Effect of light on powdery mildew in greenhouse tomato (Solanum lycopersicum 'espero').

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EFFECT OF LIGHT ON POWDERY MILDEW IN GREENHOUSE TOMATO *(Solanum lycopersicum 'Espero')*

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Abstract

Powdery mildew caused by *Oidium neolycopercisi* is one of the most destructive diseases in greenhouse tomato and has been an increasing problem in Norwegian greenhouse tomato industry. Due to the favourable environment and the lack of resistance varieties, they are extremely aggressive in greenhouse tomato. We do not want to use fungicides are frequently used to treat the tomato for powdery mildew. The most common fungicides are sulphurs. As we do not want to use these kinds of fungicides because they can be harmful to the human health and biological control agents, there is a need for alternative preventing measures that will be economical. Light regulation is one of the possible strategies that can be used in management of powdery mildew in greenhouse tomato production. In this study, the effect of light, lighting duration and its intensity on powdery mildew severity of tomato were examined under growth chamber conditions.

The powdery mildew susceptible tomato plants cv.*Espero* was inoculated by spraying conidial suspension prepared from 7-10 days old powdery mildew inoculum. Inoculated plants were exposed to different light treatment. Among the different lighting treatment inoculated plants exposed to 16 hours of daily lighting supplied by red light emitting diode (LEDs) shows significantly low level of severity on inoculated plants as well as no disease in non-inoculated plants compared to all other treatments. In the combination of HPS and LED, the powdery mildew severity has no significance after 18 days inoculation. However, tomato plants exposed to 16 hours of daily red light treatment showed symptoms of leaves in pale green colour with downward curling. Further total dry weight of above ground plant parts significantly low in plants grown under red light compared with rest of treatment. The result showed that the application of only red light has very limited potential in powdery mildew disease management in practice. Further research in combination with different spectral quality is necessary.

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Abbreviations

%	Per cent
^{o}C	Degree Celsius
cm	Centimetre
DIF	Difference between day and night temperatures
DT	Day temperature
EOD	End of Day
EC	Electrical conductivity
HPS	High Pressure Sodium Lamp
LED	Light Emitting Diode
M/S	meter per second
NT	Night temperature
ppm	parts per million
R	Red
UV	Ultraviolet Rays

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the most important vegetables used worldwide. There are different varieties of tomatoes found in the earth's ecosystem; among them some major types of tomatoes are classic round, cherry and cocktail, plum and baby plum, beefsteak, vine or truss. Tomato is generally cultivated in the warm or tropical climate. The total production of tomato in 2010 is 152 million tons whereas the production was only 89.9 million tons in 1998 (FAOSTAT 2010). USA comes in the top position to produce tomato whereas China is the second largest producer of tomato (USDA 2012). Tomato fruit production data is being yearly reported from 144 countries of the world. In the past 10 years, the most significant change occurring has been the quantity of greenhouse tomatoes being grown from major production centres in The Netherlands, Spain, Canada and the United States. Greenhouse production is the basis of high value crop industries around the world. Tomatoes can be used in both ways, i.e. fresh as well as processed for consumption later. Since tomatoes cannot be cultivated in the open field the entire year due to inclement weather conditions like frost, snow and sub-zero temperature in the temperate region, alternative means of production has been sought after. Such adverse weather condition has necessitated the use of artificial weather improvement such as the Greenhouse Plantation techniques, which provides a favourable environment for tomatoes growth by trapping the heat from the sun and thus, enhancing the temperature conditions in the greenhouse to suit the favourable growth condition essential for tomato production with great efficiency and the desired output: even in the unfavourable surface temperature and weather condition. With the success of the greenhouse technique, world has taken a rapid stride in enhancing the agricultural production like tomatoes and has been producing tomatoes the entire year with marked improvement in the production output, thus addressing the high market demand and fostering the economy. It has been observed that the tomatoes that are produced in the greenhouse are mostly used as fresh vegetable.

Northern part of Scandinavian countries such as Norway, Finland, and Sweden has short daytime and less sunlight during winter. Tomato are planted in the mid-winter and harvested until late autumn in the northern latitude. Supplementary light, CO_2, heat and relative humidity are necessary control factors in these areas for horticulture productions. Although the production cost is significant due to high electricity consumption, water and labour cost

involved. Still the growers from these areas are producing tomato with the arrangement and supply of the supplementary light and artificial control condition (Wallén 1970). Low natural light, short day time, supplementary illumination can promote plant growth and earlier yield (McCall 1996). With manipulation of various biotic and abiotic factors such as light, heat and relative humidity inside the greenhouse, production can be increased substantially. These factors are directly related to the plant growth, flowering and yielding (Taiz & Zeiger 2002).

