.,* 1988).

Lesion densities (lesion cm^{-2}) increased with increasing wet periods depending on optimum temperature in *Bipolaris oryzae* (Percich *et al*., 1997). Li *et al.* (1998) reported that the *Rhizoctonia* on potato dextrose agar (PDA; pH6.4), the minimum temperature for mycelial growth of *R. zeae* isolates was 14-18^{0}C, the maximum 38-40°C and optimum 30°C. Gross *et al*. (1998) studied that the *Rhizoctonia solani* in perennial rye grass was most severe (greater than 50 leaves with brown patch lesions per pot) when plants were in contact with the inoculum source for 24-h of leaf wetness at 24°C. The least amount of disease (0 leaves with lesions per pot) occurred at 15°C and a 9-h wet period.

Chungu *et al.* (2001) also found that the increasing incubation temperature, duration of leaf wetness, and inoculum concentration resulted in an increase in *Septoria tritici* disease severity. They found that the optimal incubation temperatures conditions for *Septoria tritici* blotch were 18°C day/15°C night and 22°C day/15ºC night.

Grove (2002) reported that the *Wilsonomyces carpophilus* disease severity increased with wetness duration at each temperature tested. At 15°C, severity increased from no lesions at wetness durations less than 1 h to 0.1 lesions / cm^2 followed by 1.9, 6.8, and 9.1 lesions / cm^2 after 6, 12, 18, and 24 h wetness duration respectively. Although severity values were different, the general responses to temperature and wetness period were similar on peach.

Samui *et al.* (2005) found that decrease in maximum and minimum temperature below 34°C and 22°C respectively and increase in morning and afternoon relative humidity above 82 and 78 per cent respectively favour the infection of the late leaf spot disease. The temperature ranges from 21-23°C and 23-27°C favoured the mycelial growth of *Alternaria brassicae* and *A. brassicicola* respectively *in-vitro*. Lower temperature (23°C) was found optimum for growth of *A. brassicae* as compared to 25°C for *A. brassicicola* (Deepak and Choudhary, 2006).

Sener and Fatih (2005) reported that the mean lesion number increased in parsley plants as wetness duration increased at 20 and 23°C, whereas disease development decreased in parsley leaves as wetness duration increased at temperatures of 15, 17, 27, and 32°C. Low levels of *Septoria* blight on parsley developed across a wide temperature range. Leaf wetness duration significantly increased disease severity, but only at optimal temperatures. In the study conducted by Becktell and Daughtrey (2005) temperatures ranging from 13 to 23°C generally were conducive to establishment of *Phytophthora infestans*. But very little establishment occurred at 28°C.

Paul and Munkvold (2005) reported that the temperature had a significant effect on lesion expansion of *Cercospora zeae-maydis* ($P \leq 0.05$). At 25 and 30°C, the rate of lesion expansion was significantly higher than at 35°C ($P \leq 0.05$). The largest lesions and the highest mean rate of lesion expansion were observed at 30°C; however, the mean lesion expansion rate at this temperature was not significantly different from that at 25°C. Castejon-Munoz (2008) stated that the temperature increase of 1°C in early August (mid-tillering stage) led to an increase in the mean intensity of *Pyricularia oryzae* disease. At temperatures slightly lower than optimum (20-25°C), mycelial development and time of appearance of the first conidiophores was delayed in tomato powdery mildew (*Oidium neolycopersici*) (Barbora and Ales, 2010). Ranjana *et al.* (2010) has also found that the disease severity of *Pestalotiopsis disseminata* was favoured in the optimum range of temperature (25 ±2°C) and RH (70%) which had a combined effect.

2.3.2. Impact of temperature on sporulation

Henry and Anderson (1948) reported that the mode of sporulation of *Rhizoctonia* with respect to time varies with temperature. At 28°C the conidia were found to be produced rapidly but production decreased after 9 days, whereas sporulation at 16-24°C tended to increase even after 15 days.

According to Kuribayashi and Ichikawa (1952) reproduction and propagation of rice blast fungus are greatest at high humidity and comparatively low temperature (21-24°C). The propagating capacity decreases if the temperature is either above or below these temperatures. If temperatures are above 31°C during the growth stage, the rice plants become resistance to disease. Optimum conditions for conidia dispersal are 20.5- 21.8°C and 90 per cent RH.

Secondary infection of *Helminthosporium teres* was found to occur at a temperature range of 8-33°C and no infection at 35°C in artificially inoculated plants; optimum temperatures for secondary infection and for further development of net-blotch of barley were found to be 25 and 29°C respectively (Sheodhan, 1962). The optimum range of temperature for *Helminthosporium turcicum* Pass spore germination lies between 20 to 30°C. The spores germinate within a range of 90.2 to 100 per cent. At 90.2 per cent RH the spore germinate in 36 hours but at 100 per cent R.H they germinate within 2 hours (Mishra and Singh, 1963).

The germination percentage of *cercospora* conidia was decreased with increased temperature above 20°C and at 20°C; it took about 12 hour for 50 per cent of the conidia to germinate (Sommartya and Beute, 1986). Sharma and Gupta (1992) reported that the germination of *Podosphaera leucotricha* conidia was observed between 5 and 30°C with optimum at 20°C. Munshi and Singh (1994) revealed that the production of conidiophores and conidia at 25°C followed by 20°C and 30°C but not at 35 and 40°C.

Chavan *et al*. (1995) reported that the temperature in the range of 12.2 to 30.1°C and RH >57.4 per cent favoured the spore production of *Uncinula necator*. According to Arun and Singh (1995) all the paddy isolates (*Pyriculeria grisea*) exhibited maximum growth and sporulation at 30°C. With the increase in incubation period, conidial germination improved upto 21°C temperature but with the rise in temperature it declined. Deepak and Choudhary (2006) reported that the maximum sporulation was supported by 23 - 25°C temperature whereas 23 - 27°C temperature supported maximum sporulation for *A. brassicicola.*

Zoospores of *Plasmopara viticola* germinated at temperatures ranging from 5 to 30°C, but not at 35°C. Germ tubes penetrated stomatal apertures at temperatures ranging from 10 and 25°C, but not at 30 or 35°C and rarely at 5°C. A 20°C dark environment favoured zoospore germination and host penetration, whereas both infection events occurred at a lower frequency in the light. (Williams *et al.*, 2007)

Leptosphaeria maculans germination began after 2 h at 10-20°C and 4 h at 5°C. After 24 h, the percentage germination of ascospores was greater at the higher temperatures of 15 and 20°C, compared with the lower temperatures of 5 and 10°C

(Nasary *et al.*, 2008). Castejon-Munoz (2008) reported that the relative humidity of 95 per cent and an average temperature of 26-27°C were optimum for infection and substantially favoured spore release in *Pyricularia oryzae*.

Bhat *et al.* (2009) stated that maximum growth and fructification of *Didymella bryoniae* was on potato dextrose agar and corn meal agar media maintained at pH 7.0 and incubated at 24±1°C. Spore germination of *Didymella bryoniae* was best at temperature and pH of 24±1°C and 7.0 respectively. Prem *et al.* (2009) reported that the optimum temperature for growth and sporulation was recorded at 28°C in *Bipolaris sorokiniana*.

Ranjana *et al.* (2010) has also found that the nonlinear relationship was found between temperature and germination percentage of *Pestalotiopsis disseminata* spores at a given relative humidity (RH). However, 25°C (±2) temperature and 70 per cent RH were the optimum parameters for better spore germination of the pathogen.

Oidium neolycopersici Conidia germinated across the whole range of tested temperatures (10- 35°C); however, at the end-point temperatures, germination was strongly limited. Conidiation occurred within the range of 15-25°C, however was most intense between 20-25°C (Barbora and Ales, 2010).

Sood (2011) stated that *Aspergillus umbrosus* growth rate was very less with minimum sporulation and light yellow colouration of the medium at below 20°C. Sporulation was also good at 26 and 30°C with dark-brown coloration of the medium, indicated the secretion of secondary metabolites. At 35°C the growth and sporulation were negatively affected and the medium colour was also greenish. Pycnidia were observed 4 days earlier when incubation temperature increased from 18°C day/15°C night to 22°C day/15°C night or when inoculum concentration increased from 1×10^6 spores/ml to 1×10^7 spores/ml (Chungu *et al.*, 2001). The optimum temperature for macroconidial production was 32°C for *Fusarium culmorum* and *F. gramineaum*, 28°C for *F. avenaceum*, and 26°C for *Microdochium nivale*. Under natural conditions, temperature affected sporulation more than the other meteorological factors (Rossi *et al*, 2002).

2.3.3. Impact of temperature on plant defence enzymes

Patel and Gemawat (1983) has also found that the enzymatic activity increased with increase in temperature from 5-25°C reaching a maximum at 25°C after which it

declined. The enzyme production was related to the amount of growth of the fungus. Similar results have been reported by Gupta and Gupta (1966) and Singh (1968) with other species of *Fusarium* and *Phoma*.

Patel and Pathak, (1996) reported that the severity of the *Rhizopus* rot along with the activities of cell wall degrading enzymes was highest at 100 per cent RH and lowest at 30 per cent RH in semi ripe fruits.

Time courses at 50°C showed a rapid loss of POD activity and a similar but slower loss of PPO activity in all tissue while incubation at 4°C and 25°C showed no significant loss of activity over the same time period. (Martin-Diana *et al.,* 2005)

2.4. Increasing temperature effects on pests

Temperature is identified as dominant abiotic factor directly affecting herbivorous insects. Temperature directly affects the development, survival and abundance of insects.

2.4.1. Impact on global warming on arthropod diversity and extinction of species

Arthropods are the most important and diverse component of terrestrial ecosystems and occupy a wide variety of functional niches and microhabitats (Kremen *et al*., 1993). We can take advantage of the terrestrial arthropod diversity as a resource for conservation and management of different eco-systems. Monitoring of terrestrial arthropods can provide early warnings of ecological changes due to climate change. Arthropods can be used as indicators of environmental change more rapidly than the vertebrates (Scherm *et al*., 2000; Gregory *et al*., 2009). At higher trophic levels, an indirect effect in terms of habitat loss and a reduction in prey availability has also been observed. Large scale changes in rainfall due to climate change will have a major effect on the abundance and diversity of arthropods. Extreme climatic events such as drought are likely to decrease multi-trophic diversity and change the composition of arthropod communities, which in turn might affect the other associated taxa. In the forest eco-systems, chronic stress significantly altered community composition, and the trees growing under high stress supported 1/10th the number of arthropods compared to trees growing under more favourable conditions (Talbot *et al*., 2008). Arthropods (insects, spiders, and mites) are the most abundant and diverse group of organisms (Kannan and James, 2009; Gregory *et al*., 2009). Increase in

rainfall in the Pampas region of Argentina will largely affect the species with poor dispersal capabilities, which will limit their ability to expand their home range. The most affected among the beetle species are the habitat specialists (Xannepuccia *et al*., 2009). Increasing tree stress was also correlated with an eight to 10-fold decline in arthropod species richness and abundance. Arthropod richness and abundance on individual trees were positively correlated with the tree's radial growth during drought, suggesting that tree ring analysis could be used as a predictor of arthropod diversity (Stone *et al*., 2010).

For monitoring purposes, indicator assemblages should exhibit varying sensitivities to environmental changes, and exhibit diversity in life-history and ecological interactions. Realistic information on arthropod diversity must be integrated into policy planning and management practices if ecosystems are to be managed for use by future generations. Ecosystem baselines that document arthropod species assemblages in a manner comparable in space and time are key to interpretation and implementation of strategies designed to mitigate the effects of global warming and climate change on biodiversity. Main effects of climate change and pollution on arthropod communities result in decreased abundance of decomposers and predators, and increased herbivory, which may have negative consequences for structure and services of the entire ecosystems. Responses of arthropods to pollution depend on both temperature and precipitation, and ecosystem-wide adverse effects are likely to increase under predicted climate change (Zvereva and Kozlov, 2010). Consequences of temperature increases of 1 to 2°C will be comparable in magnitude to the currently seen climate change in the Antarctic region (Bokhorst *et al*., 2008).

Speciation takes between 100 and 1,000,000 years, providing between 10 and 10,000 new species per annum. Nearly 99.9 per cent of all species that ever existed have become extinct. We are now living through the sixth extinction spasm, which is largely driven by human activities. The relative abundance of different insect species may change rapidly due to climate change, and the species unable to withstand the stresses may be lost in the near future (Thomas *et al*., 2004; Jump and Penuelas, 2005). The current extinction rates are 100 to 1,000 times greater than what has happened earlier, and nearly 45 to 275 species are becoming extinct every day. There was a negative impact on the biology and life table of Aphid, *Rhopalosiphum padi* (L.). at higher temperature (Auad *et al.,* 2009).

2.4.2. Impact of climate change on geographic distribution and population dynamics of insect pests

Climate change will have am major effect on geographic distribution of insect pests and low temperatures are often more important than high temperatures in determining geographical distribution of insect pests (Hill, 1987). Spatial shifts in distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry and Carter, 1989). However, whether or not an insect pest would move with a crop into a new habitat will depend on other environmental conditions such as the presence of overwintering sites, soil type, and moisture, e.g., populations of the corn earworm, *Heliothis zea* (Boddie) in the North America might move to higher latitudes/altitudes, leading to greater damage in maize and other crops (EPA, 1989). Increasing temperatures may result in a greater ability to overwinter in insect species limited by low temperatures at higher latitudes, extending their geographical range (EPA, 1989; Hill and Dymock, 1989; Elphinstone and Toth, 2008) and sudden outbreaks of insect pests can wipe out certain crop species, and also encourage the invasion by exotic species (Kannan and James, 2009). Some plant species may be unable to follow the climate change, resulting in extinction of species that are specific to particular hosts (Thomas *et al*., 2004). 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). Pest outbreaks are more likely to occur with stressed plants as a result of weakening of plants' defensive system and thus, increasing the level of susceptibility to insect pests (Rhoades, 1985). 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; Utida, 1958; Kiritani and Iwao, 1967). The expansion of its distribution ranges has usually occurred though increased density mediated by increased reproduction (Kiritani and Morimoto, 2004).

Rising temperatures are likely to result in availability of new niches for insect pests. Fecundity, egg viability, oviposition period, and adult longevity were reduced with increasing temperature (Rodrigues *et al.*, 1989). Global warming will lead to earlier infestation by *H. zea* in North America (EPA, 1989) and *Helicoverpa armigera* (Hub.) in North India (Sharma, 2010) resulting in increased crop loss. Temperature has a strong influence on the viability and incubation period of *Agrotis ipsilon* and *H. armigera* eggs (Chaudhary and Malik, 1980; Dhillon and Sharma, 2007). Egg incubation period can be predicted based on day degrees required for egg hatching, which decreases with an increase in temperature from 10 to 27°C, and egg age from 0 to 3 days (Dhillon and Sharma, 2007). An increase of 3°C in mean daily temperature would cause the carrot fly, *Delia radicum* (L.) to become active a month earlier than at present (Collier *et al*., 1991) and temperature increases of 5 to 10°C would result in completion of four generations each year, necessitating adoption of new pest control strategies. Female lifetime fecundity of Sunn pest *Eurygaster integriceps* was increased under increasing temperature (Iranipour *et al.,* 2010). 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). The mean developmental period (egg to adult) of yam moth *Euzopherodes vapidella* and corn stalk borer *Diatraea lineolata* was decreasing with increasing temperature (Rodrigues *et al.*, 1989; Ashamo and Odeyemi, 2001). An increase of 1 and 3°C in temperature will cause northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hub.) up to 1,220 km, with an additional generation in nearly all regions where it is currently known to occur (Porter *et al*., 1991).

Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build-up in numbers in the following season. These may be vulnerable to parasitoids and predators if the latter also overwinter more readily. Diamond back moth, *Plutella xylostella* L. overwintered in Alberta in 1994 (Dosdall, 1994), and if overwintering becomes common, the status of this insect as a pest in North America will increase dramatically. There may also be increased dispersal of airborne insect species in response to atmospheric disturbances. Many insects such as *Helicoverpa* spp. are migratory, and therefore, may be well adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma, 2005).

2.4.3. Effect of global warming on species diversity and its influence on pest management

Biodiversity plays an important role in abundance of insect pests and their natural enemies (Sharma and Waliyar, 2003). System diversity can be exploited to enhance the resilience of agro-eco-systems, improve resource utilization, and stabilize yields to cope with the effects of global warming and climate change on food security (Sharma and Waliyar, 2003; Newton *et al*., 2009). However, changes in cropping patterns as a result of climate change will drastically affect the balance between insect pests and their natural enemies. Since climate change will lead to a shift in cultivation of crops in non-traditional areas and crop rotations, this may influence the prevalence and importance of specific pests (Maiorano *et al*., 2008). There is a need to increase functional diversity in agro-ecosystems vulnerable to climate change to improve system resilience, and decrease the extent of losses due to insect pests (Newton *et al*., 2009).

2.4.4. Effect of climate change on expression of resistance to insect pests

The introduction of new crops and cultivars to take advantage of the new environmental conditions is one of the adaptive methods suggested as a possible response to climate change (Parry and Carter, 1989). Global warming may result on breakdown of resistance to certain insect pests. Sorghum varieties exhibiting resistance to sorghum midge, *Stenodiplosis sorghicola* (Coq.) in India become susceptible to this pest under high humidity and moderate temperatures near the Equator in Kenya (Sharma *et al*., 1999). There will be increased impact on insect pests which benefit from reduced host defences as a result of the stress caused by the lack of adaptation to sub-optimal climatic conditions. Chemical composition of some plant species changes in direct response to biotic and abiotic stresses as a result, their tissues less suitable for growth and survival of insect pests (Sharma, 2002). Global warming may also change the flowering times in temperate regions, leading to ecological consequences such as introduction of new insect pests, and attaining of a pest status by non-pest insects (Fitter and Fitter, 2002; Parmesan and Yohe, 2003; Willis *et al*., 2008). However, many plant species in tropical regions have the capability to withstand the phenological changes as a result of climate change (Corlett and LaFrankie, 1998). Host plant resistance to insects is one of the most environmental friendly components of pest management. However, climate change may alter the

interactions between the insect pests and their host plants (Bale *et al*., 2002; Sharma *et al*., 2010). However, problems with new insect pests will occur if climatic changes favour the introduction of insect susceptible cultivars or crops.

The effects of increased atmospheric CO_2 on herbivory will not only be species specific, but also specific to each insect-plant system. Although increased CO_2 tends to enhance plant growth rates, the larger effects of drought stress will probably result in slower plant growth (Coley and Markham, 1998). In atmospheres experimentally enriched with CO_2, the nutritional quality of leaves declined substantially due to dilution of nitrogen by 10 to 30% (Coley and Markham, 1998). In the enriched CO_2 atmosphere expected in the next century, many species of herbivorous insects will confront less nutritious host plants that may induce both lengthened larval developmental times and greater mortality (Coviella and Trumble, 1999). Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40%, while unusually severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* in sorghum (Sharma *et al*., 2005). Increased CO_2 may also cause a slight decrease in nitrogen-based defences (e.g., alkaloids) and a slight increase in carbon-based defences (e.g., tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity (Gore, 2006). Insect - host plant interactions will change in response to the effects of CO_2 on nutritional quality and secondary metabolites of the host plants. Increased levels of CO_2 will enhance plant growth, but may also increase the damage caused by some phytophagous insects (Gregory *et al*., 2009). Endophytes, which play an important role in conferring tolerance to both abiotic and biotic stresses in grasses, may also undergo a change in response to disturbance in the soil due to climate change (Newton *et al*., 2009).

2.4.5. Effect of global warming on the activity and abundance of natural enemies

Relationships between insect pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects (Young, 1982) and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management

(Hill and Dymock, 1989). Quantifying the effect of climate change on the activity and effectiveness of natural enemies for pest management will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is considerable evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies – pathogens, parasites, and predators (Price, 1987). Aphid abundance increases with an increase in CO_2 and temperature, however, the parasitism rates remain unchanged in elevated CO_2. Temperatures up to 25°C will enhance the control of aphids by coccinellids (Freier and Triltsch, 1996). Oriental armyworm, *Mythimna separata* (Walk.) populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall because of the adverse effects of drought on the activity and abundance of the natural enemies of this pest (Sharma *et al*., 2002). Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids (Dhillon and Sharma, 2009). The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management.

CHAPTER III

MATERIALS AND METHODS

Research investigations were conducted to study the influence of increasing temperature on pest and disease population dynamics of rice (*Oryza sativa* L.) both laboratory and control chamber. Life history traits of pest, mycelial growth, sporulation and enzyme activity of pathogen were studied under laboratory conditions.

Laboratory studies were carried out at the Department of plant pathology, Tamil Nadu Agricultural University (TNAU), Coimbatore. Control chamber experiments were conducted at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore. The materials utilized and methodologies adopted are described under this chapter.

I. STUDIES ON IMPACT OF TEMPERATURE ON RICE PATHOGENS

The important rice diseases *viz.,* rice blast (*Pyricularia grisea* Cooke) and sheath blight (*Rhizoctonia solani* Kuhn) were investigated under different temperature conditions both *in vitro* and under controlled conditions.

3.1. Isolation of pathogen and maintenance of culture

Paddy plants showing typical sheath blight symptom and paddy leaves showing typical leaf symptoms of blast were collected from Paddy Breeding Station, Coimbatore.

3.1.1. Paddy sheath blight

The diseased paddy leaves showing typical symptoms of sheath blight were surface sterilized with 0.1 per cent mercuric chloride for 60 seconds followed by 3 washings with sterile distilled water. Then the bits were placed on potato dextrose agar (PDA) medium by following half plate method. The plates were incubated at room temperature (28±2°C) for 5 days. The pathogen was purified by hyphal tip method (Rangasami, 1972) and maintained on PDA slants at 4°C throughout the study.

3.1.2. Paddy blast

Blast lesions were surface sterilized with 0.1 per cent mercuric chloride solution for one minute and placed over clean glass slides kept in sterile Petri dishes padded with moist cotton. The Petri dishes were incubated for 48 h at room temperature (28±2°C). Single conidium was identified from the sporulating lesions using a stereomicroscope and

aseptically transferred to potato dextrose agar (PDA) slants for maintenance. The purified culture was maintained on PDA slants at 4°C throughout the study.