But the Greenhouse production is not immune to various diseases that hamper plant's yield, desired productivity as well as untimely death too. Out of many diseases, Powdery Mildew is one of the economically important diseases for it significantly reduces the tomato production capacity and output. Powdery mildew is extremely aggressive in the Greenhouse cultivar tomatoes due to the favourable environment condition available for its growth inside the Greenhouse. Powdery mildew is very common in Greenhouses in various geographical regions and under a variety of growing conditions. There is no single method for the complete disease control and botanically successful growth of the plant. Disease control by synthetic chemicals had created the general perception that chemicals could provide permanent solution. However, frequent application of systemic chemicals induces the development of pathogens, isolates the fungicide resistance including powdery mildews (Hollomon & Wheeler 2002; McGrath, M. T. 2001). Since, nowadays the consumer public are increasingly aware regarding food health and strongly tilted in favour of the organically grown vegetable products, which are in fact very good to human health, thus making it a necessity that the vegetable products must have been produced with no indiscriminate use of the insecticides and pesticides. Such new development has clearly necessitated the search for an innocuous, effective and economical alternative in order to control various plant diseases with powdery mildew being one.

The most appropriate method to control disease is the use of resistance cultivar. However, majority diseases have no resistance cultivar and the manipulation of the greenhouse environment to avoid water dependent pathogen. Use of spectral quality has potential value to control powdery mildew in rose (Suthaparan et al. 2010b) and cucumber (Schuerger, A. C. & Brown, C. S. 1997; Shibuya et al. 2011; Wang, H. et al. 2010). However, there has been limited research in effect of light on powdery mildews; especially on *Oidium neolycopersici*; causal agent of powdery mildew in tomatoes (Suthaparan et al. 2010b) and cucumber (Schuerger, A. C. & Brown, C. S. 1997; Shibuya et al. 2011; Wang, H. et al. 2010).

Later it became one of the serious diseases which caused huge loss of production capacity and reduction in the economic value of the product as well. These diseases affect both on quality and quantity of fruits and flower. *Oidium neolycopersici* is causal agent of powdery mildew, which is a biotrophic pathogen spread all over the world and fungi which is biotrophic parasite only invading host epidermal cell. The epidemiology of powdery mildew is very complex. Fungi cause powdery mildew in a wide, range of plants species to the same phylum (Ascomycota). Over 500 species of powdery mildew can colonize on 10,000 distinct plants all over the world (Takamatsu 2004). Powdery mildew is one of the air borne diseases and widespread fungal disease in greenhouses. Generally; relative cool atmosphere, moderate temperature and shady area are the favourable condition for powdery mildew growth (Yarwood 1955). The greatly reduced space between the greenhouse plants is also favourable condition for the powdery mildew. The important fungi causing powdery mildew are S*paerotheca fuliginea* which significantly damages, mostly cucumber and melon.

The objectives of the present study were to optimize the efficiency of red light in terms of duration, quality, intensity and spectral balance against powdery mildew. As well as the growth potential of tomato plants under these lighting conditions also were assessed.

2. Literature Review

2.1 An Over View Over Tomato Production in Central and Northern Europe

2.1.1 Original and History

Tomato (*Lycpoersicum esculentum*) is 3000 years old culture plants which are found in the hilly regions in between South America. It is believed that tomatoes were first found in South America and spread to Europe in 1421. Wild tomatoes can be seen in Ecuador and Chile presently too. Tomato was thought to be poisonous before and not used as food. In Europe, tomato was first introduced in 1554 in Italy and in 1596 United Kingdom. Name of the plant was given as "Tomato" in 1700 Century in Denmark. But it was used as food only in the 18^{th} century. In case of Norway, tomatoes are first used in 1855 in Christiania, where it was first grown in 1890 in Rogaland. From the business point of view, grower had small interest for tomato production in Norway. The first heated greenhouse that was used to produce tomato was in 1932 (Omdal 2005). Major tomato production area in Norway is Finnøy and Rogaland. Greenhouse production constitutes major part of commercial horticultural production in Norway. In the last 30 years, greenhouses are increased by three times and half of the tomatoes produced are grown the Greenhouse. The total Greenhouse area in Norway is about 200 hector in 2010. In 2006, the number of greenhouse in Norway was about 740, which decreased by 23% with respect of 1999. Tomato, cucumber and lettuce production occupies about one half of the total area 305000 m^2. The total amount of tomatoes produced in Norway grown in 2006 was 11811.5 tons (Norway 2008) .

2.1.2 Growing System and Medium

Light condition is an essential and paramount condition for tomato production in the Greenhouse. In Norway, about 40 – 45 days old plants are planted in the Greenhouse. The harvesting time will be two month after planting. The season of tomato will remain until the mid of October. Double roves V- shaped are also common system for growing tomato(Omdal 2005). This is one of the most common cultivation systems with two rows. But some growers also choose V- system where there is only one row and another two plants are added to each

side, so that there are two rows. In recent years, some growers have also added hanging flows. It is found that various growing system according to the greenhouse. Growing medium provide the environment for plants growth and which also provide the nutrient and water to plants. The growing medium must be of good physical base for the plants growth. The different known growing physical media are soil, compost, peat, bark, Rockwool, Perlite and coir. Media must be free from diseases and should hold water with 20% air filled pore. Plant can be grown in two different lighting systems, which are with light and without light (Gislerød 2011).

Although, soil is the natural rooting medium for the plants, the fact that use of soil in long term gives lots of problem of salinity and disease due to "Soil Sickness". Soil sickness is a condition which adversely affects the plant's yield due to repetitive use of soil for the production of the same kind of plant. In quest of alternative growth substrates for plants, the concept of soilless culture began during 17^{th} century. Hydroponic system is the most intensively used growing technology in recent time, in which plants are grown under nutrient solution. This is mostly used for the production of higher quality fruits (Morard & Henry 1998). Due to this, soilless culture like Rockwool, cocco fibre perlite has great interest for greenhouse tomato production. Peat sand, perlite and perlite sand are suitable media for long-term use in the Greenhouse tomato production.

2.1.3 Nutrition and Irrigation

Nutrition and irrigation are key points for the good result of harvesting. Good routines, daily monitoring and good technical equipment are important factors for good result. All essential nutrients are given to plants during the course of each watering. Drip watering system is common in tomato production. Essential fertilizers are mixed with water in the tank with 10% to 20 % diluted solution and sent to plants through the close watering system (Omdal 2005). One of the solutions is Superba used mostly in the Greenhouse tomato which is used in combination with calcium nitrate. This is one of the most important solutions for greenhouse irrigation and nutrition.

In case of Norway, tap water is very good for irrigation purpose. But it should be analysed for pH value, bicarbonates concentrations, before mixing with different kinds of nutrients.

Irrigation varies from time to time and between the years. The important factors that affect irrigation is the light condition, in addition; temperature, relative humidity, leaf areas are also important factor which affects irrigation.

2.1.4 pH

The optimal pH for plant growth is suitable in between 5.0-6.0, with a limit down to about 4.5 and upper limit of around 6.5. The range of pH in nursery can be maintained between 4.5 to 6.5. A pH beyond this range will easily result in either toxicity or deficiency of micronutrients. The plants get weak and suffer from root fungi disease. In addition, low pH leads to degeneration of rock wool growth (Gislerød 2011).

The availability and uptake of nutrition depends upon the pH and vary with pH in case of greenhouse tomato. To avoid lack of nutrition, pH must be maintained between 5.5 to 6.2 (Omdal 2005). High pH can effect on phosphorus uptake and low pH level can effect on manganese toxic and root problem. If the level of pH of growing medium increases more than 6.2 it must be reduced by adding bicarbonates which acts as base for neutralizing. If the pH is below than5.0, it will be necessary to add hydrated lime or potassium carbonates which acts as acid again for neutralizing the condition. Use of these fertilizers can easily cause clogging of the drip so they should be mixed in a tank prior to use. The factors, which influence pH, are tap water, fertilizer and proportion of NO_3-N/ NH_4- N, growing medium, growing system and plants species.