3.2. Pathogenicity test

3.2.1. Paddy sheath blight

The pathogenecity of the isolates was tested by growing them on rice hull–rice grain medium (rice hull, 300 g; rice grain, 100 g; and distilled water, 200 ml) (Mew and Rosales, 1986). The mixture was placed in a 500-ml conical flask and autoclaved at 121°C for 20 min. A 6-mm agar disc taken from the periphery of a 5-day-old culture of *R. solani* grown on PDA in a Petri dish was transferred aseptically to the sterilised rice hull medium and incubated for 2 weeks at room temperature (27±2°C). Forty-five-day-old rice plants raised in plastic pots were inoculated with *R. solani* by placing the rice hull–rice grain inoculam (1 g) in between the stem and the basal leaf sheath of each tiller of the hill at about 3–4 cm above the water line (Vidhyasekaran *et al*., 1997). The disease intensity was recorded after symptom development.

3.2.2. Paddy blast

The pathogenecity of isolates was tested by sowing fifty seeds of rice variety ADT 43 were sown in 10 cm-dia pots containing wetland soil. Coimbatore isolate of *P. grisea* was multiplied on maize stem bits and 15 stem pieces were placed in 25 ml of sterile water, shaken well and decanted. The decanted spore suspension containing 2×10^3 conidia ml^{-1} was sprayed with 1ml of teepol on to 12-day-old rice seedlings using an automizer. The pot containing the seedlings was covered with a polythene bag and kept in chamber and observed for symptom development.

3.3. *In vitro* studies

3.3.1. Growth of *R. solani* and *P. grisea* under different temperatures on solid medium

The growth of the pathogen at different temperature levels of 25, 28, 30, 32, 35, 38, 40, 42,45, and 48°C for sheath blight and 18, 20, 22, 25, 28, 30, 32, 35, 38 and 40°C for paddy blast was tested using BOD incubators. Fifteen ml of PDA medium was poured into each of 100 ml petri dishes. After sterilization, the Petri dishes were inoculated with 5mm culture disc of mycelium. Petri dishes were incubated upto 3 days for sheath blight

and 15 days for blast at above mentioned temperature levels. Three replications were maintained for each treatment and the mycelial growth was recorded and analyzed statistically.

3.3.2. Growth of *R. solani* and *P. grisea* under different temperatures in liquid media

Potato dextrose broth containing 75 ml of PDA in 250 ml Erlenmeyer flasks was inoculated aseptically with 5 mm diameter mycelial growth at same temperatures mentioned above. The flasks were incubated for 8 days. Three replications were maintained for each treatment. The mycelial biomass was taken after the incubation period, dried in hot air oven and expressed as dry weight mycelium in mg.

3.3.3. Assessment of sporulation intensity

3.3.3.1. *R. solani*

A mycelial plug (5 mm diam) of isolate of *R. solani* was removed from a colony grown on PDA for 2 days, inoculated on PDA in a Petri dish (90 mm diam) and incubated at increasing temperatures. Number of sclerotia in each dish was determined after 1-month incubation

3.3.3.2. *P. grisea*

The intensity of sporulation of the *P. grisea* under increasing temperature was determined. Equal quantities of inoculum disc was transferred to 10 ml of sterilized potato dextrose agar slants and incubated under increasing temperature (18 to 48^0C) for a period of 15 days. After 15 days growth, sterile distilled water (10 ml) was added to each test tube and the tubes were shaken well in a mechanical shaker. The spore concentrations were checked with the help of hemocytometer.

3.4. Pot culture studies under elevated temperature

The pot culture experiments on rice diseases were carried out in plastic pots measuring 30 cm dia x 60 cm height with soil from wetland paddy field. Rice sprouted seeds of variety ADT 43 were sown in the plastic tray and thin film of water was maintained throughout the nursery. Fifteen days of seedlings were transplanted to the plastic pots. At the time of artificial inoculation these pots were transplanted to climate control chamber and further investigations were carried out (Plate 1).

3.4.1. Sheath blight of rice (*R. solani*)

The rice cultivar ADT 43 raised in pots were inoculated with rice hull grain inoculum in between the stem and the basal leaf sheath and covered with moist cotton at late tillering stage. The artificially inoculated plants were observed for development of symptom under control environment conditions at different temperatures *viz*., 25, 28, 30, 35, 38, 40 and 42^{o}C. Relative humidity also was recorded in control chamber. The PDI was calculated as per the standard grade chart given below based on the affected tillers (Anon, 2003).

Grade	Description
0	No incidence
1	< 1% incidence of affected tillers
3	1-5% incidence of affected tillers
5	6-25% incidence of affected tillers
7	26-50% incidence of affected tillers
9	51-100% incidence of affected tillers

$$PDI = \frac{\text{Sum of numerical rating}}{\text{Number of leaves observed}} \times \frac{100}{\text{Maximum disease score}}$$

3.4.1.2. Paddy leaf blast (*P. grisea*)

The paddy cv. ADT 43 was inoculated with *P. grisea* 3 weeks after transplanting by spraying with conidial suspension with 0.5 per cent gelatine (10^6 conidia ml^{-1}). The observation or disease incidence was recorded under climate control chamber at different temperature and the PDI was calculated as per the grade chart given below.

IRRI standard evaluation system

Scale	Evaluation system
0	= No lesions
1	= Small brown specks of pin head size without sporulating centre
2	= Small roundish to slightly elongated necrotic grey spots, about 1 to 2 mm diameter with distinct brown margin, lesions are mostly found on the lower leaves

3	=	Lesion type is same as in scale 2, but significant numbers of lesions are on the upper leaves
4	=	Typical sporulating blast lesions, 3 mm or longer infecting less than 2 per cent of the leaf area
5	=	Typical blast lesions infecting 2 to 10 per cent of the leaf area
6	=	Blast lesions infecting 11 to 25 per cent of the leaf area
7	=	Blast lesions infecting 26 to 50 per cent of the leaf area
8	=	Blast lesions infecting 51 to 75 per cent of the leaf area
9	=	More than 75 per cent leaf area affected

Disease reaction scores: 0-3 are rated as resistant (R), 4-6 as moderately resistant (MR) and 7-9 as susceptible (S).

3.4.2. Biometric observations

Biometric observations were recorded as per the guidelines for both the disease of All India Co-ordinated Rice Improvement Project, Hyderabad. In each pot five hills were selected at random and tagged for recording biometric observations at maximum tillering, flowering and harvest stages.

3.4.2.1. Plant height

The plant height of the five tagged plants in each pot were measured from the base of the plant to the tip of the top most leaf at maximum tillering and base to the tip of panicle at flowering and harvest stages. Mean value of the five hills was recorded and expressed in cm.

3.4.2.2. Total number of tillers

The number of tillers hill^{-1} was counted in five sample hills in each pot at maximum tillering, flowering and harvest stages and the mean value was expressed as total tillers m^{-2}.

3.4.2.3. Productive tillers

Ear bearing tillers alone were counted in tagged plants and expressed as productive tillers m^{-2}.

3.4.3. Enzyme studies

3.4.3.1. Sample collection

Samples were collected from individual treatments to study the induction of defense enzymes in response to pathogen attack in paddy plants under elevated temperature. Sheath and leaf tissues from artificially inoculated plants were collected at 0 day, 1st day, 3rd day, 5th day and 7th day after pathogen inoculation.

3.4.3.2. Enzyme extraction

The leaf tissues were collected from artificially inoculated paddy plants under elevated temperature and immediately homogenized with liquid nitrogen. One g of powdered sample was extracted with 2 ml of 0.1 M sodium citrate buffer (PH 5.0) at 4°C. The homogenate was centrifuged for 20 min at 10,000 rpm. Protein extracts prepared from rice plant tissues were used for estimation of defense enzymes. Sodium phosphate buffer 0.1 M (PH 7.0) was used for the extraction of polyphenol oxidase, and phenylalanine ammonia lyase enzymes.

3.4.3.3. Assay of phenylalanine ammonia-lyase (PAL)

One gram of plant sample was homogenized in 3 ml of ice cold 0.1 M sodium borate buffer, pH 7.0, containing 1.4 mM of 2-mercaptoethanol and 50 mg of insoluble polyvinylpyrrolidone (PVP). The resulting extract was filtered through cheese cloth and the filtrate was centrifuged at 20,000 g for 15 min at 4°C and the supernatant was used as the enzyme source. PAL activity (EC 4.3.1.5) was determined as the rate of conversion of L-phenylalanine to trans-cinnamic acid at 290 nm. Sample containing 0.4 ml of enzyme extract was incubated with 0.5 ml of 0.1 M borate buffer, pH 8.8 and 0.5 ml of 12 mM L-phenylalanine in the same buffer for 30 min at 30°C. The amount of trans-cinnamic acid synthesized was calculated using its extinction coefficient of 9630 $M^{-1}cm^{-1}$ (Dickerson *et al.*, 1984). Enzyme activity was expressed in fresh weight basis as n mol trans-cinnamic acid min^{-1} mg^{-1} of sample.

3.4.3.4. Assay of polyphenoloxidase (PPO)

One gram of sample was homogenized in 2 ml of 0.1 M sodium phosphate buffer (pH 6.5) at 4°C. The homogenate was centrifuged at 20,000 g for 15 min at 4°C. The supernatant served as enzyme source and polyphenoloxidase (EC 1.14.18.1) activity

was determined as per the procedure given by Mayer *et al* (1965). The reaction mixture consisted of 1.5 ml of 0.1 M sodium phosphate buffer (pH 6.5) and 200 µl of the enzyme extract. To start the reaction, 200 µl of 0.01 M catechol was added and the activity was expressed as change in absorbance $min^{-1}mg^{-1}$ of protein.

3.5. Statistical analysis

The data were statistically analysed by using AGDATA and AGRES. The data values were represented in least significant difference (LSD) and analysed by completely randomized design.

II. STUDIES OF TEMPERATURE IMPACT ON RICE PESTS

The important rice pests *viz.,* brown planthopper (BPH) (*Nilaparvata lugens*) and yellow stem borer (YSB) (*Scirpaphoga incertulas*) were investigated under different temperatures in climate control chamber.

3.5. Insect culture

Insect rearing is a complex and specialized field. It is a backbone of modern experimental entomology. The development of new pest control strategies depends upon our ability to rear and manage quality insects in the insectary. BPH (*N. lugens*) and YSB (*S. incertulas*) were used as the test insects during the investigation.

3.5.1. Brown planthopper (BPH)

The nucleus cultures of planthoppers were collected from the paddy fields of Paddy Breeding Station, Tamil Nadu Agricultural University, Coimbatore. In order to maintain an uniform and continuous culture of the hoppers, the insects were mass cultured using potted TN1 rice plants. Ten days old TN1 rice seedlings were transplanted in plastic pots (30 cm dia and 45 cm height) at the rate of five seedlings per pot. Thirty days after transplanting, the plants in individual pots were cleaned and outer leaf sheaths were removed to destroy any possible oviposition by other insects. The plants were then covered with cylindrical mylar film cages (9cm dia; 45cm height) with fine mesh screen windows. About thirty to forty gravid hopper females along with five to ten males were released inside each mylar cage for oviposition. The potted plants provided for oviposition were replaced every two days with new sets of plants of similar age. The oviposited plants were transferred to a wooden

cage (45 x 45 x 60 cm) and watched for hatching of the eggs. This phenomenon was followed throughout the experimental period and thus continuous availability of the test insects was obtained. During the whole process of culturing, the potted plants were placed in galvanized iron trays with ten cm depth of water. The plants that showed wilting due to nymphal feeding were renewed regularly from the rearing cage (Plate 2).

3.5.2 Yellow stem borer

For getting uniform population of *S. incertulas* mass culturing was done by following the method described by Chandramohan (1983). As it was difficult to mass culture the insect under green house conditions the requisite population of *S. incertulas* adults were collected from the rice fields of Paddy Breeding Station when necessary. The collected moths were confined four to five days old plants grown in clay pots of seven cm height and ten cm dia. The next day, the leaves with egg masses were clipped and confined in a 7.5 x 2.5 cm glass tube till completion of the incubation period and the larvae that hatched were used for further studies.

3.6. Construction of life and fecundity tables

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. 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 economic entomologists.

The consequence of certain population biology features as expressed life and fecundity-table-parameters are reviewed and critically analysed by Lewontin (1965), Gadgil and Bossert (1970), Stearns (1977) and Carey (1993).

3.6.1. Principles and basic notions

Lotka (1925) stated that if the food resources are excedentary and the space availability is unlimited, then the growth of the population will be exponential, which can be expressed as

$$\frac{dN}{dt} = rN \qquad (3.1)$$

or in integrated form as

$$N_t = N_i e^{rt} \qquad (3.2)$$

Ni : Effective initial size of the population

Nt : Effective initial size of the population at time 't'

r : coefficient of growth

e : base of natural logarithm

Nevertheless, he stated that the coefficient of growth or the intrinsic rate of natural increase would be constant when the population attains stable age distribution. Otherwise the rate of increase varies with time until the population attains stable age distribution. Although it seems to be unrealistic to conceive that the population can change at a constant rate, Carey (1993) felt that this equation is fundamental to the study of demography for the following three reasons. First, it defines the population changes as a compounding process. Second, it helps to examine the population changes over well-set-time-intervals. Third, it forms the basis, upon which complicated models can be built.

3.6.1.1. Intrinsic rate of natural increase (r_m)

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*. From the basic equations 1 and 2 the value of r_m can be calculated from the data on survival and fecundity of individuals of known age. The data on survival and fecundity are age specific and combined in the life table in the following columns:

l_x *:* Age specific survival of the individuals (normally females) at the age interval '*x*' starting '*i*' to '∞'

m_x : the mean number of offspring (normally females) produced per surviving females at the age interval '*x'* starting '*i*' to '∞'

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

If the total daily progeny and the sex ratios are known rather than the actual number of progeny maturing as females, then m_x can be calculated by

$$m_x = Pm'_x$$

Where,

P : Proportion of females in the sex ratio

m'_x : total progeny produced per surviving females at the age interval *'x'* starting from '*i*' to '∞'

Using the Euler equation

$$\int_i^{\infty} e^{-r_m x} l_x m_x dx = 1 \qquad (3.3)$$

The value of r_m may be estimated from the discrete approximation

$$\sum_{x=i}^{\infty} e^{-r_m x} l_x m_x = 1 \qquad (3.4)$$

Since the Euler equation explicitly refers to separate r_m's for each age class average r_m representing all age classes can be calculated by substituting 'T' for '*x'*, where 'T' is mean generation time.

$$\sum_{x=i}^{\infty} e^{-r_m T} l_x m_x = 1 \qquad (3.5)$$

The exponential term is now constant and can be brought outside the summation symbol. Thus

$$\sum_{x=i}^{\infty} l_x m_x = e^{-r_m T} \qquad (3.6)$$

Taking logarithm of both sides

$$r_m T = \log_e \sum_{x=1}^{\infty} l_x m_x$$

$$r_m T = \frac{\log_e \sum_{x=1}^{\infty} l_x m_x}{T} \qquad (3.7.1)$$

$$r_m = \frac{R_O}{T} \qquad (3.7.2)$$

Where the terms 'T' and 'R_O' are mean generation time and net reproductive rate terms respectively. With the advent of the computers the calculation of 'r_m', can be done easily by iteration. Here different values of r_m may be tried and the one satisfies the relation () can be taken into account.

3.6.1.2. Finite rate of increase (λ)

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

$$\lambda = e^{rm} \qquad (3.8)$$

In some circumstances it might be useful to calculate the finite rate of increase, i.e. the number of times the population multiplies in an 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

$$\frac{N_{t+1}}{N_t} = \lambda$$

3.6.1.3. Gross reproduction rate (GRR)

The gross reproduction rate represents the mean number of females oviposited by a female during its time of reproduction

$$G.R.R. = \sum_{x=1}^{\infty} m_x \qquad (3.9)$$

In order words, it is the number of time the population can multiply in each generation if there is no mortality during its ovipositional period. Although it is hypothetical, yet it is an important parameter for population comparisons.

3.6.1.4. Net reproductive rate

This is the rate of multiplication in one generation (Lotka, 1945) and is best expressed as the ratio of total female birth in two successive generations. In fact it corresponds to the number of female replacing a female in each generation

$$R_O = \int_i^{\infty} l_x m_x dx \qquad (3.10.1)$$

$$R_O = \sum_{x=1}^{\infty} l_x m_x \qquad (3.10.2)$$

However the comparison of two or more population by means of net reproduction ratio may be quite misleading unless the mean lengths of generation are same. Two or more population may have the same net reproduction values but their intrinsic rate may quite different lengths of their generations. For these reasons the parameter R_0 has limited value of interest and it must always be considered in relation to the lengths of the generations.

3.6.1.5. Doubling time of population (t)

As written it is the effective time necessary for doubling of population and is arrived at by the following formula

$$t = \frac{\ln 2}{r_m} \qquad (3.11)$$

3.6.2. Experimental protocols

Experiments were carried out with an aim to estimate the duration of different stages of insects, to compare the proportion of duration of different stages in its life span and to analyse the probability of its survival and fecundity under increasing temperature *viz*., 30, 32, 34, 36 and 38^0C.

3.6.2.1. Brown Planthopper (BPH)

Thirty day old rice plants in a pot were placed on the floor of the insect cage. One gravid female adult BPH was released into each insect cage. The total numbers of eggs laid were recorded daily until the all released BPH females had died. The eggs were counted using a magnifying glass. Otherwise calculated from the number of emerging instars. Emerging BPH nymphs were maintained in mylar cages as described in para 3.2.1. and observed daily until their death (Plate 3a). Life history traits such as survival, fecundity, development time and longevity were recorded at different temperatures.

To study nymphal survival (NS), ten first instar BPH nymphs were released on 35 days old caged plants. The number of nymphs that reached adulthood was counted and the percentage of nymphal survival was calculated (Heinrichs *et al.*, 1985). Developmental period (DP) of nymphs was studied by releasing three first instar nymphs on 35-day old caged plants. The nymphs were observed daily for ecdysis and the number of days taken for the nymphs to reach the adult stage was recorded (Pong Prasert and Weerapat, 1979).

Adult longevity (AL) of BPH males (ALM) and females (ALF) was studied by releasing three pairs of newly emerged adults on 35 days old caged plants. The adult BPHs were observed daily for their survival. Upon mating adulthood, the surviving BPH were sexed and fecundity of each female was counted daily.

3.6.2.2. Yellow stem borer (YSB)

This study was carried out first by collecting the female moths from the paddy fields and the moths were kept separately each in an insect cage **(**Height - 2 ¾ feet, Width - 2 ½ feet, Length – 2 ½ feet, Netted in three side) with 1 month duration crop of paddy in a pot under 5 different temperatures for egg laying (Plate 3b). Date of hatching and percentage of egg hatch were recorded. Egg masses with leaves were kept in a Petridishes in incubator to maintain temperatures. To prevent drying, the one end of which was covered with moist cotton. Observations of these eggs were made till they hatched and the incubation period of these eggs was determined under different temperatures. Then freshly emerged larvae were kept separately by introducing them in a piece of rice stem, covered with moist cotton at one end to prevent drying. The rice stem with larvae inside were kept separately in test tubes of 5x1cm size, plugged with cotton and all the tubes were kept under different temperature conditions. The rice stems of which the larvae fed were changed every day during which the observations were made on the development of the caterpillars. The pupae were observed by carefully opening the rice stems in which the larvae pupated. Before emergence of the moths about two or 3 days the pupae were kept out-side the rice stems but still remaining in the test tubes for easy observation until the adults emerged.

For the study of longevity of adults, freshly emerged moths both male and female were kept together in a glass cage provided with rice seedlings for mating. By observing the first laying of eggs by the female moth, the pre-oviposition period was back calculated, and these eggs were observed till they hatched. By observing the period between the emergence and death of the adults the longevity period was calculated.

3.6.3. Estimation of life history traits

3.6.3.1. Brown planthopper

The mean duration of egg and immature stages of BPH has been determined from the experiments explained as 6.8 and 22.4 days respectively. However, they have been observed on 7^{th} and 22^{th} day as these events must have taken place between 6^{th} and 7^{th} and 22^{nd} and 23^{rd} days for respectively. Hence it is admitted here that the duration of egg stage is 7 days and the duration of immature stages is another 14 days. Nevertheless, the latter is composed of larva or nymphal stages. Like the same way, the adults are assumed to emerge on 23^{rd} day.

The probability of survival at birth attaining 15 day is l_{15} = 0.662. Likewise the fecundity rate of an individual age *x*, m_x was computed as a mean oviposition between two successive observations. For example, the fecundity rate of an individual on 26^{th} day is m_{26}=3.873.

3.6.3.2. Yellow stem borer

The mean duration of egg and immature stages of insect has been determined from the experiments explained as 8.1 and 40.1days respectively. However, they have been observed on 8^{th} and 40^{th} day as these events must have taken place between 8^{th} and 9^{th} and 40^{th} and 41^{st} day for respectively. Hence it is admitted here that the duration of egg stage is 8 days and the duration of immature stages is another 30 days. Nevertheless, the latter is composed of larval and pupal period. Like the same way, the adults are assumed to emerge on 41^{st} day.

The values of l_x and m_x were estimated by the regular observations on the same cohort for a period of one generation until the death of the last individual. The age *x* is the interval of time separating two consecutive observations and all the events (birth and death) took place were supposed as to happen in such intervals. The probability of an individual at birth attaining the age *x*, l_x is estimated by the proportion of individuals observed to attain such age. For example the probability of survival at birth attaining 15^{th} day is l_{15} = 0.89. Likewise, the fecundity is the rate of an individual at age *x*, m_x was computed as a mean oviposition between two successive observations. For example, the fecundity rate of an individual on 25^{th} day is m_{25}=73.60.

3.7. Statistical analysis

The effect of temperature on life stage durations was analyzed at each life stage by using one way analysis of variance (ANOVA). Within instars, one way ANOVA was performed to analyze the effects of temperature on life stage duration. Percentage of egg hatch was analyzed as a two way ANOVA to test for the effects of temperature and time. Percentage data were converted using arcsine transformation, but values are presented as untransformed means (Sokal and Rohlf, 1995). All statistical analyses were performed using AGRES software.