2.1.5 Salinity

The total concentration of solutes in the nutrient solution is characterized by the electrical conductivity (EC). Usually EC in greenhouse tomato production is in the range of 2- 5 dsm^{-1}. Too low concentrations cause mineral deficiency and restrict plants growth (Winsor & Adams 1987). High concentrations of salt cause water deficit, ion imbalance, ion toxicity or a combination of any of these adverse factors (Greenway & Munns 1980). To avoid deficiencies and to control the growth and quality of product, large amount of nutrients are

added to the irrigation water. Reuse of drain water enables economic use of water and fertilizer combined with an ample supply to the crop (Sonneveld & Welles 1984). Tomato yields decrease with the increase of salinity. Uptake of water into the fruits is reduced by a high osmotic pressure of the irrigation water and as a result the fruits size is smaller (Ethret & Ho 1986). Fruits disorders can be seen caused by low concentration (Chiu & Bould 1976). On the other side mild salinity can improve the product and dry matter on fruits (Chiu & Bould 1976). Salinity plays important role for nutrient uptake and root development. Salinity in between 1.0 – 1.2 m s cm^{-1} is very low and in between 1.3- 3.0 is normal condition. Similarly greater than 7.1 level is toxic (Omdal 2005)

2.1.6 Climate

2.1.6.1 Temperature

Solar radiation contributes to heating a greenhouse. The temperature has been use in recent year for controlling growth of plants which could help to produce the well-shaped plants without affecting the delay of flowering and fruiting. Diurnal temperature alteration can be achieved by difference between by; (1) day temperature and night temperature (DIF) (Erwin et al. 1989). (2) Temperature drop i.e. diurnal temperature decreased for 2-4 hours. Temperature also plays an important role in pollen characteristic and fruits set. Low temperature that is lesser than 13ºC reduce the pollen viability whereas higher temperature more than 30ºC has good to excessive growth of the style which reduces the pollination. Temperature has a direct influence on plant metabolism and plays vital role for vegetative and reproductive growth. The higher temperature within certain limits fosters the development. Temperature must be adjusted to produce high yield. Temperature may influence the distribution of photo assimilates between fruits and vegetative part as well as their rate of growth (Heuvelink 1999). Higher temperature more than 32º C limit can reduce the tomato production because it effects on the pollen development (Warrag & Hall 1984). High temperature favours the distributions assimilates to fruits, at the expense of vegetative growth (De Koning 1990). Moreover it is found that positive correlation between photo-assimilate import to fruit and fruit temperature (Walker & Ho 1977). Generally night temperature cooler than 18ºC delay the development and decrease the early yield of tomato (Cholette & Lord 1989). Generally we can say that good lighting and high CO_2 concentration requires a higher temperature than low light and low CO_2 concentrations.

The heating system varies for the respective species. A small effect was exhibited on the growth and fruits or flower production of tomatoes and lilies when a lower temperature, a method known as spilt night temperature regime, replaced a portion of the optimal night temperature period. But common day temperature that is suitable for tomato growth is 18 $^{\circ}$C - 20°C whereas night temperatures are suitable in range from 16 $^{\circ}$C - 17°C. Higher temperature promotes fruits development and fruits ripening whereas lower temperature promotes vegetative growth. Ventilating must be fitted in the temperature of 21 $^{\circ}$C -24°C (Omdal 2005).

2.1.6.2 CO_2

Carbon dioxide is also important factor for the production of greenhouse tomato. The CO_2 enrichment for greenhouse crops increase plants growth, fruits set, the number of fruits and average fruits weight (Frydrych 1984). The carbon dioxide is the principle element for life. Several researches has proved that the linear effect on photosynthetic rate up to 1000- 1500 ppm (quoted by Omdal 2005). The photosynthetic rate increased by 50 – 70% with the increased of carbon dioxide from 300 ppm to 1000 ppm. This do not have any effect on fruits quality (Davies & Winsor 1967).The major dry part of plants is composed by carbon. The total amount of carbon in tomato plant is about 30% – 40% (Ho 1976). The rate of photosynthesis depend upon the amount of carbon dioxide surrounding which promotes the yielding too (Idso et al. 1987). The amount of carbon dioxide from 365 ppm to 800 ppm increases plants growth by 15% to 30 % whereas increase of carbon dioxide from 200 ppm to 300 ppm increases 35%- 40% growth. But increase of carbon dioxide from 900 ppm to 1000 ppm is only increasing about 2% growth. The pure carbon dioxide 3 kg per 1000 m^2 per hectors gives about 800 ppm. Carbon dioxide can be given by burning propane gas, which gives 20 kg carbon dioxide per hour (Omdal 2005).