CHAPTER IV

RESULTS

I. STUDIES ON IMPACT OF TEMPERATURE ON RICE PATHOGENS

Two rice pathogens *viz*., *P. grisea* causing rice blast and *R. solani* causing sheath blight were tested under different temperatures both under *in vitro* and under pot culture conditions and enzyme studies were also carried out in this study. The results are presented here under.

4.1. Isolation of pathogen and pathogenecity test

4.1.1. Paddy sheath blight (*R. solani*)

The rice variety ADT 43 raised in potted plants was artificially inoculated with *R. solani*, 45 days after transplanting. The typical sheath blight symptom was observed after seven days of inoculation. The pathogen was re-isolated and inoculated at 45 days after transplanting. Typical symptom of sheath blight was observed and Koch's postulates proved (Plate 4)

4.1.2. Paddy blast (*P. grisea*)

The rice variety ADT 43 raised in planted pots was artificially inoculated with *P. grisea* on 12 day old rice seedlings. The typical symptom was observed 15 days after inoculation. The pathogen was re-isolated and rice seedlings inoculated. Typical blast symptoms were observed and Koch's postulates proved (Plate 5)

4.2. *In vitro* studies

4.2.1 Growth of pathogen under increasing temperatures

4.2.1.1. *R. solani* in solid medium

Mycelial growth of *R. solani* in PDA media under *in vitro* conditions was observed at increasing temperatures *viz.*, 25, 28, 30, 32, 35, 38, 40, 42, 45, and 48^0C. Among the different temperatures tested the growth of the mycelium was maximum at 30^0C (8.67 cm) followed by 32^0C (7.90 cm), 28^0C (7.57 cm), 35^0C (7.33 cm) and 38^0C (6.23 cm). After 40^0C the growth of *R. solani* was reduced with increasing temperatures and at 48^0C there was no growth at all (Table 1, Figure 1 and Plate.6).

4.2.1.2. *P. grisea* in solid medium

The mycelial growth of *P. grisea* under different temperatures was studied as per the procedure outlined in 3.3.2. Mycelial growth was maximum at 28^0C (8.70 cm) twelve days after inoculation and was statistically significant followed by 30^0C (7.07 cm) and 25^0C (6.90 cm). The growth of the mycelium was affected below 25^0C and above 32^0C with increasing temperature and finally at 40^0C there was no growth (Table 2, Figure 2 and Plate 7).

4.2.2. Dry mycelial weight of pathogen under increasing temperature

4.2.2.1. *R. solani* in liquid media

The growth of *R. solani* in potato dextrose broth was observed under increasing temperatures. The maximum mycelial dry weight of *R. solani* was noted at 30^0C (430.18 mg) followed by 32^0C (367.28 mg) and 30^0C (301.6 mg). Above 38^0C and below 28^0C, significant reduction was observed in dry mycelial weight. There was no mycelial growth after 45^0C (Table 3, Figure 3).

4.2.2.2. *P. grisea* in liquid media

The growth of *P. grisea* in potato dextrose broth at different temperature revealed that at 28^0C maximum mycelial dry weight was recorded at twelfth day after inoculation (302.88 mg) followed by 25^0C (256.36 mg) and 30^0C (211.74 mg). Mycelial dry weight was decreased significantly from above 32^0C and below 25^0C with increasing temperatures and also there was no growth at 40^0C (Table 4, Figure 4).

4.2.3. Impact of temperature on sporulation of pathogen

4.2.3.1. *R. solani*

The sclerotia production by *R. solani* was screened under different temperatures from 25^0C to 48^0C under *in vitro* condition. Maximum number of sclerotia production was produced at 30^0C (20.67) followed by 32^0C (17.67) and 35^0C (15.00). Above 38^0C the sclerotia formation was drastically reduced and there was no sclerotia formation at 48^0C (Table 5, Figure 5, Plate 8).

4.2.3.2. *P. grisea*

The intensity of sporulation by *P. grisea* was studied under different temperature ranging from 18 - 40^{0}C under *in vitro* condition. Maximum intensity of sporulation was observed at 28^{0}C (28.67) followed by 25^{0}C (19.00) and 30^{0}C. There was drastic reduction in growth of *P. grisea* below 22^{0}C and above 32^{0}C. At 40^{0}C there was no growth of the pathogen (Table 6, Figure 6).

4.3. Pot culture experiment results

4.3.1. Impact of elevated temperature on sheath blight *(R. solani)* incidence

Pot culture experiments were carried out in climate control chamber under different temperature ranged from 25- 42°C.The results revealed that optimum temperature required for the maximum disease incidence was 30°C (52.85 PDI) with maximum lesion number (4.99) and maximum lesion size. This coincided with the relative humidity of 93.4 per cent. There was gradual reduction in disease incidence from above and below 30°C and least incidence was observed at 42°C (Table 7, Figure 7, Plate 9).

4.3.2. Impact of elevated temperature on growth attributes of rice plants artificially inoculated with *R. solani*

Results of pot culture experiments under artificially inoculated conditions revealed that significantly maximum plant height, increased number of tillers per hill, maximum number of panicles per tiller recorded at 32°C (72.50 cm, 12.33 and 10.67) followed by 30°C (71.50 cm, 11.00 and 9.29). There was minor reduction in all the biometric observation both below 32°C *viz.*, 30, 28 and 25°C and above 32°C (32, 35, 38, 40 and 42°C) (Table 8, Figure 8).

4.3.3. Impact of elevated temperature on rice blast (*P. grisea)* incidence

Paddy pot culture experiments were carried out in climate control chamber under artificially inoculated conditions ranges from 25- 42°C.The results revealed that optimum temperature required for the maximum disease incidence was 28°C (48.42 PDI) with maximum lesion number (4.87) and lesion size and this was coincided with the relative humidity of 94.7 per cent. With increase of temperatures from 30°C *viz.*, 32, 35, 38 and

40°C and decrease of temperature from 28°C there was gradual reduction in disease incidence and least disease incidence was observed at 40°C (Table 9, Figure 9, Plate 10).

4.3.4. Impact of elevated temperature on growth attributes of rice plants artificially inoculated with *P. grisea*

Pot culture experiments under artificially inoculated conditions revealed that maximum plant height and number of tillers per hill was recorded at 30°C (42.32 cm, 8.00) followed by 28°C (40.73 cm, 7.00). There was slight reduction in all the biometric observation both below 30°C *viz.*, 28°C, 25°C and above 30°C (32, 35, 38, 40 and 42°C) (Table 10, Figure 10).

4.3.5. Enzyme studies

4.3.1. Induction of polyphenoloxidase (PPO) activity in artificially inoculated paddy plants under increasing temperature

PPO activity of *R. solani* inoculated plants was studied under increasing temperatures. This enzyme activity was maximum at 30°C (1.520) followed by 32°C (1.490), 35°C (1.460) and 25°C (1.450) at 5 days after inoculation. In all temperatures, enzyme activity slowly increased from first to fifth day and then declined on seventh day. Above 38°C and at 25°C, the PPO activity decreased drastically (Table 11, Figure 11).

Similar trend in enzyme activity was observed in *P. grisea* inoculated plants. But PPO activity was maximum at 28°C (1.460) followed by 25°C, 30°C (1.43) and 32°C (1.390). Above 35°C there was significant decrease in enzyme activity with increasing temperatures and finally at 40°C least activity of 0.390 was observed (Table 12, Figure 12).

4.3.3. Induction of phenylalanine ammonia lyase (PAL) activity in artificially inoculated paddy plants under increasing temperature

PAL activity in *R. solani* inoculated plants was studied under increasing temperatures. In this study PAL activity was observed to be maximum at 30°C (48.320) followed by 32°C (47.000), 28°C (45.620) and 25°C (40.230) at 5 DAT. Enzyme activity was increased in each day after inoculation upto fifth day then the enzyme activity declined on seventh day. Above 35°C the enzyme activity was drastically reduced in *R. solani* inoculated plants and least activity was observed at 45°C (33.28) (Table 13, Figure 13).

But in *P. grisea* inoculated plants PAL activity was maximum at 28^{o}C (48.320) and was statistically significant followed by 25°C (46.000), 30°C (45.12) and 32°C (43.870) 5 DAT. The minimum PAL activity was observed at 38°C (Table 14, Figure 14).

II. STUDIES ON IMPACT OF TEMPERATURE ON RICE PESTS

Experiments were conducted on the rice yellow stem borer (*S. incertulas*) and BPH (*N. lugens*) at different temperatures such as 30°C, 32°C, 34°C, 36°C and 38°C. The results on the duration of different stages, development rate, survival and fecundity are presented here. The kinetics of pests population growth analysed using life and fecundity tables are also presented here.

4.4. Duration of different stages

The duration of different stages developed under varying temperatures are presented in Table 15, 16, 17 and 18.

4.4.1. Yellow stem borer (YSB)

In general, the duration of different stages of yellow stem borer under varying temperatures varied significantly (Table 15 and 16). 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. In general, it was observed that there was an inverse relationship between temperature and bionomics of yellow stem borer.

4.4.2. Brown planthopper (BPH)

Like YSB, the same trend was observed in BPH (Table 17 and 18). BPH took 6.7 mean days for hatching out into nymphs. However this period decreased significantly at higher temperature. As observed in YSB there was an inverse relationship between temperature and duration of different life stages.

4.5. Effect of temperature on survivorship

Slobodkine (1966) stated that four types of relationships exist to describe the survival of an animal in function of time viz., logistic, linear, logarithmic and exponential.

These shapes are characterized by the mortality patterns of the animals. Accordingly mortality is concentrated only on old animals, characterized by a constant number of deaths per unit time; the risk of death is constant per unit time or concentrated at the young stages respectively.

In the case of YSB as well as BPH the mortality is characterized by a constant number of deaths per unit time and the survival curve tends to be linear (Table 19 and 20, Figure 15 and 16).

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 live 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 (Table 21 and 22). At higher temperature, BPH died faster than at lowest temperature.

4.6. Developmental time and longevity

The mean developmental time is defined as time taken by individual to become an adult. On the other hand the longevity is defined as the length or duration of entire life. Negative correlation was observed between the developmental time and temperature. Similarly negative correlation was also obtained between longevity and temperature in both YSB and BPH. YSB took 40.15 days duration before adult stage at 30°C. However, it took 32.78 days to develop into adult at 38°C (Table 15). However the YSB lived out its life in 6.0 days at 30°C and lived only 5.2 days at 38°C (Table 23, Figure 17).

The same trend was observed in BPH. BPH took 22.4 days to become adult at 30°C. However it took 18.2 days to develop into adult at 38°C (Table 17). However, BPH lived out its life in 19.58 days at 32°C and lived only 16.58 days at 38°C (Table 24, Figure 18).

4.7. Development rate

The development rate is defined as the rate at which the individual grows. It was calculated by using the formula *i.e.* 1/duration of life stage. Generally both YSB and BPH

tend to develop at faster rate at higher temperature than the lower temperature. In the case of YSB, the developmental rate at 30°C was 0.2513, whereas it was 0.03032 at 38°C (Table 25, Figure 19). In the case of BPH, the development rate at 30°C was 0.0446, whereas it was 0.05519 at 38°C (Table 26, Figure 20).

4.8. Life history parameters

Life and fecundity table for YSB and BPH were established as per the principles explained from the results of other experiments. A composite summary of different life history of YSB and BPH are presented in Table 27 and 28, respectively. Detailed age specific life and fecundity tables of YSB and BPH at different temperature are presented in Table 29 and 30, Plate 11 and 12.

4.8.1. Yellow stem borer

Value of intrinsic rate of natural increase (r_m) at 30°C was 0.0846 and this parameter was found to be increased at in increasing temperatures (Table 27). These permits to find out finite rate of increase which defines constant by which the population is expected to multiply in each day. Since the growth rate increased with the increasing temperatures, the population of YSB doubles at faster rate. 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. Net reproductive rate (Ro) was 42.79 individuals and the generation time (T) was 44.05 days at 30°C. However, at 36°C Ro was 51.0 individuals and T was 37.56 days (Table 31, 32 and 33, Figure 21 and 22). In other words, if one assumes at the birth where constant at one moment, consecutive generation will be separated in 44.05 days at 30°C and 37.56 days at 36°C or YSB increases 42.79 times in 44.05 days at 30°C and 51 times in 37.56 days at 36°C. Thus the population of YSB, at higher temperature reproduces more in short duration.

4.8.2. Brown planthopper

Value of intrinsic rate of natural increase (r_m) at 30°C was 0.1398 and this parameter was found to be increased at increasing temperatures (Table 28). These permit to find out finite rate of increase which defines constant by which the population is expected to multiply in each day. Since the growth rate increased with increasing temperatures the population of BPH doubled at faster rate. 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. Net reproductive rate (Ro) was 64.43 individuals and the generation time (T) was 29.56 days at 30°C (Table 34, 35 and 36, Figure 23 and 24). However, the same was 77.71 individuals and 28.27 days at 38°C. In other words if one assumes at the birth where constant at one moment consecutive generation will be separated in 29.56 days at 30°C and 28.27 days in 38°C or BPH increases 64.43 times in 29.56 days at 30°C and 77.71 times in 28.27 days at 36°C. Thus the population of BPH at higher temperature reproduces more in short duration.

CHAPTER V

DISCUSSION

I. STUDY OF IMPACT OF TEMPERATURE ON RICE PATHOGENS

The equilibrium that was established under conventional agricultural system between crops and their pathogens has now been disturbed because of modern commercial agriculture systems and human induced climate change by increasing the green house gas concentrations in the atmosphere, which lead to constant threat of disease epidemics resulting in severe losses (IPCC, 2007). In the near future, there will certainly be changes in the phytosanitary scenario attributed to global climate change which will cause an increase in rainfall in some areas, which would lead to an increase of atmospheric humidity and the duration of wet seasons. Combined with higher temperature, these could favour the development of fungal diseases. Similarly with high temperatures and humidity, there could be an increased pressure on insects and disease vectors (Alexey *et al*., 2007). These impacts will have positive, negative or neutral, since these changes can decrease, increase or have no impact on diseases, depending on each region or period (Manning and Tiedemann, 1995). It was also found that major negative effects of future climate change on rice are projected due to increase in temperature under enriched carbon dioxide levels (Srivani *et al*., 2007). So, in the present study severity of diseases under elevated temperature was taken to assess the impact of climate change on rice blast and sheath blight and the results are discussed.

5.1. Impact of elevated temperature on *R. solani* and *P. grisea* under *in vitro*

Temperature is an important factor governing growth, reproduction and survival of the fungus. All fungus has a minimum temperature below which they cannot grow or they are inactivated or killed. Each fungus has its temperature range for growth and sporulation. Peetz *et al.* (2009) reported that hop powdery mildew growth was significantly reduced at ≥30°C with a reduction in inoculum activity when ambient temperature exceeds 30°C. In the present investigation the optimum temperature required for *R. solani* (sheath blight of paddy) both in solid media and liquid media was found to be 30°C . For sclerotia production also 30°C was optimum. There was decrease in growth of pathogen production and production of sclerotia with subsequent increase in temperature and at

40°C there was no growth at all (Fig. 5; Plate 7). Similar results were obtained by Dahl (1933). The sclerotia produced by sheath blight (*R. solani*) survive in soil and disseminated by irrigation water and infection takes place under ideal condition. At higher temperature the sclerotia are not germinating and also not producing infection. Anguiz and Martin (1989) reported that the sclerotial germination occurred over a broad temperature range of 10°-30°C and sclerotium yield was optimal between 20-25°C.

Maximum growth or sporulation of *P. grisea* was observed at 28°C and subsequently with increase in temperature the growth and sporulation was found to be totally affected at 40°C (Fig. 2 and 4; Plate 8). These results are in conformity with Gopal Iyer and Chattoo (2003) who obtained maximum growth of *P. grisea* at 28°C. Arun and Singh (1995) and Okeke *et al*. (1992) also reported that the growth of *P. grisea* was optimum at 28^{o}C, moderate at 23^{o}C and minimum at 15^{o}C and growth was inhibited at a temperature of > 37^{o}C. Suzuki (1975) also found that the optimum temperature for sporulation was 25-28^{o}C and there was no sporulation below 9^{o}C and over 35^{o}C. In the present study *P. grisea* sporulation period and the total number of spores produced was greater at moderate temperature than at high temperature which was similar to the results of Kato (1974), this may be due to dehydration and denaturation of proteins in spores because of thermal loss of viability (Roy and Prasada, 1991).

5.2. Enzyme studies

The activation of phenyl propanoid pathway in plants by environmental stimuli is one of the universal biochemical stress responses known. PAL catalyzes the deamination of L phenylalanineto trans – cinnamic acid, which is the first step in the biosynthesis of large group of plant products such as lignin monomers and phytoalexins. PAL plays an important role in the biosynthesis of phenolic phytoalexins (Daayf *et al*., 1997). In the establishment phase of a pathogen within the host tissues, PAL activity often increases. In several host – pathogen interactions, increased levels have been shown to be correlated with incompatibility (Rathmell, 1973; Bhattacharya and Ward, 1988; Ralton *et al*., 1989). The product of PAL activity is transcinnamic acid which is an immediate precursor for the biosynthesis of salicylic acid, a signal molecule in systemic acquired resistance (SAR) (Klessig and Malamy, 1994). Enhanced PAL enzyme activity and quantitative

increase as well as change in peroxidase isozyme pattern by pathogen attack are well-recognized components of plant defence response (Nagarathna *et al*., 1993; Ludwig-Muller *et al*., 1994; Guleria *et al*., 2001).In the present investigation phenylalanine ammonia lyase (PAL) activity was increased up to 30^{o}C for sheath blight and 28^{o}C for blast infected paddy plants. Thermostatically studies on the extract showed an initial rapid loss of activity followed by a slower decline, which could be due to the presence of different isoenzyme forms of PPO with different thermolability profiles (Martin *et al.*, 2005). Alternatively, it could be due to the formation of a less active (damaged) form of PPO as a result of the heat treatment. In the present investigation, PPO activity increased from first day after inoculation and was maximum on fifth day after challenge inoculation and under elevated temperature enzyme activity was increased up to 30^{o}C and 28^{o}C in sheath blight and blast disease respectively. Kinetic studies of PPO activity are less heat tolerant in crude extracts (Whitaker and Lee, 1995).

5.3. Impact of elevated temperatures on *R. solani* and *P. grisea* under pot culture

Climate change and agriculture are inter-related process both of which takes place on a global scale. Climate change is projected to have significant impact on conditions affecting agriculture by causing change in temperature, precipitation and glacial run off (Godderis and Joachimski, 2004). Consequently, several changes in the climate have been registered. The average global surface temperature has increased by 0.2°C per decade in the past 30 years (Hansen *et al*., 2006). Agriculture has less shown to provide significant effects on climate change not only on the production and release of greenhouse gases such as carbon dioxide, methane as nitrous oxide but wholly altering the earth's land cover, which can change its ability to absorbs on reflect heat and light, thus contributing to positive radiative forcing resulting in warming of the earth's surface (Sausen *et al*., 2005). In the present study maximum disease incidence in paddy for sheath blight and blast was observed at 30^{o}C and 28^{o}C respectively with high relative humidity above 90 per cent which is similar to the result of Mew *et al.* (2004). In their study the sheath blight occurrence was found to be more between the temperature range of 23 to 35°C and high humidity (>95%) in the crop canopy. In favorable environmental conditions (high humidity and ±30°C), the pathogen was able to spread as mycelial strands from the lower parts to the upper parts of the plant (Taheri and Tarighi, 2009).

The denser plant canopy of some cultivars creates a favourable microclimate with high humidity and enhances sheath blight development (Slaton *et al*., 2003). Because basidiospores can germinate only in high moisture and the hyphae is produced by germinating these spores (Sneh *et al*., 1991).

Fungal pathogens are often strongly dependent on humidity or dew for plant infection (Huber and Gillespie, 1995). According to Kuribayashi *et al.* (1952), the reproduction and multiplication of the rice blast fungus are greatest at high humidity and comparatively low temperature (21-24 ^{o}C). The inoculum density decreases if the temperature either increases above or below these temperatures.

The high temperature and humidity that prevail in the tropics favour the development of the sheath blight disease. Under regimes of low night temperatures (20-24^{o}C) and high humidity the severity of infection by paddy sheath blight is high on susceptible varieties (Datta and Surajit, 1981). Sarkar and Chowdhury (2003) reported that high temperatures and high humidity favor sheath blight lesion development both length wise and breadth wise in rice under laboratory conditions. In the present study maximum lesion size was observed at 30°C which is similar to Varun and Paul (2005) and at high RH of 93 per cent. Percich *et al.* (1997) reported that lesion densities were decreased at increased temperature in *Bipolaris oryzae* with decreased humidity.

Similarly other pathogens causing disease in different crops has also shown similar results. Delp (1954) reported that rapid germination, infection and growth of *Uncinula necator* on grapes took place from 21-30°C. But infection did not occur above 31.5°C and also extremely low relative humidity adversely affected the growth of this pathogen (Oku *et al*, 1975). Gupta (1963) reported that the *Sclerotina sclerotium* under high temperature tend to depress its growth. Ward and Manners (1974) showed that conidia formed at high relative humidity, lost their ability to germinate under drier environmental conditions more rapidly than conidia formed at lower relative humidity. Beyer and Vereet (2005) observed no germination at relative humidity lower than 30 %. Lesser plant height, lower number of tillers hill^{-1} and lower number of panicle tiller^{-1} was observed in the crop inoculated with sheath blight and blast pathogens under elevated

temperature. Kondo and Okamura (1931) also reported that under inoculated condition the plant height was decreased with increasing temperature.

In this study we found out that when the temperature increases the disease incidence decreased. In future due to climate change there is possibility of increase in temperature of 1.8°C to 4.0°C over the next 100 years which would reduce disease incidence but, the pathogens have the capacity to genetically modify themselves tolerate to higher temperature. In case of rusts of wheat it was found to adapt to increased temperature associated with climate change by developing new races evolving faster and the reduced effectiveness of rust resistances. It is also forecasted, increased biomass of wheat crops grown in the presence of elevated CO2 concentrations and higher temperatures will increase the leaf area available for attack by the pathogen. This combined with increased speed of the pathogen's life cycle, may increase the rate of epidemic development in many environments (Chakraborty *et al.,* 2010). Similar situation developing in the case of *P. grisea* may also occur as there are many races occurring. Recent studies suggest that rust pathogens can adapt to different optimal temperatures. Annual race surveys in the Eastern USA showed that contemporary *Puccinia striiformis* f. sp. *tritici* races have different temperature optima and virulence profiles than races collected before 2000 (Markell and Milus, 2008). Latent period and spore germination studies indicated that the contemporary population was better adapted to high temperature. Both populations had similar latent period and spore germination rates at 12°C, but at 18°C, isolates of the new population had shorter latent periods and higher germination rates than the old isolates. Such adaptation may have been responsible for the more widespread stripe rust epidemics covering at least 20 central and southern states of the USA in 2000 (Milus *et al*., 2006). Further studies showed that recent severe stripe rust epidemics were most likely magnified by increased pathogen aggressiveness at higher temperature. This demonstrates adaption of *P. striiformis* f. sp. *tritici* to warmer temperatures to cause severe disease in previously unfavorable environments (Milus *et al*., 2009).

Recent studies at ICRISAT, Hyderabad, has demonstrated that, under emerging climate change, high temperature and the resultant rapid loss of soil moisture at the reproductive stage of growth predispose chickpea to outbreaks of dry root rot caused by *Rhizoctonia bataticola* which reduce chickpea yield. Higher temperatures are predicted to

accelerate the breakdown of plant disease resistance through higher disease pressure and or altered resistance gene efficacy in many host–pathogen systems. Webb *et al*. (2010) demonstrated that rice with *Xa7* R gene exhibited less bacterial blight caused by *Xanthomonas oryzae* pv. *oryzae* at higher temperatures than *Xa3*, *Xa4*, *Xa5* genes which exhibited better control at low temperatures. Hence the future studies can be made based on genetic character of pathogen as well as the host.

II. STUDY OF IMPACT OF TEMPERATURE ON RICE PESTS

Temperature is an important factor for insect establishment and success (Lenteren *et al.,* 2006). In order to assess the effect of temperature on the development, survival, reproduction and population increase, life history parameters of paddy yellow stem borer and brown plant hopper, experiments were conducted at five constant temperatures (ranging from 30 to 38^0C) in the present work. The results of this study are discussed in the light of the best physical conditions for controlling the pests.

5.4. Impact of temperature on duration of different stages of pest

Many authors reported that the development time is more important than the fecundity itself individually (Caswell and Hastings, 1980). Period of immature stages was formed to be decreased at 38^0C than lower temperatures in YSB and BPH. The immature period has decreased to 32.78 days at 38°C from 40.15 days at 30°C in yellow stem borer and 22.4 days at 30°C to 18.2 days at 38°C in brown plant hopper. Sanchez - Ramos *et al*. (2007) found that the duration of the immature stages of cheese mites, *Acarus farris* (Oudemans) and *Tyrophagus neiswanderi* Johnston and Bruce decreased as temperature increased until the highest temperature was reached; the egg stage accounted for the longest development time among all immature stages. But in contrast no developmental inhibition at high temperatures was observed in egg development of *Chironomus crassicaudatus* (Jan *et al.,* 2002). Tamiru *et al*. (2011) reported that the developmental time was inversely related to temperature. Mean duration of *Chilo partellus* life cycle was 70.2 days at 22°C and 80% RH, whereas it took only 26.5 days to complete its life cycle at 30°C and 40% RH. However in any organism the period of reproduction is more important as it is only in this period the organism multiplies. A survey of literature indicated that there is an inverse relationship between temperature and developmental

period. Further it is the developmental time that otherwise indicates the time to mature to oviposit. 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. In the present studies, both in YSB and BPH, the insects matured and started ovipositing early, which will result in explosion of the population of these pests earlier than expected. Accordingly control strategies have to be planned much ahead.

5.5. Impact of temperature on survivorship

Percentage of survival has decreased at 38^{o}C than at 30^{o}C in paddy YSB and BPH. All stages were found to decline under increasing temperature. Komi *et al.* (2004) also reported the same result of decreased survivorship with increasing temperature in *Anagrus atamus*. These results are also supported by studies of Joel *et al.* (2001) in *Sitotroga cerealella* (Angoumois grain moth). Olivier (1999) reported decreased female survivorship in *Tetranychus evansi* under increasing temperature. But in present study revealed that decreasing survivorship was compensated by advancement in reproduction capacity of both the insects under increasing temperatures.

5.6. Impact of temperature on development rate, time and longevity

Most of the insect pests are classified under poikilothermic animal and therefore its development rate depends substantially on environmental temperature (Broufas and Koveos, 2001; Trudgill *et al*., 2005). Present results showed that the development rate was increasing under increasing temperature for both insects. Jesusa *et al*. (2008) also reported the same that immature developmental rate was significantly increased at higher temperature in lady bird beetle *Delphastus catalinae*.

In the present investigation, under increasing temperature developmental time and adult longevity decreased in both the insects. Jesusa *et al.* (2009) also reported the same results for cactus moth adult life span. Similar result was reported by Bin *et al.* (2009) as the total developmental time, longevity and oviposition period of *Aleuroglyphus ovatus* shortened as temperature increased. This indicates that most of the females had shorter life span and oviposited female eggs in the early part of their life at increasing temperature. This apparently suggests that there is probability a tradeoff between

development rate and longevity. Generally at lower temperature both YSB and BPH tend to live longer and at lower temperature, they spend most of their energy in reproduction and multiplication.

5.7. Impact of temperature on life history parameters

Life cycle parameters are good indicators of population growth (Bin *et al.,* 2009). The net productive rate R_o or the generation turnover rate is the rate of multiplication in one generation (Lotka, 1945). Oviposition period and egg hatchability of both YSB and BPH decreased under increasing temperature. But oviposition rate increased during earlier days at increasing temperature. Because of this oviposition behavior, the net reproductive rate increased with increasing temperature for both insects. Decrease in survivorship (l_x) and increase in fecundity was observed with increasing temperature in the present study in both YSB and BPH.

Temperature influences the rate of insect growth and development (Ya *et al*., 2009). In present study, the intrinsic rate of increase increased under increasing temperature for both insects. But generation time has decreased with increasing temperature for both pests. Lewontin (1965) stated that r_m is more sensitive to changes in the development time. 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. Decreasing generation time and earlier reproduction was significant effect on intrinsic rate. Similar result was reported by Iranipour *et al*. (2010) in *Eurygaster integriceps* and he stated that developmental time is one of the reasons for the intrinsic rate of natural increase r_m to increase with temperature. So earlier maturity of female and net reproductive rate of insect might influence the population with increasing temperature.

CHAPTER VI

SUMMARY AND CONCLUSION

Investigations were made to study the influence of increasing temperature on the dynamics of pest and disease of rice under laboratory and pot culture. Experiments were conducted on two paddy pathogens *viz.,* rice blast (*P. grisea)* and sheath blight (*R. solani)* and rice pests *viz.,* Brown Planthopper (BPH) (*N. lugens*), Yellow Stem Borer (YSB) (*S. incertulas*) to measure the impact of elevated temperatures on these rice crop.

The results obtained in the above studies are summarized here.

- Two rice pathogens *viz.,* paddy blast (*P. grisea*) and sheath blight (*R. solani*) pathogenecity were established.
- Under *in vitro* condition, maximum mycelial growth and dry weight of blast and sheath blight were observed at 28°C and 30°C respectively. Under higher temperature there was significant decrease in growth upto 40°C.
- Sporulation was highest at 28°C for blast disease and production of sclerotia attained maximum peak at 30°C in sheath blight. The sporulation of *P. grisea* and sclerotia production of *R. solani* decreased with increasing temperature upto 40°C
- Maximum per cent disease intensity with maximum lesion size were observed at 28°C for blast and 30°C for sheath blight in artificially inoculated paddy plants, with high relative humidity. At higher temperature the disease incidence decreased and least disease incidence was observed at 40°C for blast and 42°C for sheath blight.
- Artificially inoculated paddy plants with sheath blight and blast recorded maximum plant height and tiller production at 35°C and 32°C respectively. At higher temperature there was no significant changes.
- Pholyphenoloxidase and phenylalanine ammonia lyase activity was greatest at the time of maximum infection at 30°C and declined above 32°C upto 40°C.

- In rice pests, BPH and YSB duration decreased at higher temperature. The larval development of YSB and nymphal development of BPH decreased at 38°C when compared to 30°C.
- At increasing temperature the 50 per cent mortality rate in YSB and BPH was preponed.
- Survivorship and longevity of YSB and BPH was drastically decreased at increasing temperature.
- Faster developmental rate of YSB and BPH was noticed at 38°C when compared to 30°C.
- Both insects had an increase in the intrinsic rate of natural increase and finite rate of increase at increasing temperature.
- Both insects had increased net reproductive rate (Ro) at increasing temperatures and decreasing generation time with increasing temperature.

Conclusion

The following conclusions are drawn from the study

- Rice pathogens showed decreased incidence under elevated temperatures both under *in vitro* and pot culture studies. Defense enzymes like Pholyphenoloxidase and phenylalanine ammonia lyase activity decreased at higher temperatures
- Growth rate of rice pests like YSB and BPH increased with increase in temperature and the population of both pests doubled at faster rate. The net reproductive rate increased at increasing temperatures and duration was getting shortened at higher temperature. In other words, population of insect pests will get exploded at astronomical level at shorter period of time if left unchecked.

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INFLUENCE OF ELEVATED TEMPERATURE ON THE DYNAMICS OF PESTS AND DISEASES OF RICE

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Research Findings

Investigations were made to study the influence of increasing temperature on the dynamics of pest and disease of rice under laboratory and pot culture. Experiments were conducted on two paddy pathogens *viz.,* rice blast (*P. grisea)* and sheath blight (*R. solani)* and rice pests *viz.,* Brown Planthopper (BPH) (*N. lugens*), Yellow Stem Borer (YSB) (*S. incertulas*) to measure the impact of elevated temperatures on these rice crop.

Two rice pathogens *viz.,* paddy blast (*P. grisea*) and sheath blight (*R. solani*) pathogenecity were established. Under *in vitro* condition, maximum mycelial growth and dry weight of blast and sheath blight were observed at 28°C and 30°C respectively. Under higher temperature there was significant decrease in growth upto 40°C. Sporulation was highest at 28°C for blast disease and production of sclerotia attained maximum peak at 30°C in sheath blight. The sporulation of *P. grisea* and sclerotia production of *R. solani* decreased with increasing temperature upto 40°C. Maximum per cent disease intensity with maximum lesion size were observed at 28°C for blast and 30°C for sheath blight in artificially inoculated paddy plants, with high relative humidity. At higher temperature the disease incidence decreased and least disease incidence was observed at 40°C for blast and 42°C for sheath blight. Artificially inoculated paddy plants with sheath blight and blast recorded maximum plant height and tiller production at 35°C and 32°C respectively. At higher temperature there was no significant changes. Pholyphenoloxidase and phenylalanine ammonia lyase activity was greatest at the time of maximum infection at 30°C and declined above 32°C upto 40°C.

In rice pests, BPH and YSB duration decreased at higher temperature. The larval development of YSB and nymphal development of BPH decreased at 38°C when compared to 30°C. At increasing temperature the 50 per cent mortality rate in YSB and BPH was preponed. Survivorship and longevity of YSB and BPH was drastically decreased at increasing temperature.Faster developmental rate of YSB and BPH was

noticed at 38°C when compared to 30°C. Both insects had an increase in the intrinsic rate of natural increase and finite rate of increase at increasing temperature.

Conclusions are drawn from this study, Rice pathogens showed decreased incidence under elevated temperatures both under *in vitro* and pot culture studies. Defense enzymes like Pholyphenoloxidase and phenylalanine ammonia lyase activity decreased at higher temperatures. Growth rate of rice pests like YSB and BPH increased with increase in temperature and the population of both pests doubled at faster rate. The net reproductive rate increased at increasing temperatures and duration was getting shortened at higher temperature. In other words, population of insect pests will get exploded at astronomical level at shorter period of time if left unchecked.

Table 1. Effect of temperature on mycelial growth of *R. solani*

Temperature (°C)	Mycelial growth* (cm)			
	1 day	**2 days**	**3 days**	**Mean**
25	4.37 ^{i}	5.47 ^{f}	6.30 ^{e}	**5.38**
28	4.73 ^{h}	6.40 ^{e}	7.57 ^{c}	**6.23**
30	5.37 ^{fg}	7.60 ^{c}	8.67 ^{a}	**7.21**
32	5.17 ^{g}	6.43 ^{e}	7.90 ^{b}	**6.50**
35	4.60 ^{h}	5.40 ^{f}	7.33 ^{d}	**5.78**
38	3.37 ^{j}	4.30 ^{i}	6.23 ^{e}	**4.63**
40	2.50 ^{k}	3.50 ^{j}	5.57 ^{f}	**3.86**
42	1.43 ^{m}	2.60 ^{k}	4.30 ^{i}	**2.78**
45	1.20 ^{n}	1.77 ^{l}	2.40 ^{k}	**1.79**
48	0.00 ^{o}	0.00 ^{o}	0.00 ^{o}	**0.00**
Mean	**3.27**	**4.35**	**5.63**	

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 2. Effect of different temperature on mycelial growth of *P. grisea*

Temperature (°C)	Mycelial growth* (cm)			
	4 days	**8 days**	**12 days**	**Mean**
18	1.13 ^{q}	2.23 ^{n}	2.23^{k}	**2.17**
20	1.90 ^{o}	3.27 ^{k}	5.00 ^{h}	**3.39**
22	2.40 ^{mn}	4.63 ^{i}	6.33 ^{d}	**4.46**
25	3.30 ^{k}	5.57 ^{f}	6.90 ^{c}	**5.26**
28	3.53 ^{j}	6.60 ^{c}	8.70 ^{a}	**6.28**
30	3.17 ^{k}	5.30 ^{g}	7.07 ^{b}	**5.18**
32	2.50 ^{m}	4.43 ^{i}	5.97 ^{e}	**4.30**
35	1.53 ^{p}	2.83 ^{l}	3.60 ^{j}	**2.66**
38	1.23 ^{q}	1.80 ^{o}	2.57 ^{m}	**1.87**
40	0.00 ^{r}	0.00 ^{r}	0.00 ^{r}	**0.00**
Mean	**1.96**	**3.44**	**4.61**	

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 3 . Effect of different temperature on mycelial dry weight of *R. solani*

Temperature (°C)	Dry weight * (mg)			
	1 day	**2 days**	**3 days**	**Mean**
25	85.01^{t}	105.37^{r}	127.84^{op}	**106.07**
28	126.14^{p}	233.58^{g}	293.59^{d}	**217.77**
30	190.36^{i}	301.60^{c}	430.18^{a}	**307.38**
32	172.03^{i}	246.98^{f}	367.28^{b}	**262.09**
35	153.18^{l}	199.24^{h}	281.18^{e}	**211.20**
38	131.18^{no}	166.03^{k}	187.58^{i}	**161.59**
40	110.76^{q}	142.98^{m}	163.17^{k}	**138.97**
42	89.61^{st}	134.07^{n}	150.63^{l}	**124.77**
45	86.23^{t}	86.23^{s}	113.99^{q}	**95.48**
48	0^{u}	0^{u}	0^{u}	**0**
Mean	**114.45**	**161.61**	**211.54**	

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 4. Effect of temperature on mycelial dry weight of *P. grisea*

Temperature (°C)	Dry weight * (mg)			
	4 days	**8 days**	**12 days**	**Mean**
18	0.00^{p}	0.00^{no}	$0.00l^{m}$	**0.00**
20	92.87^{no}	134.53^{gh}	122.60^{ij}	**116.67**
22	115.21^{jk}	178.84^{d}	206.34^{c}	**166.80**
25	121.74^{ijk}	213.10^{c}	256.36^{b}	**197.07**
28	132.53^{h}	247.95^{b}	302.88^{a}	**227.79**
30	113.47^{jkl}	165.33^{ef}	211.74^{c}	**163.51**
32	97.83^{mn}	142.99^{g}	170.30^{de}	**137.04**
35	90.57^{nop}	128.39^{hi}	159.85^{ef}	**126.27**
38	85.26^{op}	98.26^{mn}	112.34^{kl}	**98.62**
40	0.00^{q}	0.00^{q}	0.00^{q}	**0.00**
Mean	**84.95**	**130.94**	**154.24**	

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 5. Effect of different temperature on sclerotia production of *R. solani*

Temperature (°C)	No. of sclerotia *
25	8.33[f]
28	13.00[d]
30	20.67[a]
32	17.67[b]
35	15.00[c]
38	11.33[e]
40	8.00[f]
42	5.67[g]
45	2.67[h]
48	0.00[i]

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 6. Effect of temperature on sporulation of *P. grisea*

Temperature (°C)	Spores * (10^3)
18	0.00^{g}
20	11.33^{f}
22	15.33^{d}
25	19.00^{c}
28	27.67^{a}
30	16.00^{b}
32	11.00^{d}
35	7.33^{e}
38	3.33^{f}
40	0.00^{g}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 7. Effect of temperature on sheath blight (*R. solani*) incidence in pot culture

Treatments (°C)	Relative Humidity (%)	Lesion No. (cm*)	lesion size (cm*)		PDI (*)
			Length	Width	
25	93.3^{b}	1.35^{e}	1.57^{de}	0.60^{d}	30.68^{c}
28	96.2^{a}	2.80^{c}	2.43^{c}	0.83^{b}	44.76^{b}
30	93.4^{b}	4.99^{a}	4.20^{a}	1.23^{a}	52.85^{a}
32	88.6^{c}	3.96^{b}	3.60^{b}	0.83^{b}	43.63^{b}
35	84.2^{cd}	2.86^{c}	2.20^{c}	0.70^{b}	32.73^{c}
38	78.5^{d}	2.33^{d}	1.77^{d}	0.47^{de}	26.32^{d}
40	72.1^{e}	1.24^{e}	1.33^{e}	0.40^{e}	11.52^{e}
42	68.4^{e}	0.87^{f}	0.97^{f}	0.23^{f}	3.2 ^{g}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 8. Effect of temperature on biometrics of rice plant inoculated with *Rhizoctonia solani*

Treatments (°C)	Plant height (cm*)	Number of tillers hill^{-1} (*)	Number of panicle tiller^{-1} (*)
25	67.63^{c}	9.52^{c}	5.67^{d}
28	69.80^{bc}	10.33^{b}	8.00^{c}
30	71.50^{b}	11.00^{b}	9.29^{b}
32	72.50^{a}	12.33^{a}	10.67^{a}
35	70.30^{bc}	10.00^{b}	7.33^{c}
38	69.45^{bc}	9.87^{bc}	8.67^{d}
40	68.60^{bc}	10.33^{b}	6.00^{d}
42	68.23^{c}	9.23^{c}	6.00^{d}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 9. Effect of temperature on rice blast (*P. grisea*) incidence in pot culture

Treatments (°C)	Relative Humidity (%)	Lesion No. (*)	Lesion size(cm*)		PDI (*)
			Length	Width	
25	93.2^{c}	1.25^{de}	0.27^{d}	0.37^{d}	38.71^{e}
28	94.7^{a}	4.87^{a}	0.80^{a}	3.53^{a}	48.42^{a}
30	91.4^{b}	2.69^{b}	0.47^{b}	1.03^{b}	36.63^{b}
32	86.5^{c}	1.76^{c}	0.40^{bc}	0.70^{c}	24.66^{c}
35	82.1^{d}	1.32^{d}	0.30^{cd}	0.50^{cd}	18.81^{d}
38	75.4^{e}	1.13^{e}	0.23^{d}	0.43^{cd}	12.63^{e}
40	69.2^{f}	0.51^{f}	0.12^{e}	0.21^{e}	2.34^{f}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 10. Effect of temperature on biometrics of rice plant inoculated with *P. grisea*

Treatments (°C)	Plant height (cm *)	Number of tillers hill^{-1} (*)
25	38.57^{c}	5.60^{d}
28	39.12^{c}	6.67^{bc}
30	40.73^{b}	7.00^{b}
32	42.32^{a}	8.00^{a}
35	40.30^{b}	6.00^{c}
38	39.50^{c}	5.52^{d}
40	38.27^{c}	5.33^{d}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 11. Induction on polyphenoloxidase (PPO) activity in paddy plants artificially inoculated with *R. solani* under increasing temperature (changes in absorption at 490nm min^{-1} gram of fresh $tissue^{-1}$)

Treatments (°C)	0 DAI	1 DAI	3 DAI	5 DAI	7 DAI
25	0.470^{c}	1.230^{ab}	1.340^{ab}	1.450^{bc}	1.360^{bc}
28	0.480^{c}	1.260^{a}	1.310^{b}	1.420^{c}	1.340^{c}
30	0.530^{a}	1.280^{a}	1.370^{a}	1.520^{a}	1.430^{a}
32	0.510^{ab}	1.250^{ab}	1.340^{ab}	1.490^{ab}	1.410^{ab}
35	0.490^{bc}	1.230^{ab}	1.320^{ab}	1.460^{bc}	1.370^{bc}
38	0.430^{d}	1.190^{b}	1.290^{b}	1.430^{c}	1.340^{c}
40	0.400^{e}	0.830^{c}	1.010^{c}	1.080^{d}	0.980^{d}
42	0.380^{e}	0.390^{d}	0.410^{d}	0.430^{e}	0.390^{e}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 12. Induction on polyphenoloxidase (PPO) activity in paddy plants artificially inoculated with *P. grisea* under increasing temperature (changes in absorption at 490nm min^{-1} gram of fresh $tissue^{-1}$)

Treatments (°C)	0 DAI	1 DAI	3 DAI	5 DAI	7 DAI
25	0.430^{b}	1.210^{a}	1.320^{ab}	1.430^{ab}	1.320^{ab}
28	0.450^{a}	1.250^{a}	1.360^{a}	1.460^{a}	1.340^{a}
30	0.420^{a}	1.230^{a}	1.330^{a}	1.430^{ab}	1.310^{ab}
32	0.380^{a}	1.180^{a}	1.280^{bc}	1.390^{bc}	1.290^{ab}
35	0.370^{c}	1.150^{a}	1.250^{c}	1.340^{c}	1.260^{b}
38	0.350^{c}	0.450^{b}	0.950^{d}	1.160^{d}	0.980^{c}
40	0.340^{d}	0.360^{b}	0.390^{e}	0.420^{e}	0.370^{d}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 13. Induction of phenylalanine ammonia lyase (PAL) activity in paddy plants artificially inoculated with *R. solani* under increasing temperature (nmol min^{-1} g^{-1})