2.1.6.3 Relative Humidity

Relative humidity is important for the nutrition and water uptake as well as cooling the plants. Relative humidity in the greenhouse is the result of balance between transpiration of crop and soil evaporation, transpiration, condensation of the greenhouse cover and vapour loss during the ventilation. Humidity is in low level in case of winter due to low transpiration and high level of condensation but it is high in spring and autumn. Energy conservation feature also help to increase relative humidity. Relative humidity plays important role disease control and fruit quality. Relative humidity is suitable for the tomato greenhouse range from 70% – 80% (Peet & Welles 2005). Relative humidity means delta x like to 3- 5. Delta x tells about how many gram water contain per meter cube. The air relative humidity comes from transpiration of plants (Omdal 2005). Ventilation plays important role taking out about 80% relative humidity from greenhouse during summer whereas condensation takes out about 75% during spring (winter) (Jahns & Smeenk 2009). Heat pipe between plants and in the ground must be maintained at 40ºC so that it helps to dry air and its movement.

2.1.6.4 Light

The productivity of greenhouse tomato is influenced by the total solar radiance. Light is one of the most important factor that control plants growth and development. Red and blue light are more efficiently absorbed by the photosynthetic pigment than the other spectral region (McCree 1972). Maximum yield occurs near 600 nm, and rapidly decrease with the wave length shorter than 400nm and greater than 680 nm (Evans 1987). Blue light helps to the formation of chlorophyll, and also help to opening stomata and morphogenesis (Senger 1982). Light between 390- 760 nm has been recognized as essential factor for the photosynthesis, which convert solar energy to biochemical energy. Photon flux between 400-700 nm waveband is most essential for photosynthesis (Gardner et al. 2003). Many researchers have shown that using the supplementary light can increase the growth and yield of greenhouse vegetable during the winter. In greenhouse generally photoperiod between 14-17 hours are used. It is well established that the use of HPS supplementary lighting during period of low light intensity encourages greenhouse tomato growth and productivity and enable production on a year–long basis (Janes et al. 1992). It has been noticed that longer

photoperiod more than 20 hour per day in tomato growth can causes chlorosis (Vézina et al. 1991).

2.1.6.4.1 HPS Light:

HPS lighting system is common and popular in greenhouse tomato production which has high electric efficiency, long operating time and wide spectrum of light which are suitable for many plants species. HPS lamp emits light visible between 400-700 nm and in the invisible ranges. HPS lamp has a high radiant emission, high photosynthetic active radiation with only 5% blue light. HPS emits the peak emission yellow that is 590 nm. HPS lamp produces lesser heat than the LED. Because of less heat production, HPS light can be used near to tomato plants (Engbers et al. 2006)

2.1.6.4.2 LED Light

Light Emitting Diodes (LEDs) are solid-state semiconductor devices that produce narrow spectrum when voltage is applied. This is solid state, durable, long-lived light source that provides the narrow – band spectral emission. Light from LED is generated inside the p-n junction of a sample diode, which is made of two different alloys of different potentials energies. As current flows from one to another alloy, photons are released. LED has several unique characters that make their use in the greenhouse control, research and use of supplementary light in the greenhouse. LED contains the ability to control the spectral composition that provides the high output with low irradiance (Stutte 2009).

2.2 Regulation of Plants Growth

Temperature and light can be used for regulating plants growth and fruits production. In the long cropping cycle of typical of greenhouse growth, tomato tends to vegetative growth in the beginning and generative growth could be witnessed later. Temperature is one of the most important tools to control flowering and fruits growth and determine the yield of tomato

production. Plants hormone are used for the regulation of plants growth and ripening of fruits (Crane 1969). Carbon dioxide is known to enhance the growth and productivity of glasshouse and agriculture crop.

2.3 Pollination

Well pollination is required for the optimum production of plants. Tomato plants can use its self-pollination; besides this, mechanical pollination too, is common. It is done through vibrating flower and stamen by using vibrates. Bruising is also one of the method that can be used for pollination (Omdal 2005).