Treatments (°C)	0 DAI	1 DAI	3 DAI	5 DAI	7 DAI
25	32.130^{ef}	34.560^{d}	38.670^{c}	40.230^{c}	39.210^{b}
28	36.560^{d}	39.260^{c}	43.760^{b}	45.620^{b}	43.530^{a}
30	43.560^{a}	46.870^{a}	47.320^{a}	48.320^{a}	44.540^{a}
32	41.450^{b}	44.650^{b}	46.780^{a}	47.000^{a}	44.780^{a}
35	38.650^{c}	40.540^{c}	42.230^{b}	44.650^{b}	43.320^{a}
38	33.890^{e}	35.670^{d}	36.780^{d}	37.860^{d}	34.650^{c}
40	32.540^{e}	34.640^{d}	35.430^{d}	36.540^{d}	34.540^{c}
42	30.570^{f}	31.230^{e}	32.670^{e}	33.280^{e}	31.700^{d}

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 14. Induction of phenylalanine ammonia lyase (PAL) activity in paddy plants artificially inoculated with *P. grisea* under increasing temperature (nmol min^{-1} g^{-1})

Treatments (°C)	0 DAI	1 DAI	3 DAI	5 DAI	7 DAI
25	42.450[a]	44.230[b]	45.780[b]	46.000[b]	45.780[a]
28	43.360[a]	46.670[a]	47.420[a]	48.320[a]	44.540[ab]
30	40.450[b]	41.650[c]	43.76[c]	45.12[bc]	43.21[b]
32	38.560[c]	39.540[c]	42.560[c]	43.870[c]	42.560[b]
35	34.000[d]	35.760[d]	36.870[d]	37.230[d]	36.430[c]
38	32.520[d]	33.560[d]	35.670[d]	36.610[d]	34.670[c]
40	30.230[e]	30.430[e]	31.540[e]	32.120e	32.560[e]

* Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 15. Development of YSB (*S. incertulas)* immature stages under increasing temperature

Values are mean of four replications

Life stage (days)	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
Egg	8.10[a]	8.03[a]	7.05[c]	7.28[b]	7.08[c]
Larva	25.88[a]	24.43[b]	24.13[b]	20.55[c]	20.18[d]
Pupa	6.08[a]	4.93[c]	5.68[b]	4.65[d]	6.23[a]
Immature	40.15[a]	36.75[b]	34.73[c]	33.18[d]	32.78[e]

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 16. Instar – specific duration of YSB (*S. incertulas*) under increasing temperature

Instars (days)	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
I	6.18[a]	4.25[c]	5.13[b]	3.83[d]	3.75[d]
II	5.75[c]	6.38[a]	5.40[d]	6.15[b]	5.08[e]
III	6.65[c]	6.90[b]	6.65[c]	7.25[a]	5.85[d]
IV	6.63[a]	7.08[a]	6.95[a]	5.13[c]	5.00[c]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 17. Development of BPH (*N. lugens*) immature stages under increasing temperature

Stages	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
Egg	6.7^{b}	7.0^{a}	6.6^{c}	6.4^{d}	6.0^{e}
Nymph	15.4^{a}	11.5^{d}	12.6^{b}	12.1^{c}	11.2^{e}
Immature	22.4^{a}	19.7^{b}	19.2^{c}	18.4^{d}	18.2^{e}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 18. Instar-specification duration of BPH (*N. lugens*) under increasing temperature

Nymph	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
I	4.76^{a}	4.17^{b}	3.10^{c}	3.32^{d}	3.32^{e}
II	4.15^{a}	3.12^{b}	2.83^{c}	2.12^{d}	1.78^{e}
III	3.09^{a}	2.26^{bc}	2.35^{b}	2.12^{c}	2.41^{b}
IV	3.09^{b}	2.12^{cd}	2.22^{c}	3.35^{a}	2.06^{d}
V	3.37^{a}	2.71^{b}	2.16^{c}	2.24^{c}	1.41^{d}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 19. Effect of temperature on immature survival of YSB (*S. incertulas)*

Parameters	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
Egg	81.22^{a}	76.46^{b}	68.55^{c}	63.73^{d}	62.71^{d}
Larva	44.74^{c}	44.61^{c}	49.28^{b}	50.63^{a}	41.82^{d}
Pupa	70.20^{a}	63.12^{b}	55.53^{cd}	54.21^{d}	55.80^{c}
Male	42.54^{a}	37.75^{b}	40.68^{a}	34.94^{c}	41.41^{a}
Female	58.03^{d}	62.54^{b}	60.92^{c}	64.49^{a}	60.66^{c}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 20. Effect of temperature on survival of YSB (*S. incertulas)* female adult

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	1.00^{a}	1.00^{ab}	1.00^{bc}	1.00^{a}	1.00^{a}
2	0.82^{e}	0.94^{c}	0.87^{d}	0.86^{de}	0.83^{de}
3	0.71^{g}	0.76^{f}	0.73^{fg}	0.71^{g}	0.58^{h}
4	0.41^{j}	0.56^{h}	0.60^{h}	0.57^{h}	0.33^{k}
5	0.29^{l}	0.25^{m}	0.47^{i}	0.21^{mn}	0^{*}
6	0^{*}	0^{*}	0.20^{n}	0^{*}	0^{*}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 21. Effect of temperature on immature survival of BPH (*N.lugens*)

Parameters	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
Egg	86.33[b]	90.35[a]	85.94[b]	76.54[c]	64.19[d]
Nymphal	42.01[e]	50.54[d]	53.61[c]	55.12[b]	61.78[a]
Adult male	32.63[c]	27.73[d]	33.09[c]	35.63[b]	39.06[a]
Female	67.24[b]	72.14[a]	66.43[bc]	63.34[d]	64.66[cd]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 22. Effect of temperature on female survival of BPH (*N.lugens*)

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
2	1.00^{a}	0.97^{ab}	1.00^{a}	1.00^{a}	1.00^{a}
3	0.96^{abc}	0.97^{ab}	0.91^{cde}	0.94^{abc}	0.93^{abcd}
4	0.96^{ab}	0.94^{bc}	0.85^{fghi}	0.87^{efgh}	0.82^{hij}
5	0.88^{efg}	0.84^{fghi}	0.76^{klm}	0.77^{jklm}	0.75^{mn}
6	0.88^{defh}	0.83^{gi}	0.76^{klm}	0.70^{nop}	0.71^{nop}
7	0.76^{lm}	0.81^{ijk}	0.73^{mnop}	0.70^{nopq}	0.71^{nopq}
8	0.68^{pqr}	0.81^{ijkl}	0.73^{mno}	0.67^{qrs}	0.68^{opqr}
9	0.64^{rs}	0.77^{jklm}	0.67^{qrs}	0.63^{st}	0.57^{uv}
10	0.52^{vwxy}	0.69^{opqrs}	0.67^{qrs}	0.53^{vwx}	0.54^{uvw}
11	0.40	0.67^{qrs}	0.58^{tu}	0.53^{vwx}	0.50^{wxyz}
12	0.28^{mn}	0.56^{uv}	0.52^{vwxy}	0.50^{wxyz}	0.46^{z}
13	0.16 β	0.47^{yz}	0.48^{xyz}	0.40 β	0.39 β
14	0 *	0.36^{rs}	0.39 β	0.33 β	0.33 β
15	0 *	0.22^{mn}	0.30 β	0.17 β	0.14 β
16	0 *	0.17^{β}	0.22 β	0.11 β	0.11 β
17	0 *	0 *	0.12 β	0 *	0 *

Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 23. Effect of temperature on longevity of adult YSB (*S. incertulas)*

Temperature (°C)	Longevity (days)
30	5.8[cd]
32	6[c]
34	7.2[a]
36	6.3[b]
38	5.2[d]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 24. Effect of temperature on female longevity of BPH (*N. lugens*)

Temperature (°C)	Longevity (days)
30	14.25[d]
32	19.58[a]
34	18.25[b]
36	17.50[bc]
38	16.58[c]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 25. Effect of temperature on development rate of YSB (*S. incertulas)*

Temperature (°C)	Development rate
30	0.02513[d]
32	0.02704[c]
34	0.02875[b]
36	0.03031[a]
38	0.03032[a]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 26. Effect of temperature on development rate of BPH (*N. lugens*)

Temperature (°C)	Development rate
30	0.04461[d]
32	0.05048[c]
34	0.05175[b]
36	0.05411[a]
38	0.05519[a]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 27. Life history parameters of YSB (*S. incertulas)* under increasing temperature

Parameter	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
Age of first oviposition	42^{a}	40^{b}	40^{b}	36^{c}	34^{d}
Age of last oviposition	45^{a}	43^{b}	43^{b}	40^{c}	38^{d}
Age of maximum oviposition	43^{a}	41^{b}	41^{b}	37^{c}	35^{d}
Length of oviposition period	4^{b}	4^{b}	4^{b}	5^{a}	5^{a}
Net reproductive rate (R_O)	42.79^{c}	49.21^{b}	35.54^{e}	51.00^{a}	38.73^{d}
Gross reproductive rate(GRR)	293.17^{b}	303.91^{a}	261.83^{d}	274.70^{c}	243.87^{e}
Generation time (T)	44.05^{b}	41.36^{a}	41.32^{d}	37.56^{c}	35.48^{e}
Intrinsic rate of increase (Rm)	0.0846^{e}	0.0952^{c}	0.0871^{d}	0.1050^{a}	0.1034^{b}
Finite rate of increase (λ)	1.0882^{e}	1.0992^{c}	1.0908^{d}	1.1115^{a}	1.1091^{b}
Doubling rate (DT) NS	8.19^{a}	7.28^{c}	7.95^{b}	6.60^{e}	6.71^{d}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 28. Life history parameters of BPH (*N. lugens*) under increasing temperature

Parameter	Temperature (°C)				
	29-30	**32**	**34**	**36**	**38**
Age of first oviposition	25^{a}	24^{b}	24^{b}	23^{c}	22^{d}
Age of last oviposition	36^{a}	34^{b}	34^{b}	34^{b}	32^{c}
Age of maximum oviposition	31^{a}	29^{c}	30^{b}	30^{b}	30^{b}
Length of oviposition period	12^{b}	11^{a}	11^{a}	13^{a}	11^{a}
Net Reproductive Rate (R0)	64.43^{b}	59.15^{d}	62.01^{c}	76.95^{a}	77.71^{a}
Gross Reproductive Rate (GRR)	284.89^{b}	164.11^{d}	233.94^{c}	378.21^{a}	376.68^{a}
Generation Time (T) NS	29.56	28.64	28.80	28.68	28.27
Intrinsic Rate Of Increase (Rm)	0.1398^{d}	0.1424^{c}	0.1426^{c}	0.1524^{b}	0.1541^{a}
Finite rate of increase (λ)	1.1495^{c}	1.1530^{b}	1.1540^{b}	1.1641^{a}	1.1664^{a}
Doubling rate (dt)	4.93^{a}	4.88^{a}	4.86^{a}	4.57^{b}	4.50^{b}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 29. Life and age specific fecundity table of YSB (*S. incertulas*) at different temperatures

$\boldsymbol{x}$	Age interval in days
$\boldsymbol{l_x}$	Population surviving to each age (x)
$\boldsymbol{m_x}$	Population fecundity in each age (x)
$\boldsymbol{\sum l_x m_x}$	Net reproductive rate (Ro)
$\boldsymbol{\sum m_x}$	Gross reproductive rate (GRR)
$\boldsymbol{\sum (x l_x m_x)/R_O}$	Generation time (T)
$\boldsymbol{ln\ R_O/T}$	Intrinsic rate of increase (r)
$\boldsymbol{exp(r)}$	Finite rate of increase (λ)
$\boldsymbol{ln\ (2)/r}$	Doubling time (DT)

a) At 30°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0
3	1.00					0
4	1.00					0
5	1.00					0
6	1.00					0
7	1.00					0
8	1.00					0
9	1.00					0
10	0.98					0
11	0.95					0
12	0.94					0
13	0.92					0
14	0.91					0
15	0.89					0
16	0.88					0
17	0.85					0
18	0.85					0
19	0.80					0
20	0.80					0
21	0.77					0
22	0.74					0
23	0.72					0
24	0.71					0
25	0.68					0
26	0.68					0
27	0.65					0
28	0.60					0
29	0.57					0
30	0.52					0
31	0.51					0
32	0.48					0
33	0.46					0
34	0.45					0
35	0.42					0
36	0.40					0
37	0.37					0
38	0.34					0
39	0.32					0
40	0.29					0
41	0.26					0
42	0.22	736.00	73.60	15.85	665.80	0.45
43	0.18	736.00	73.60	13.59	584.27	0.36
44	0.11	513.00	73.29	7.89	347.26	0.19
45	0.08	366.00	73.20	5.63	253.38	0.12
46	0.00					

b) At 32°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	1.00					0.00
9	1.00					0.00
10	0.93					0.00
11	0.90					0.00
12	0.87					0.00
13	0.85					0.00
14	0.82					0.00
15	0.80					0.00
16	0.79					0.00
17	0.75					0.00
18	0.75					0.00
19	0.74					0.00
20	0.74					0.00
21	0.72					0.00
22	0.70					0.00
23	0.67					0.00
24	0.67					0.00
25	0.64					0.00
26	0.62					0.00
27	0.61					0.00
28	0.56					0.00
29	0.54					0.00
30	0.51					0.00
31	0.48					0.00
32	0.44					0.00
33	0.43					0.00
34	0.39					0.00
35	0.34					0.00
36	0.31					0.00
37	0.28					0.00
38	0.28					0.00
39	0.26					0.00
40	0.25	750.00	75.00	18.44	737.70	0.41
41	0.20	750.00	75.00	14.75	604.92	0.30
42	0.15	691.00	76.78	11.33	475.77	0.21
43	0.07	307.00	76.75	5.03	216.41	0.08
44	0.00					0.00

c) At 34°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	1.00					0.00
9	0.98					0.00
10	0.95					0.00
11	0.91					0.00
12	0.89					0.00
13	0.87					0.00
14	0.85					0.00
15	0.85					0.00
16	0.82					0.00
17	0.78					0.00
18	0.76					0.00
19	0.76					0.00
20	0.73					0.00
21	0.71					0.00
22	0.71					0.00
23	0.69					0.00
24	0.69					0.00
25	0.67					0.00
26	0.64					0.00
27	0.64					0.00
28	0.64					0.00
29	0.55					0.00
30	0.53					0.00
31	0.49					0.00
32	0.47					0.00
33	0.44					0.00
34	0.42					0.00
35	0.42					0.00
36	0.36					0.00
37	0.31					0.00
38	0.27					0.00
39	0.24					0.00
40	0.20	589.00	65.44	13.09	523.56	0.40
41	0.16	589.00	65.44	10.71	439.07	0.30
42	0.13	458.00	65.43	8.33	349.75	0.21
43	0.05	196.00	65.33	3.56	153.24	0.08
44	0.00			0.00	0.00	0.00

d) At 36°C

Pivotal Age (*x*)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	1.00					0.00
9	0.96					0.00
10	0.94					0.00
11	0.94					0.00
12	0.92					0.00
13	0.90					0.00
14	0.88					0.00
15	0.84					0.00
16	0.82					0.00
17	0.78					0.00
18	0.76					0.00
19	0.75					0.00
20	0.73					0.00
21	0.73					0.00
22	0.69					0.00
23	0.65					0.00
24	0.63					0.00
25	0.61					0.00
26	0.57					0.00
27	0.53					0.00
28	0.51					0.00
29	0.47					0.00
30	0.41					0.00
31	0.37					0.00
32	0.35					0.00
33	0.33					0.00
34	0.31					0.00
35	0.29					0.00
36	0.27	492.00	54.67	15.01	540.24	0.34
37	0.24	498.00	55.33	13.02	481.73	0.27
38	0.20	492.00	54.67	10.72	407.32	0.20
39	0.16	438.00	54.75	8.59	334.94	0.14
40	0.06	164.00	54.67	3.22	128.63	0.05
41	0.00	0.00	0.00	0.00	0.00	0.00

e) At 38°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	1.00					0.00
9	0.96					0.00
10	0.94					0.00
11	0.92					0.00
12	0.90					0.00
13	0.88					0.00
14	0.84					0.00
15	0.80					0.00
16	0.76					0.00
17	0.76					0.00
18	0.72					0.00
19	0.68					0.00
20	0.64					0.00
21	0.60					0.00
22	0.58					0.00
23	0.56					0.00
24	0.52					0.00
25	0.50					0.00
26	0.46					0.00
27	0.42					0.00
28	0.38					0.00
29	0.38					0.00
30	0.36					0.00
31	0.32					0.00
32	0.30					0.00
33	0.28					0.00
34	0.26	341.00	48.71	12.67	397.5086	0.35
35	0.22	341.00	48.71	10.72	341	0.26
36	0.16	341.00	48.71	7.79	245.52	0.17
37	0.14	341.00	48.71	6.82	252.34	0.15
38	0.10	195.00	48.75	4.88	148.2	0.08
39	0.00			0.00	0	0.00

Table 30. Life and age specific fecundity table of *N. lugens* fed on paddy in different temperatures

a) At 30°C

Pivotal Age (*x*)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	0.97					0.00
9	0.94					0.00
10	0.92					0.00
11	0.83					0.00
12	0.80					0.00
13	0.77					0.00
14	0.70					0.00
15	0.66					0.00
16	0.63					0.00
17	0.59					0.00
18	0.56					0.00
19	0.55					0.00
20	0.51					0.00
21	0.51					0.00
22	0.49		0.00			0.00
23	0.49		0.00			0.00
24	0.48		0.00			0.00
25	0.42		0.00			0.00
26	0.42	220.00	9.17	3.87	100.70	0.08
27	0.41	268.00	11.17	4.56	123.15	0.08
28	0.41	520.00	21.67	8.85	247.79	0.13
29	0.39	796.00	33.17	13.08	379.31	0.17
30	0.35	1068.00	50.86	17.91	537.22	0.20
31	0.34	1260.00	66.32	22.42	694.91	0.21
32	0.28	416.00	24.47	6.89	220.58	0.06
33	0.24	524.00	30.82	7.38	243.55	0.05
34	0.18	252.00	14.82	2.71	92.28	0.02
35	0.11	192.00	19.20	2.16	75.72	0.01
36	0.08	23.00	3.29	0.28	10.00	0.00
37	0.04	0.00	0.00	0.00	0.00	0.00

b) At 32°C

Pivotal Age (*x*)	l_x	**Egg laid**	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	0.91					0.00
9	0.84					0.00
10	0.84					0.00
11	0.82					0.00
12	0.79					0.00
13	0.67					0.00
14	0.66					0.00
15	0.63					0.00
16	0.60					0.00
17	0.58					0.00
18	0.54					0.00
19	0.49					0.00
20	0.49					0.00
21	0.45					0.00
22	0.42		0.00			0.00
23	0.37		0.00			0.00
24	0.37		0.00			0.00
25	0.36	160.00	7.27			0.00
26	0.36	218.00	9.91	3.55	92.29	0.11
27	0.33	430.00	19.55	6.42	173.28	0.18
28	0.33	678.00	30.82	10.12	283.34	0.25
29	0.28	888.00	42.29	11.99	347.75	0.25
30	0.25	406.00	22.56	5.72	171.69	0.11
31	0.24	350.00	19.44	4.64	143.95	0.08
32	0.19	114.00	7.60	1.47	47.19	0.02
33	0.15	63.00	4.85	0.72	23.87	0.01
34	0.10	2.00	0.18	0.02	0.65	0.00
35	0.06	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00

c) At 34°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	1.00					0.00
8	0.91					0.00
9	0.84					0.00
10	0.84					0.00
11	0.82					0.00
12	0.79					0.00
13	0.67					0.00
14	0.66					0.00
15	0.63					0.00
16	0.60					0.00
17	0.58					0.00
18	0.54					0.00
19	0.49					0.00
20	0.49					0.00
21	0.45					0.00
22	0.42		0.00			0.00
23	0.37		0.00			0.00
24	0.37		0.00			0.00
25	0.36	111.00	5.84			0.00
26	0.36	181.00	9.53	3.41	88.72	0.08
27	0.33	337.00	18.72	6.15	165.99	0.13
28	0.33	620.00	34.44	11.31	316.68	0.21
29	0.28	770.00	48.13	13.65	395.77	0.22
30	0.25	987.00	65.80	16.70	500.87	0.23
31	0.24	433.00	30.93	7.39	228.96	0.09
32	0.19	165.00	13.75	2.67	85.37	0.03
33	0.15	47.00	4.70	0.70	23.15	0.01
34	0.10	12.00	1.71	0.18	6.09	0.00
35	0.06	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00

d) At 36°C

Pivotal Age (x)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					
1	1.00					
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	0.97					0.00
8	0.95					0.00
9	0.88					0.00
10	0.83					0.00
11	0.78					0.00
12	0.73					0.00
13	0.70					0.00
14	0.67					0.00
15	0.65					0.00
16	0.60					0.00
17	0.55					0.00
18	0.50					0.00
19	0.50					0.00
20	0.47					0.00
21	0.43					0.00
22	0.38		0.00			0.00
23	0.35	69.00	4.60			0.00
24	0.35	111.00	7.40			0.00
25	0.33	267.00	17.80			0.00
26	0.32	420.00	30.00	9.50	247.00	0.18
27	0.27	540.00	41.54	11.08	299.08	0.18
28	0.27	642.00	49.38	13.17	368.74	0.18
29	0.25	768.00	64.00	16.00	464.00	0.19
30	0.20	816.00	81.60	16.32	489.60	0.17
31	0.17	412.00	51.50	8.58	266.08	0.08
32	0.08	111.00	22.20	1.85	59.20	0.01
33	0.05	23.00	7.67	0.38	12.65	0.00
34	0.03	1.00	0.50	0.02	0.57	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00

e) At 38°C

Pivotal Age (*x*)	l_x	Egg laid	m_x	$l_x m_x$	$xl_x m_x$	$e^{-rmx}(l_x m_x)$
0	1.00					0.00
1	1.00					0.00
2	1.00					0.00
3	1.00					0.00
4	1.00					0.00
5	1.00					0.00
6	1.00					0.00
7	0.94					0.00
8	0.88					0.00
9	0.84					0.00
10	0.80					0.00
11	0.78					0.00
12	0.76					0.00
13	0.72					0.00
14	0.72					0.00
15	0.68					0.00
16	0.62					0.00
17	0.56					0.00
18	0.56					0.00
19	0.52					0.00
20	0.46					0.00
21	0.42					0.00
22	0.40		0.00			0.00
23	0.40	36.00	2.77			0.00
24	0.38	94.00	7.83			0.00
25	0.32	192.00	17.45			0.00
26	0.30	336.00	33.60	10.08	262.08	0.19
27	0.28	422.00	42.20	11.82	319.03	0.19
28	0.26	514.00	57.11	14.85	415.77	0.20
29	0.22	590.00	73.75	16.23	470.53	0.19
30	0.18	816.00	136.00	24.48	734.40	0.25
31	0.08	22.00	5.50	0.44	13.64	0.00
32	0.06	2.00	0.67	0.04	1.28	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00

Table 31. Effect of temperature on egg hatchability percentage of YSB (*S. incertulas)* at different duration

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	86.57[a]	81.33[b]	73.18[e]	68.42[f]	66.68[g]
2	80.27[c]	76.52[d]	64.78[h]	55.87[i]	53.27[k]
3	76.43[d]	63.80[h]	54.99[j]	36.78[n]	34.37[o]
4	53.23[k]	51.69[l]	33.98[p]	39.23[m]	37.44[n]
5	33.33[p]	24.65[r]	37.99[n]	23.87[s]	20.84[t]
6	37.15[n]	29.63[q]	23.34[s]	19.60	16.45[w]
7	20.85[t]	18.41[v]	11.44[y]	10.10[z]	10.04[z]
8	11.95[y]	12.44[x]	0[*]	0[*]	0[*]

Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 32. Effect of temperature on egg hatchability of YSB (*S. incertulas)*

Temperature (°C)	Egg hatch (%)
30	86.54[a]
32	81.45[b]
34	73.18[c]
36	68.42[d]
38	66.68[e]

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 33. Effect of temperature on oviposition rate of YSB (*S. incertulas)*

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	0^{*}	0^{*}	0^{*}	0^{*}	0^{*}
2	0^{*}	0^{*}	0^{*}	0^{*}	18.985^{r}
3	0^{*}	0^{*}	0^{*}	0^{*}	31.3425^{m}
4	0^{*}	0^{*}	0^{*}	32.77^{l}	48.5375^{g}
5	0^{*}	0^{*}	0^{*}	56.78^{d}	20.2225^{p}
6	0^{*}	0^{*}	34.4525^{k}	45.3025^{h}	0^{*}
7	0^{*}	43.33^{i}	53.755^{f}	30.11^{m}	0^{*}
8	0^{*}	56.395^{d}	65.325^{c}	19.6775^{a}	0^{*}
9	34.445^{k}	76.395^{a}	34^{k}	0^{*}	0^{*}
10	73.4525^{b}	42.4375^{j}	23.1^{o}	0^{*}	0^{*}
11	55.775^{e}	20.1125^{pq}	13.4975^{s}	0^{*}	0^{*}
12	23.9825^{n}	0^{*}	0^{*}	0^{*}	0^{*}
13	11.3475^{t}	0^{*}	0^{*}	0^{*}	0^{*}

Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 34. Effect of temperature on percentage of hatchability of BPH *(N.lugens)* at different duration

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	80.55^{d}	91.45^{q}	85.84^{b}	76.69^{e}	64.58^{f}
2	63.80^{f}	84.60^{c}	64.76^{f}	56.87^{h}	52.43^{i}
3	51.39^{i}	59.22^{g}	56.56^{h}	34.00^{m}	31.21^{n}
4	27.16^{o}	34.00^{m}	38.00^{k}	40.10^{j}	35.76^{l}
5	32.28^{n}	36.00^{l}	40.00^{j}	17.34^{r}	14.56^{s}
6	17.33^{r}	21.45^{q}	23.00^{p}	0*	0*
7	4.47^{v}	10.60^{t}	9.00^{u}	0*	0*

Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 35. Effect of temperature on percentage of hatchability of BPH *(N.lugens)*

Temperature (°C)	Egg hatch (%)
30	85.95^{b}
32	91.11^{a}
34	85.96^{b}
36	76.9^{c}
38	65.14^{d}

Values are mean of four replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Table 36. Effect of temperature on oviposition rate of BPH *(N.lugens)*

Days	Temperature (°C)				
	30	**32**	**34**	**36**	**38**
1	0^{*}	0^{*}	0^{*}	0^{*}	0^{*}
2	0^{*}	0^{*}	0^{*}	4.60^{p}	2.77^{q}
3	0^{*}	0^{*}	0^{*}	7.40^{o}	7.83^{op}
4	0^{*}	0^{*}	5.84^{o}	17.81^{k}	17.45^{k}
5	0^{*}	7.28^{op}	9.53^{n}	30.11^{h}	33.60^{g}
6	9.17^{n}	9.95^{n}	18.73^{k}	41.54^{ef}	42.20^{ef}
7	11.17^{m}	19.55^{j}	34.44^{g}	49.37^{de}	57.11^{d}
8	21.67^{j}	30.82^{h}	48.13^{e}	64.00^{c}	73.75^{b}
9	33.17^{g}	42.29^{ef}	65.80^{c}	81.60^{b}	126.00^{a}
10	50.86^{d}	22.56^{j}	30.93^{hg}	51.50^{de}	5.50^{p}
11	66.32^{c}	19.44^{jk}	13.75^{l}	22.20^{j}	0.67^{r}
12	24.47^{i}	7.60^{o}	4.70^{p}	7.67^{o}	0^{*}
13	30.82^{h}	4.85^{p}	1.71^{r}	0.50^{s}	0^{*}
14	14.82^{l}	0.18^{s}	0^{*}	0^{*}	0^{*}
15	19.20^{jk}	0^{*}	0^{*}	0^{*}	0^{*}
16	3.29^{q}	0^{*}	0^{*}	0^{*}	0^{*}

Values are mean of three replications

In a column, means followed by a common letter are significantly different at 5 % level of LSD

Fig. 1. Effect of temperature on mycelial growth of *R. solani*

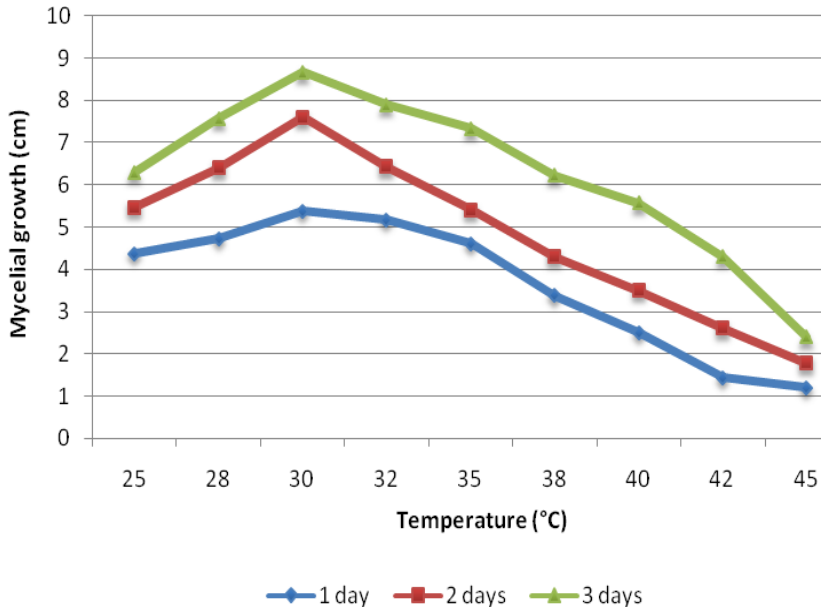


Fig. 2. Effect of Temperature on mycelial growth of *P. grisea*

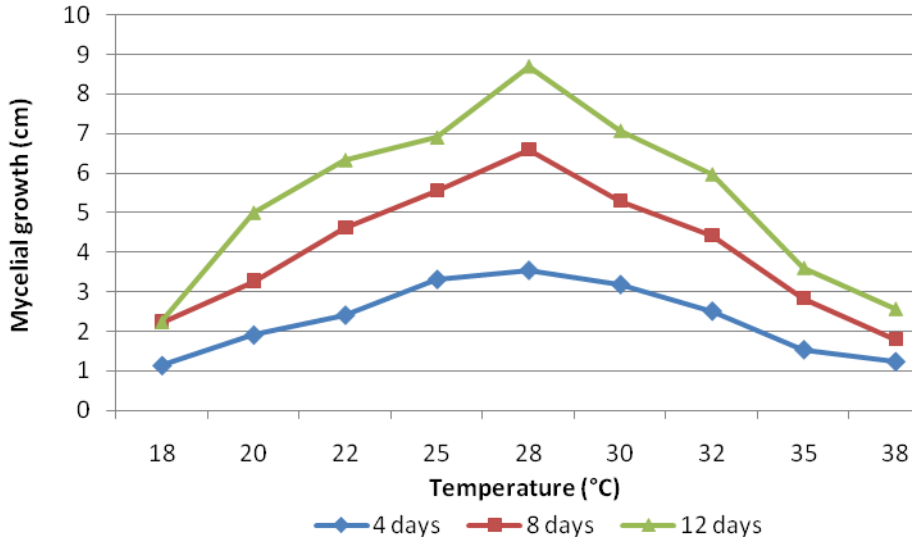


Fig. 3. Effect of temperature on mycelial dry weight of *R. solani*

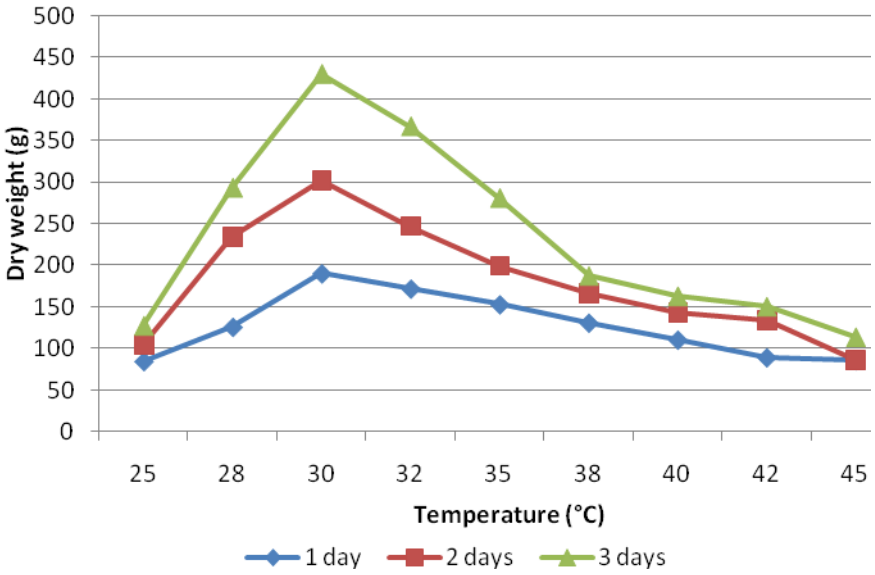


Fig. 4. Effect of temperature on mycelial dry weight of *P. grisea*

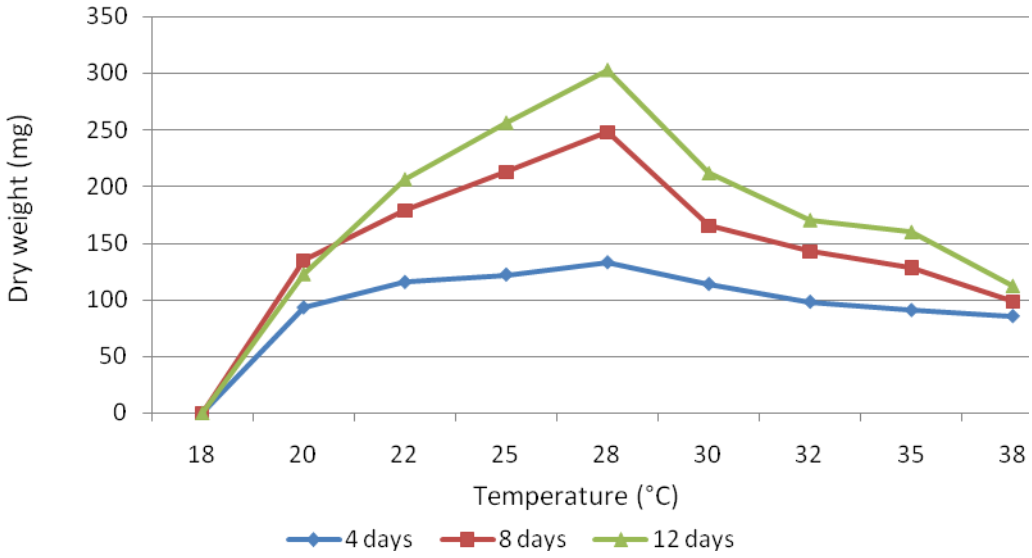


Fig. 5. Effect of temperature on sclerotia production of *R. solani*

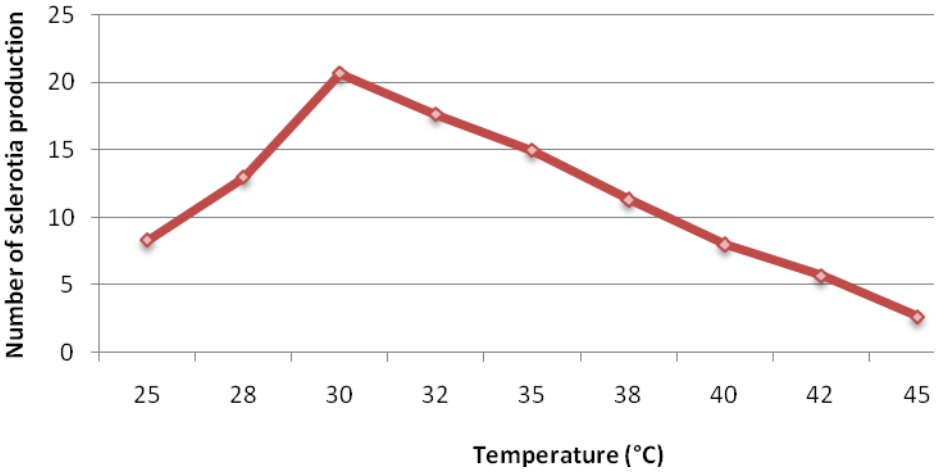


Fig. 6. Effect of temperature on sporulation of *P. grisea*

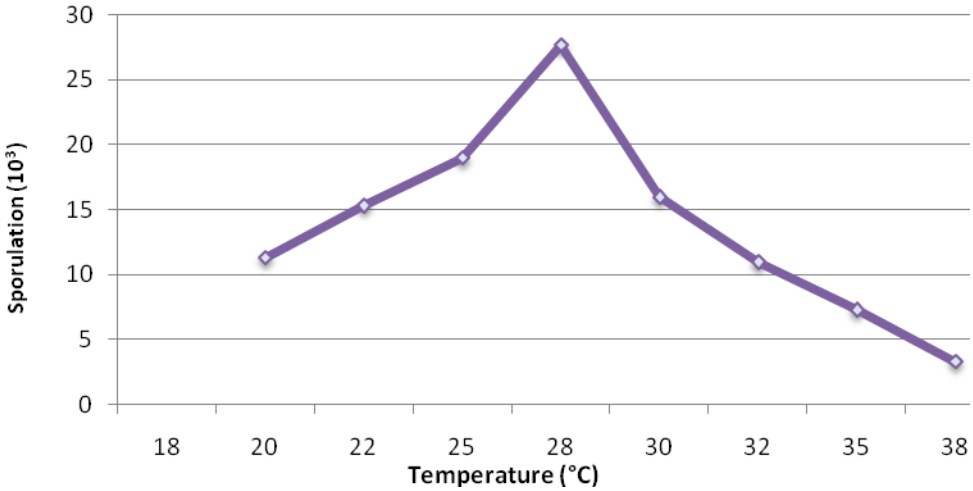


Fig. 7. Impact of elevated temperature on sheath blight (*R. solani*) incidence in pot culture

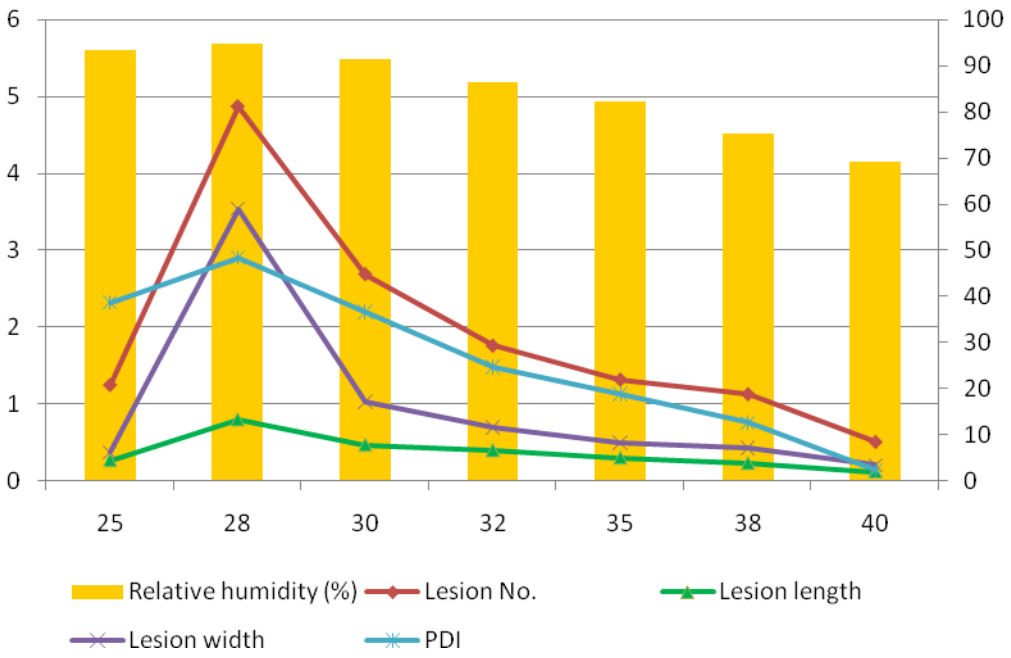


Fig. 8. Impact of elevated temperature on biometrics of rice plant inoculated with *R. solani*

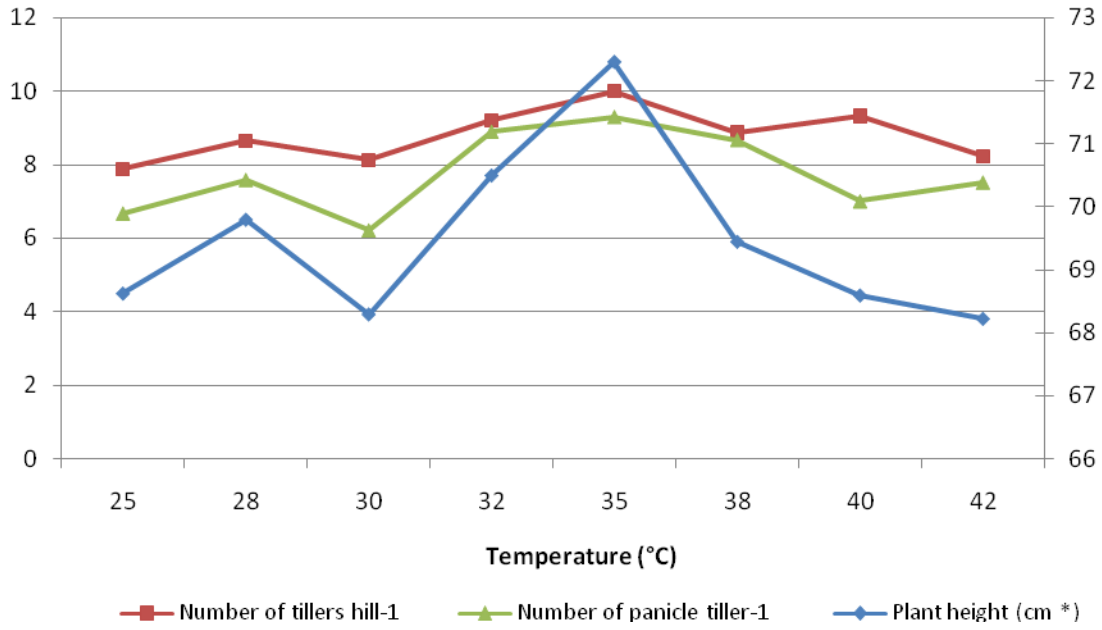


Fig. 9. Impact of elevated temperature on rice blast (*P. grisea*) incidence in pot culture

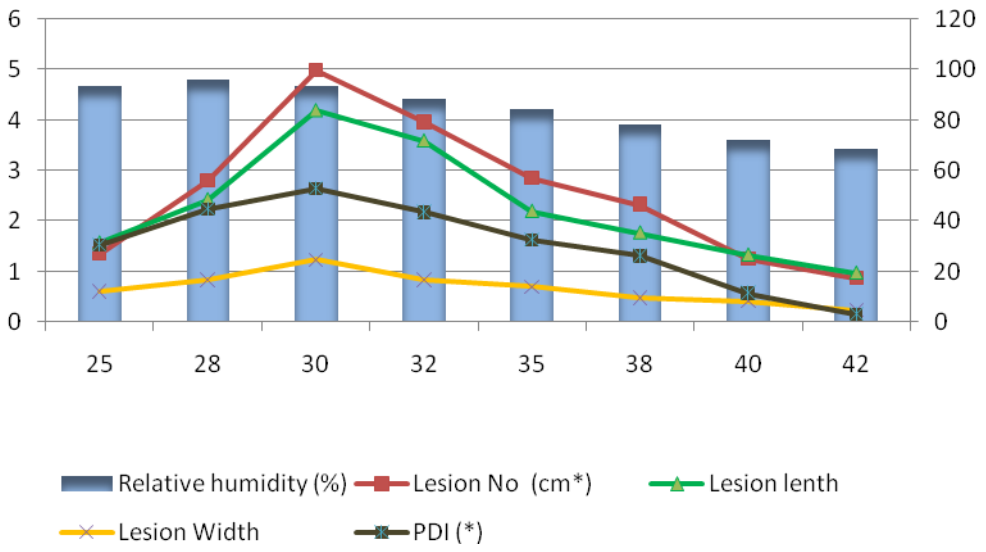


Fig. 10. Impact of elevated temperature on biometrics of rice plant inoculated with *P. grisea*