Pollination is the one of a great problem in the greenhouse production especially in the winter. But nowadays Pollination can be conducted through the bumblebee. Plant pollination from this method bears good results than mechanical pollination method. It takes about eight week from fruition to harvest. Use of the bumblebee for pollination makes certain of pollination and saves great working time. Bee takes pollens and nectar from flowers for feeding. In tomato production, bees collect the pollens from tomato flowerers and additional sugar water from the garden. They work whole time until there is light. They are more active in the morning time and evening time. When bees are visiting the flower, they grab hold of the trumpet and shake the flower at their wing movements which help in pollination and fertilizations. Pollination in winter can be problematic due to less activity of bees.

The amount of pollen can vary from plant to plant. Especially vegetative, fodder and bush has small amount pollen. They have large flower and are difficult to open naturally, thus such plants has difficulty in pollination. Generative and small stress plants have large amount pollen, which makes it easy for pollination and fruition (Omdal 2005).

2.4 Quality Management

Tomato fruit is a living part; it continues to respire through its life, which results in degradation of the quality towards senescence. Tomato quality is affected by pre-harvest factors followed by post-harvest factors. The best way to obtain good quality is to optimize growth condition and to preserve the quality by proper storage conditions (Aguayo et al.

2004). Different climatic condition such as temperature, light condition, relative humidity and carbon dioxide have effect on the quality of fruits. Temperature during the growth and post-harvest has significant effect on the quality of tomato. Proper and optimum temperature is required during growth period to produce better edible quality. Beside this, light has positive impact and harvest index (Kays 1999). Excessive heat leads to the damage of colour, protein content and shape of tomato fruits. Direct effects of high temperature stress include damage to cellular membranes, proteins, and nucleic acids (Kays 1999).

2.5 Powdery Mildew in Tomato

Powdery mildew is one of the major problems in the Greenhouse tomato production. This belongs to the order of *Erysiphale* and widely distributed all over the world. *Oidium* species causes powdery mildew in tomato. Other species also causing tomato powdery mildew is *E. orandi* but this has minor economic value because it does not damage plants. *Oidium neolycopersici* causes powdery mildew on numerous wild tomato as well as cultivated plants. There are two species of powdery mildew under *Oidium* genus: *Oidium lycopersici* is common in Australia whereas *Oidium neolycopersici* is found all over the world. *Oidium neolycopersici* is a highly polyphagous powdery mildew fungus which infects tomatoes. It causes powdery white lesions on the adaxial tomato leaf surface. The fungus can also infect abaxial surfaces, petioles and the calyx but the fruit remains uninfected. Severe infections lead to leaf chlorosis, premature senescence and a marked reduction in fruit size and quality (Whipps et al. 1998).*Oidium neolycopersici* currently poses a significant threat to glasshouse-grown tomatoes and is of increasing importance on field-grown tomato crops (Jones et al. 2001).

The mature conidia are mostly released by the help of wind at the rate of wind velocity between 0.8 to 1.2 m/s and cannot release in below than 0.8 m/s wind velocity (Oichi et al. 2006). It can easily transmit near to leaves and plants via air current as well as effecting production activity. Due to high wind speed pseudopodia gets transported on plant leaves. This is the main cause of infection in plants. These fungi can survive in weed host as mycelium and in living plants in between crops (Douglas 2003). The powdery mildew is more problematic in the spring season in the Greenhouse and poses fewer problems when day

night temperature is in favour of high relative humidity. Powdery mildew epidemic is largely influenced by the interaction of humidity and temperature.

Different powdery mildew fungi are reusing different optimum condition for disease development (Yarwood 1978). The tomato plant is a principal host of *Oidium neolycopersici* but it can be seen on large variety of plants species. Powdery mildew is normally found in 13 families including Cucurbitaceae and Solanaceae. It has been reported first time in 2001(Kiss et al. 2001). They produce single and pseudo conidiophores chain. Each pseudo chain contains about four mature conidia (Oichi et al. 2006). The environment factor also influences germination, formation release and survival of spores as well as mycelium development (Reuveni & Rotem 1974). Besides this, powdery mildew caused by *Laveillula taurica* is more common in Israel. This disease has a very short latent period. These can germinate within 3 hours and produce germ tube until they enter to stomata. Powdery mildew colonies were first observed after 4 days of inoculation. One of the colonies contained 10 - 20 conidiophores per colony, which was erected from the superficial mycelia of the pathogen. After 6 days, the mature conidia were seen in the tips (Nonomura et al. 2009). But it is interesting; the number of conidia is up to 5 in case of greenhouse tomato production. These conidia separate from pseudo chain and start a new life cycle. (Whipps & Budge 2000) .
Fungicides are important tools for controlling powdery mildew (McGrath & Thomas 1996). Fungicides that are systematic or trans-laminar activity are needed to obtain adequate protection of leaf surface, where conditions are more favourable for the development of pathogens than on ad axial surface (McGrath, M.T. 2001). Unfortunately, these fungi have high risk of developing resistance because they have specific mode of action, and the powdery mildew have high potential for resistance development against fungicides.