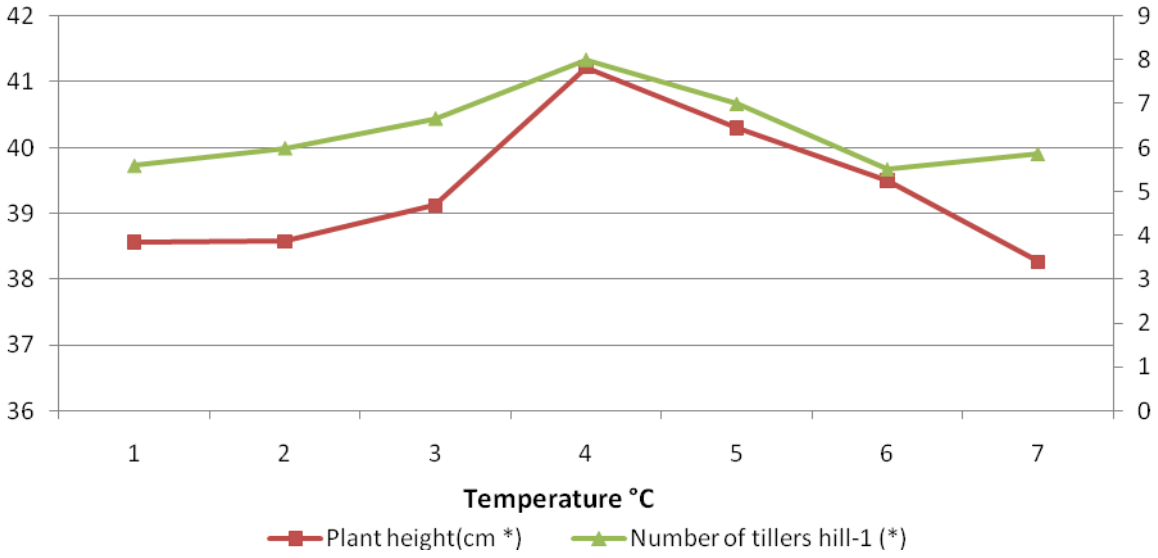


Fig. 11. Induction of phenylalanine ammonia lyase (PAL) activity in paddy artificially inoculated with *R. solani* under increasing temperatures

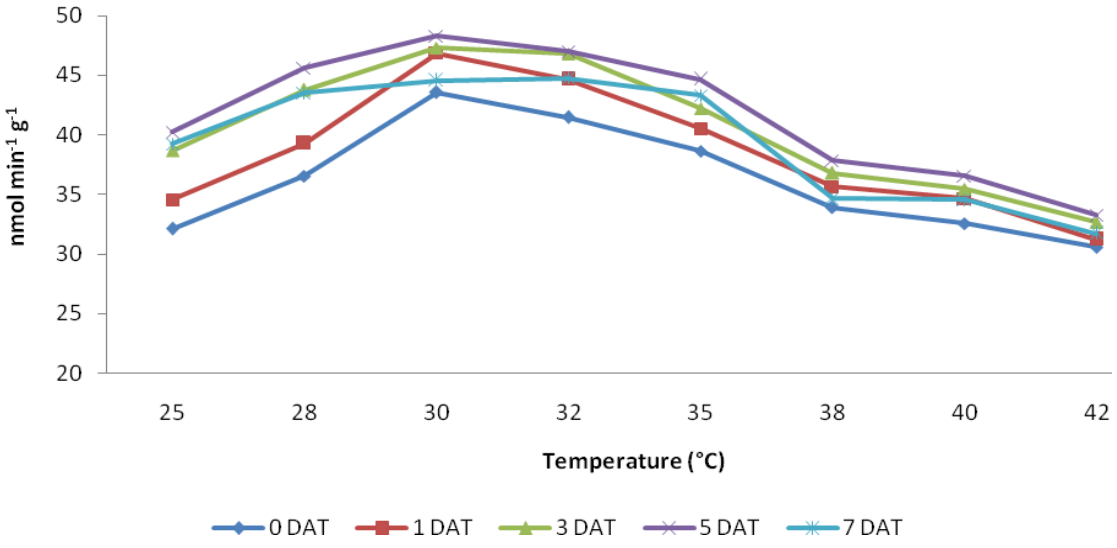


Fig. 12. Induction of phenylalanine ammonia lyase (PAL) activity in paddy plants artificially inoculated with *P. grisea* under increasing temperatures

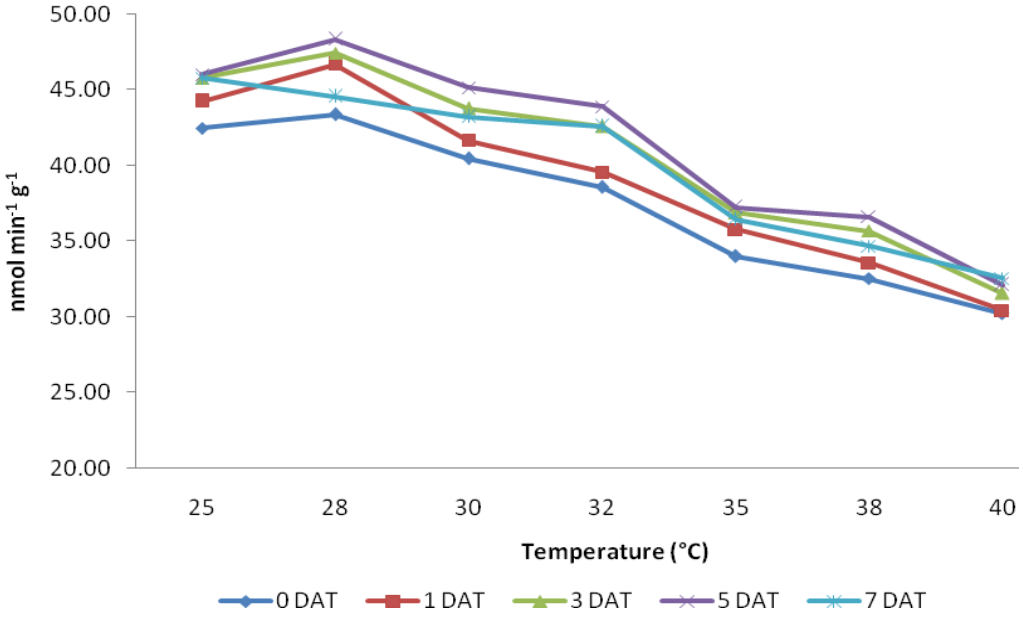


Fig. 13. Induction of polyphenol oxidase (PPO) activity in artificially inoculated paddy plants with *R. solani* under increasing temperatures

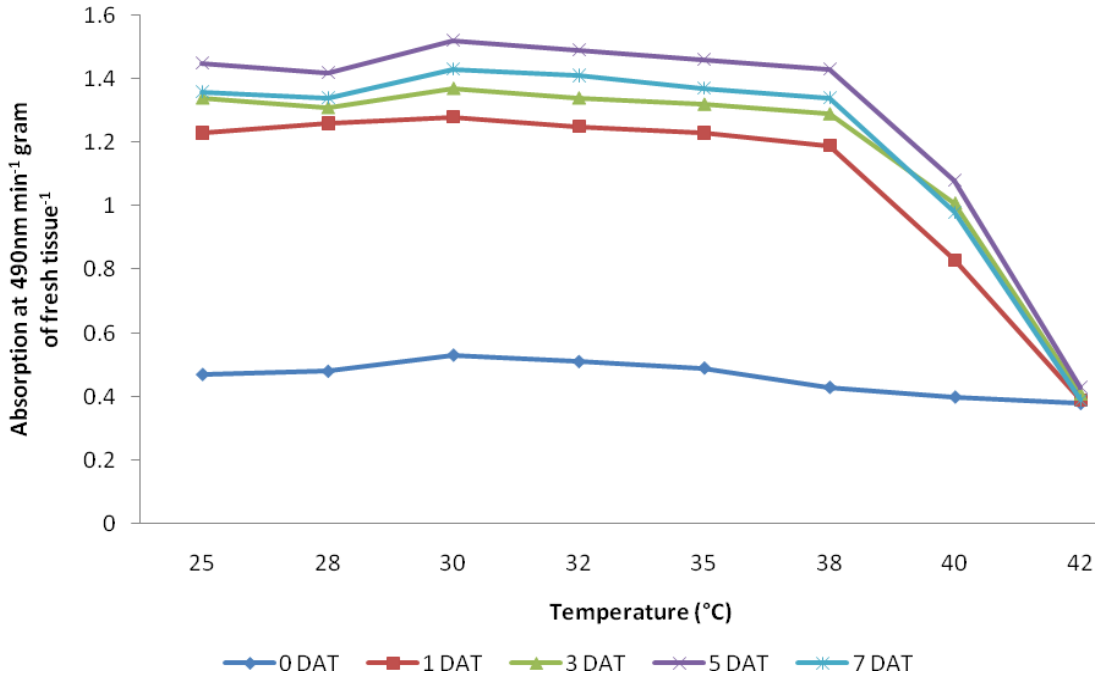


Fig. 14. Induction of polyphenol oxidase (PPO) activity in artificially inoculated paddy plants with *P. grisea* under increasing temperatures

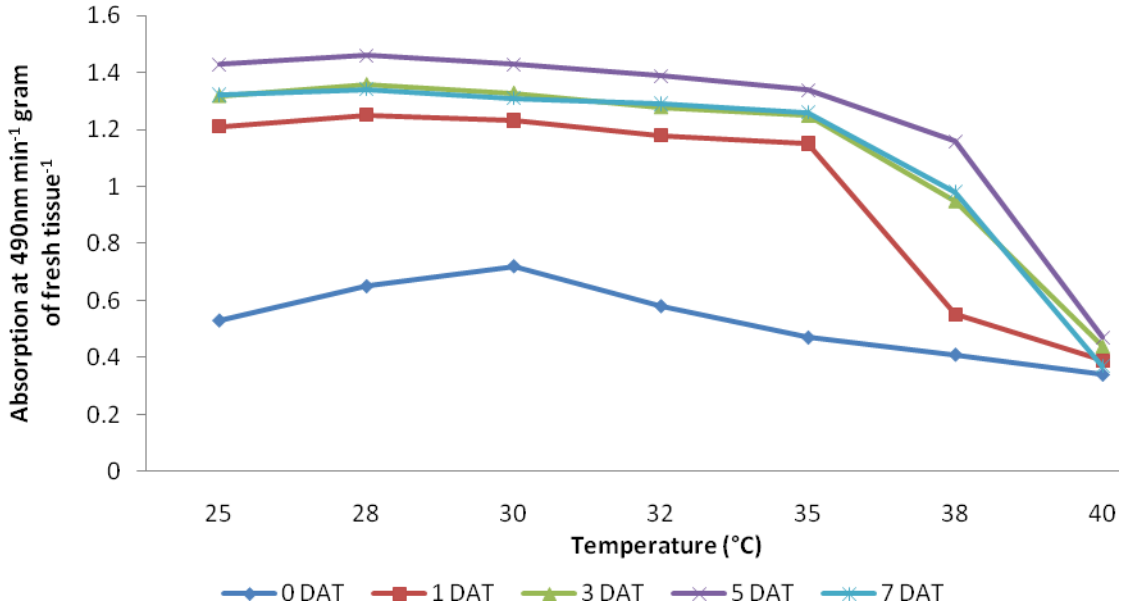
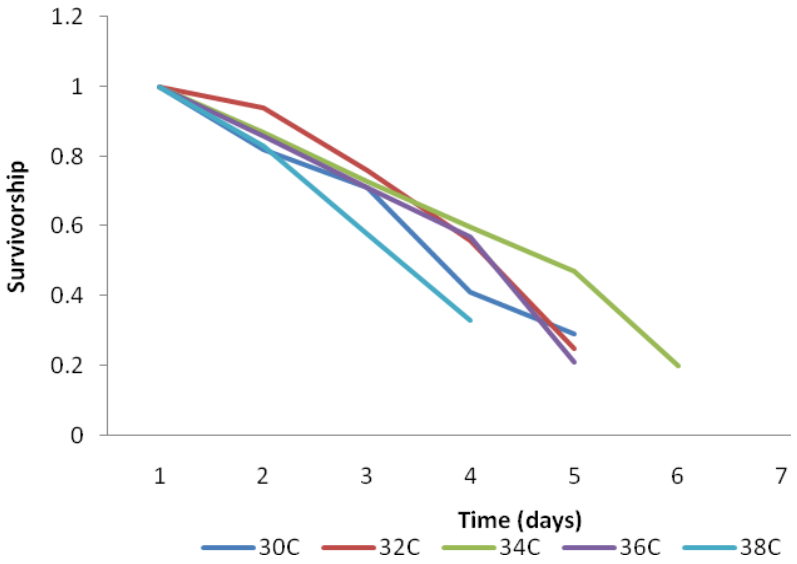
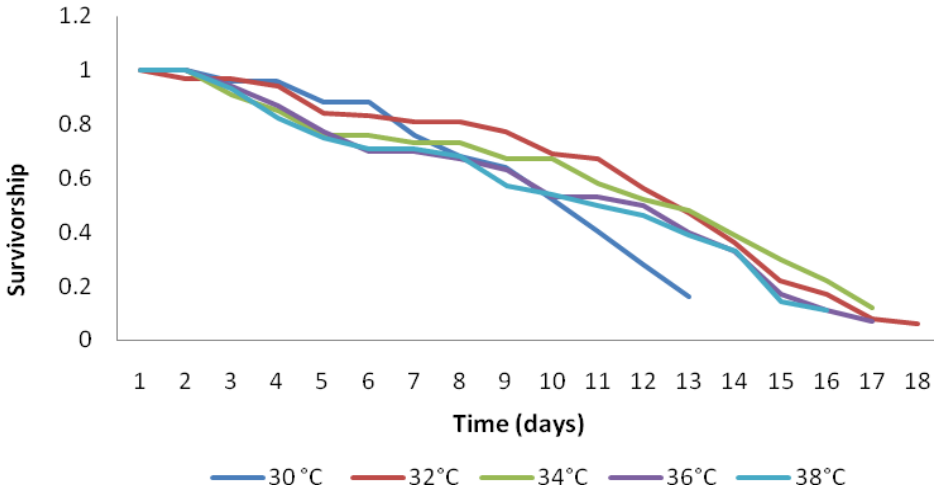


Fig. 15. YSB (*S. incertulas)* female survivorship under increasing temperatures



Temperature (°C)	30	32	34	36	38
Linear equation	y = -0.183x + 1.195	y = -0.188x + 1.266	y = -0.152x + 1.178	y = -0.187x + 1.231	y = -0.226x + 1.25
R^2	0.978	0.946	0.979	0.949	0.992

Fig. 16. BPH (*N.lugens*) female survivorship under increasing temperatures



Linear equation	y = -0.070x + 1.196	y = -0.058x + 1.174	y = -0.050x + 1.084	y = -0.057x + 1.103	y = -0.056x + 1.086
R^2	0.932	0.933	0.960	0.972	0.971

Fig. 17. YSB (*S. incertulas*) adult female longevity under increasing temperatures

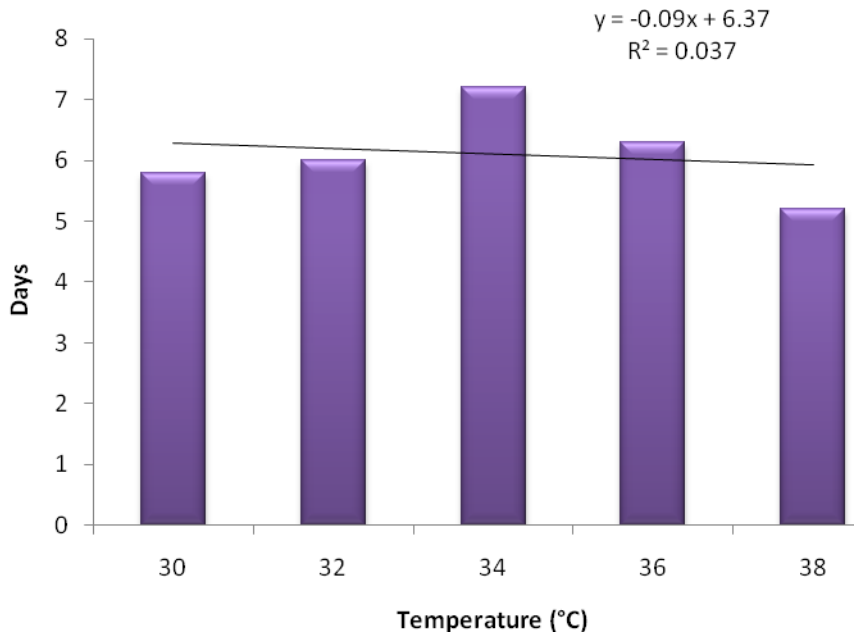


Fig. 18. BPH *(N. lugens)* adult female longevity under increasing temperatures

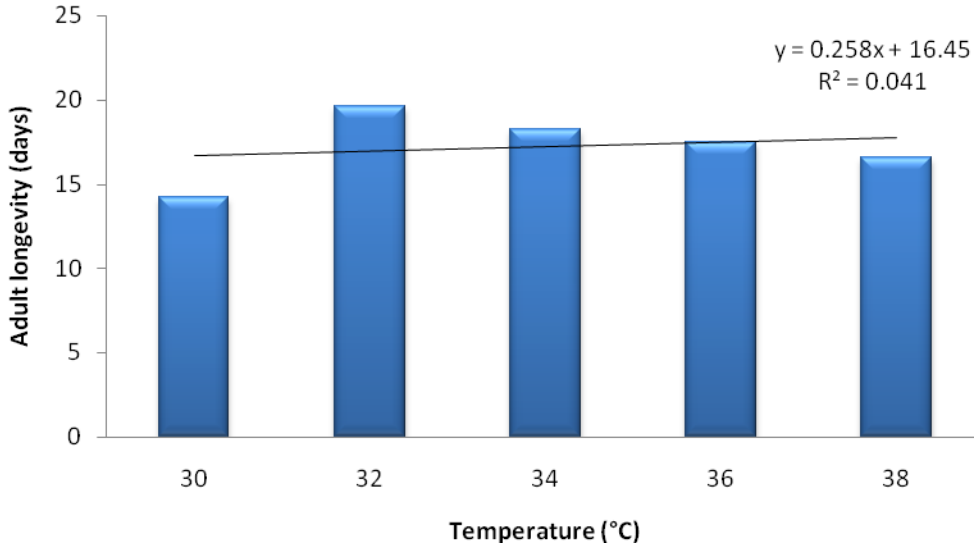


Fig. 19. YSB (*S. incertulas*) development rate under increasing temperatures

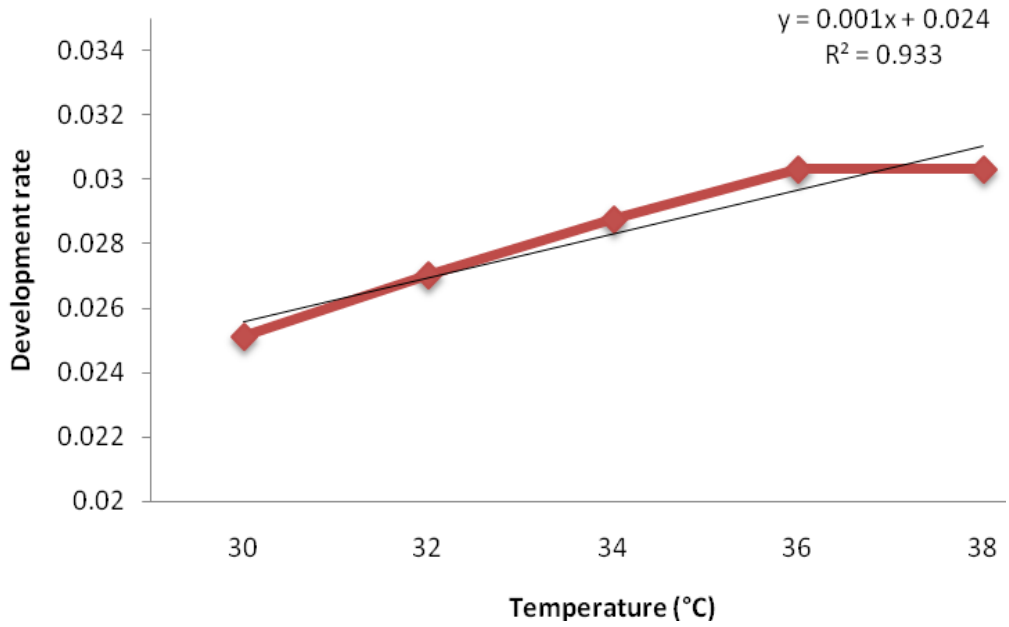


Fig. 20. BPH (*N. lugens*) development rate under increasing temperatures

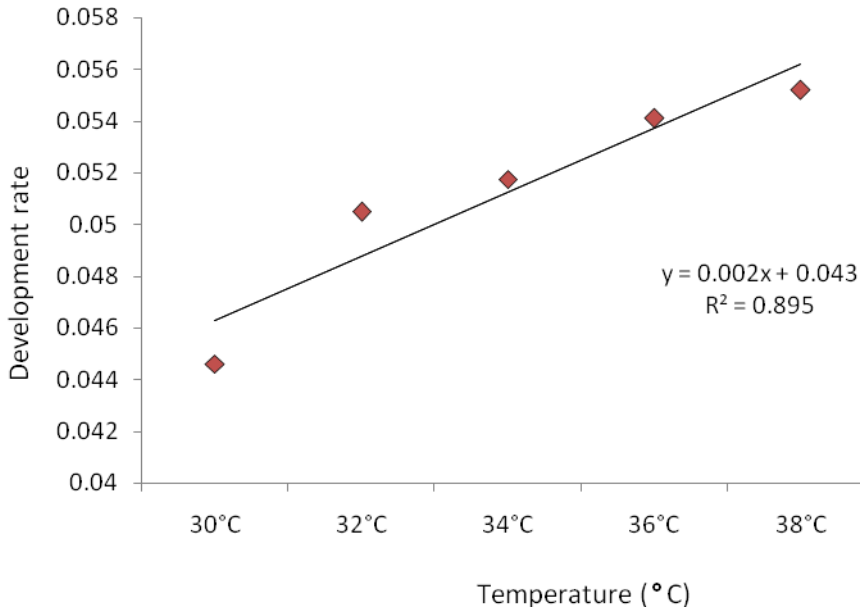
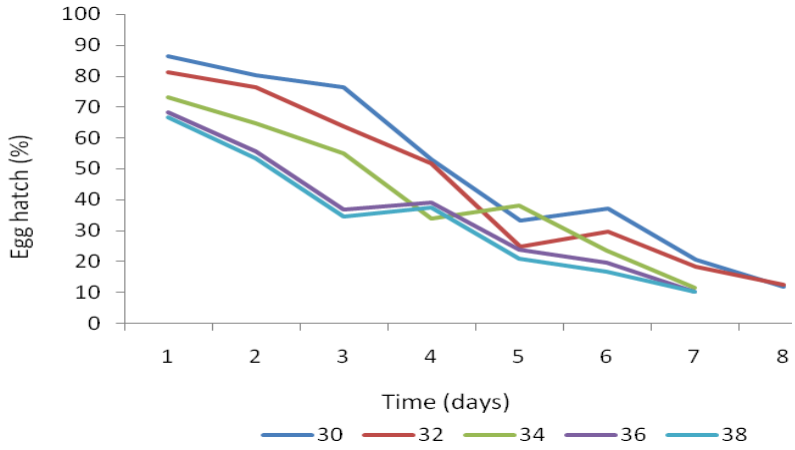


Fig. 21. YSB (*S. incertulas*) egg hatchability percentage under increasing temperatures with duration



Temperature (°C)	30	32	34	36	38
Linear equation	y = -11.39x + 101.2	y = -10.74x + 93.14	y = -10.18x + 83.54	y = -9.300x + 73.46	y = -9.181x + 70.88
R^2	0.956	0.944	0.962	0.952	0.941

Fig. 22. YSB (*S. incertulas*) egg hatchability percentage under increasing temperatures

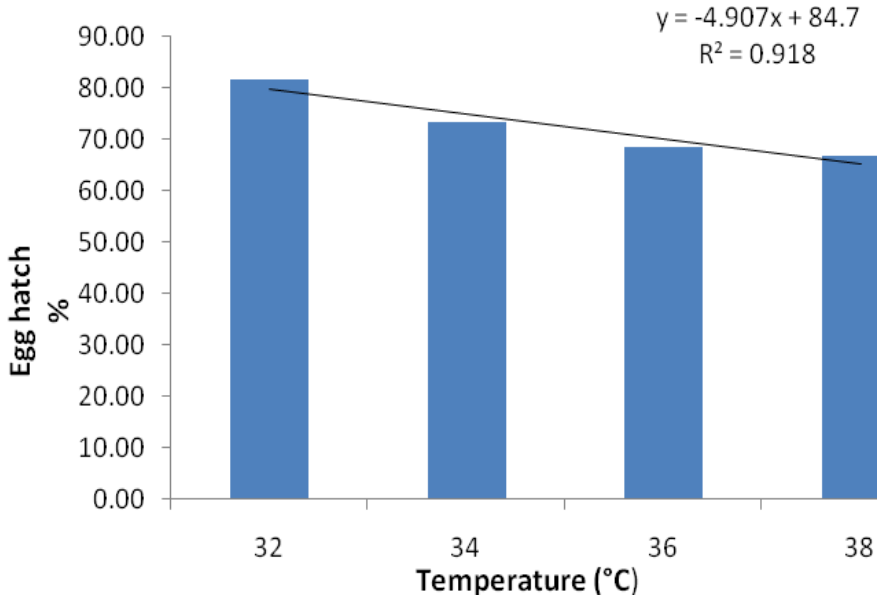
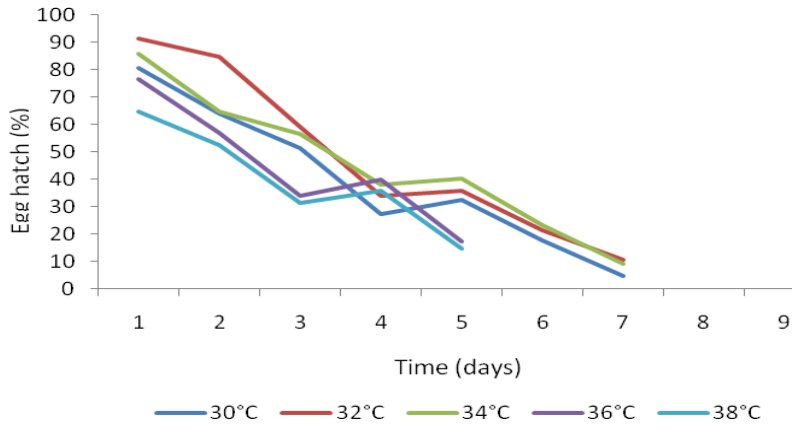


Fig. 23. BPH *(N.lugens)* egg hatchability percentage under increasing temperatures with duration



	y = -12.15x + 88.18	y = -14.00x + 104.2	y = -11.80x + 92.53	y = -13.54x + 85.64	y = -11.67x + 74.72
	R^2 = 0.952	R^2 = 0.947	R^2 = 0.964	R^2 = 0.892	R^2 = 0.907

Fig. 24. BPH (*N.lugens*) egg hatchability percentage under increasing temperatures

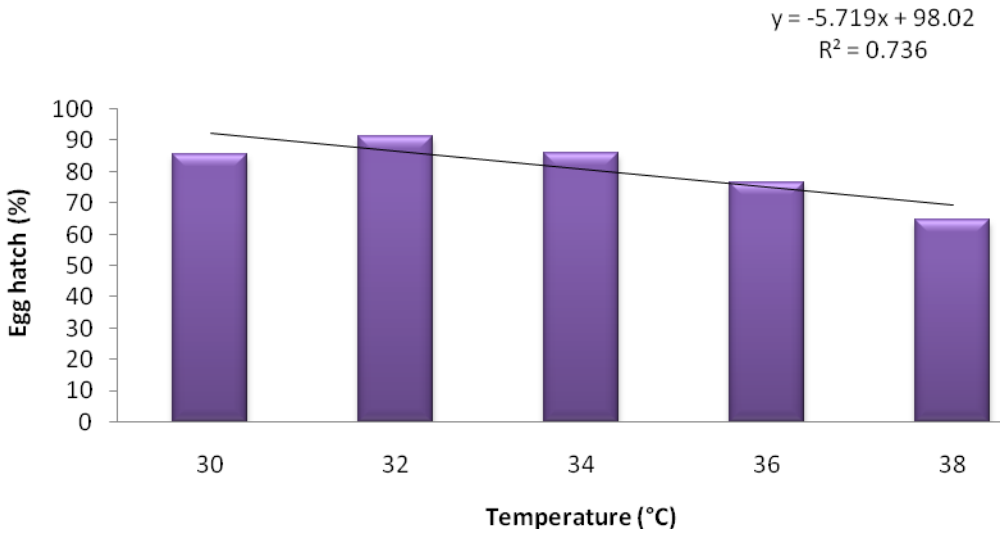


Plate 1. Over view of Climate Control Chamber (CCC)

Plate 2. Brown planthopper mass culture

Plate 4. Symptom of *R.solani* on paddy sheath

Plate 5. Symptom of *P. grisea* in paddy leaf

Plate 3a. Oviposition cage to observe fecundity rate of YSB

Plate 3b. Oviposition cage to observe fecundity rate of BPH

Plate 6. Effect of increasing temperatures on mycelial growth of *R.solani*

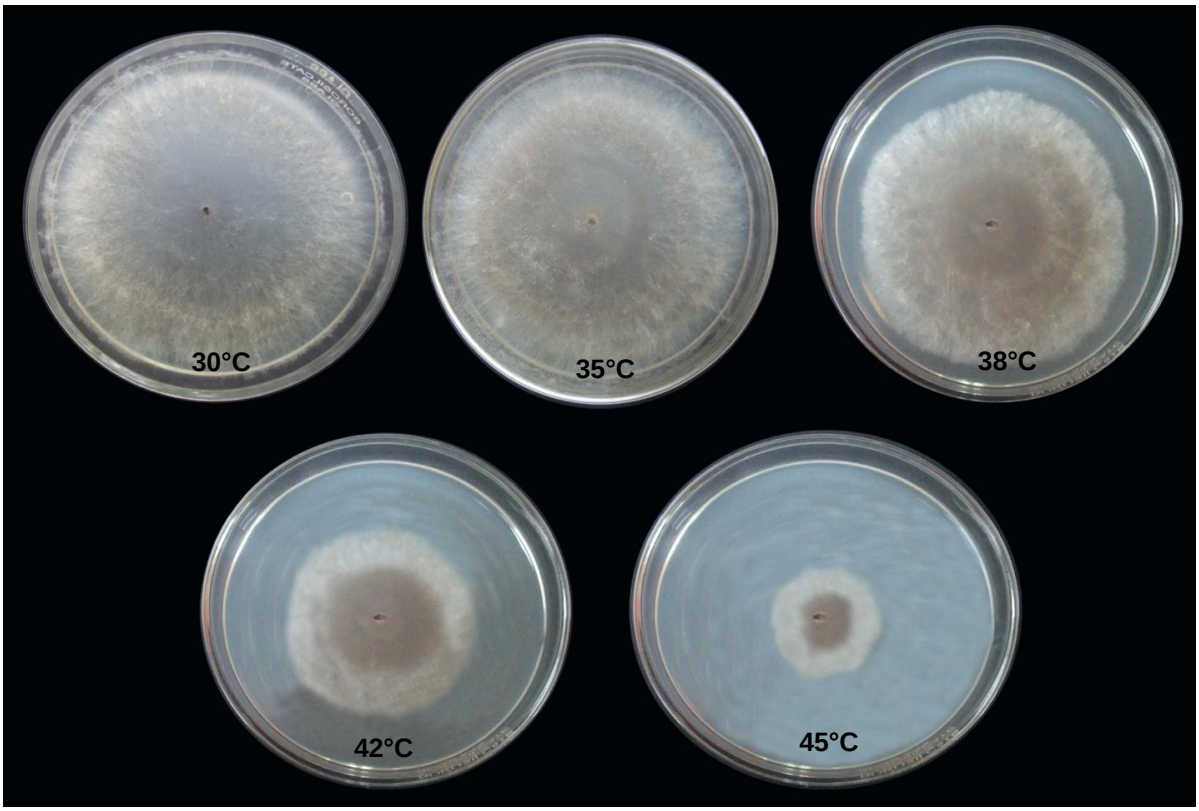


Plate 7. Effect of increasing temperatures on mycelial growth of *P. grisea*

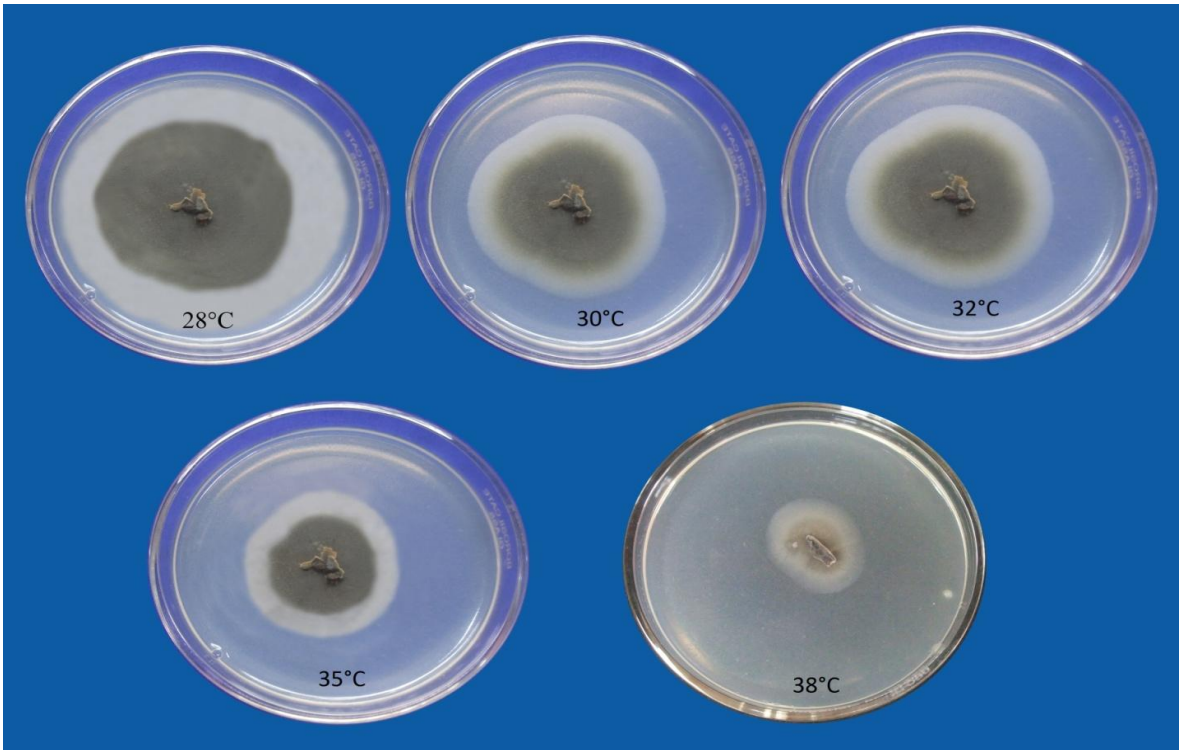


Plate 8. Effect of high temperature on sclerotia production of *R. solani*

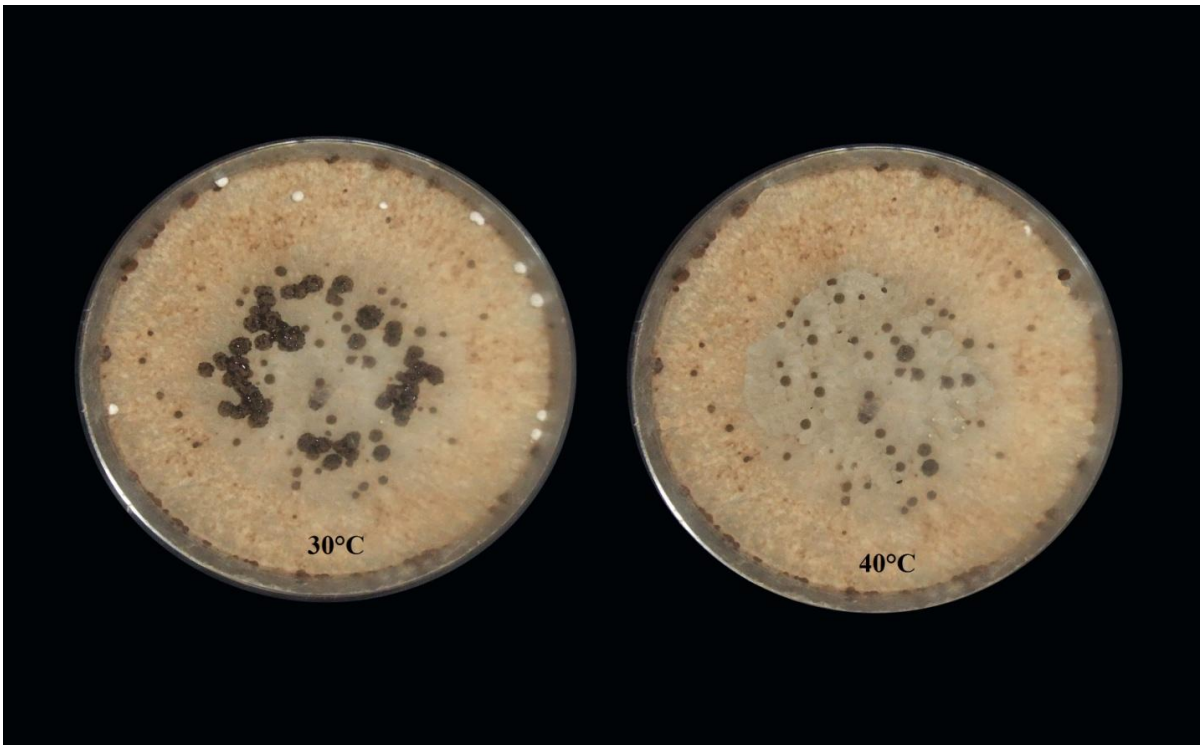


Plate 9. Impact of elevated temperature on sheath blight (*R. solani*) incidence in pot culture

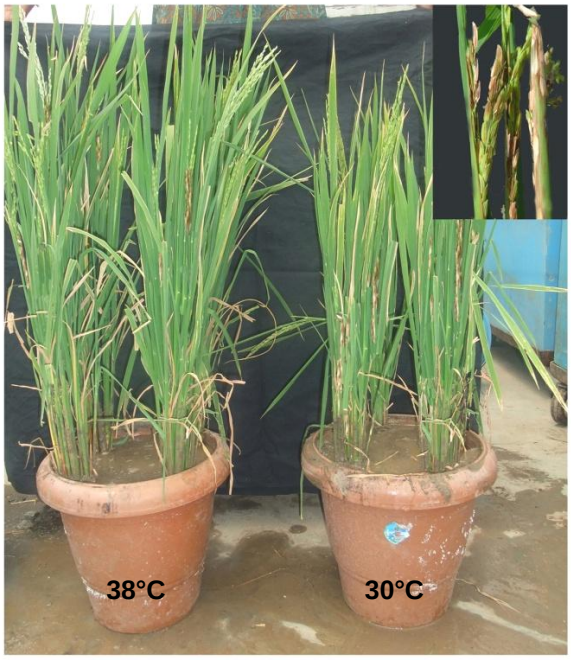


Plate 10. Impact of elevated temperature on paddy blast incidence in pot culture

Plate 11. Life cycle period of YSB under increasing temperatures

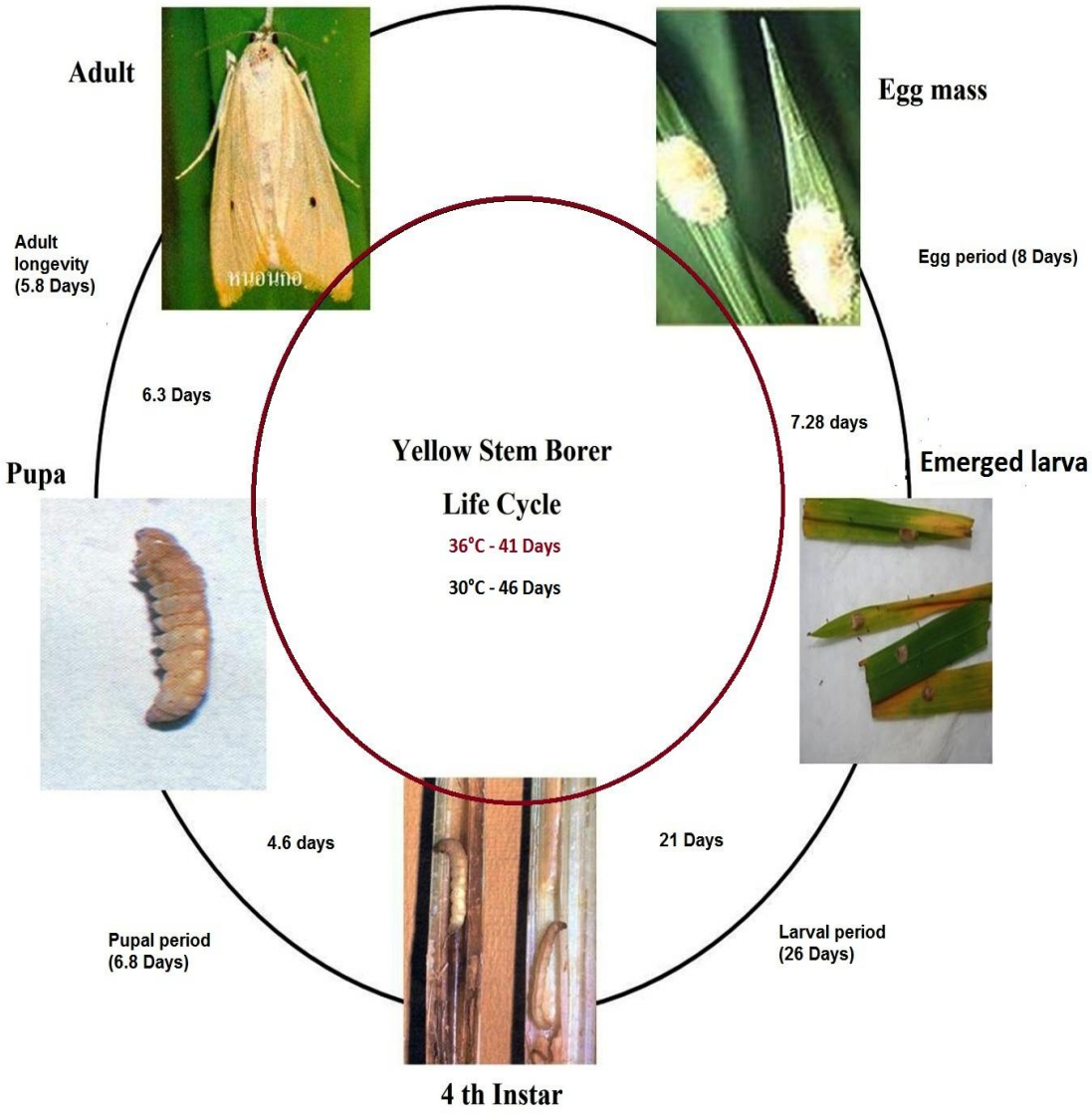


Plate 12. Life cycle period of BPH under increasing temperatures