Biological control can also be an alternative control of powdery mildew. Biological control of various mildew has been studied quite extensively in the past. A few microorganisms have found to give some control. For examples, *Ampelo myces quisqualis, Spoothrix flocculosa, Stephanoascus regulosus,* were used for the biological control (Falk et al., 1995). An experiment reported that foliar spray of *Sporothrix flocculosa* can also reduce the development of *Oidium neolycopersici* on the Greenhouse tomato (Falk et al. 1995; Jones et al. 2000).

A wide level of research has been launched to find resistant cultivar resistance with various level that has been found in wild tomato such as *Lycopersicon chesmani, L.chilense*

(Lindhout et al. 1993). Another resistance to *Oidium neolycopersici* has been found in *L.esculetum* var. *Cerasiforme* which is hybrid obtained from wild tomato (Ciccarese et al. 2002).

2.6 Light Effect on Powdery Mildew

2.6.1 Light

Light is an essential and important factor in plants production. Light has primarily two functions during plant's growth and development. The first is light influenced plant growth and second is light influenced several development processes such as germination and seed production. It also acts as a signal that is photo morphogenesis and photoperiods. Light is an important environmental factor that regulates many aspects of growth and developmental processes as well as physiological development in living organisms, including plants and fungi. Light has electromagnetic wave and wavelength i.e. distance between two succeeding wave and frequency (number of wave depression per time unit). Sun spectrum has visible light 400-740 nm that is photosynthetic active light (PAR). Light has influence rate that is µ mol m^{-2} s^{-1}.

Light is a visible part of the electromagnetic spectrum to human eye, plays vital role in growth and development of almost all livings in the earth. Light is an important source of energy for living in the earth which is primarily harvested by green plants via photosynthesis. Light has different form and has direct effects on the plants development, plants size, production, length, disease resistance, and disease spreading in all plant. Light is also an important factor for living organisms, which gives sensory stimuli to adapt changing environmental condition. Light transduction are mediated by single or group of sensory photoreceptor molecules (Smith 2000). The influence of light can be termed as day length, intensity, quality and integral. Photosynthesis is the major process that makes interaction between plants and light. Photoreceptor is a plant part that helps to absorb light energy from sun. Light energy captured by photoreceptor is a part biological process.

Supplementary lighting is very common in northern hemisphere because of short period of day length. Supplementary lighting has been used to grow plants nearly 150 years. supplementary lighting can be divided three category which are invention of filament lamp by Edison, open arc lighting that are typical for used carbon rod and popular for street light

and gaseous discharge mercury lamp (Wheeler 2008). Most commonly high pressure sodium lamp (HPS) is used for lighting in greenhouse production. Supplementary light is given by light emitting diodes which is first used in 1990 (Bula et al. 1991). LED generates the light through an electro luminescent principle, which has several advantages. It is possible to specify the desirable spectrum and they have long life. It has been found that UV radiation can help to reduce powdery mildew infection in several plants (Willocquet et al. 1996). Similarly, it has been seen that filtration of far red light can reduce powdery mildew in greenhouse crop. The powdery mildew lives outside of infected tissue where they are directly exposed to the UV light. Powdery mildew has not any pigment that can protect from the radiation (Wilcox et al. 2008). UV-C has been used to reduce the grape wine powdery mildew. Similarly UV-B was reported for controlling plant diseases. Increasing UV-B has been found to reduce severity of powdery mildew in grapevine when plant canopies were manipulated to increase light penetration (Austin et al. 2011).

2.6.2 Light Intensity

Photosynthesis active radiation is a radiation in the range 400-700 nm. This is evaluated on the quantum which are suitable when photochemical process are being consider and it is measure of the quantum flux of electromagnetic radiation from all direction in the 400-700 nm waveband per unit surface. This is expressed as mol m^{-2} s^{-1} (Thimijan & Heins 1983). Light intensity influences photosynthesis and plant's growth parameters such as branching, stem thickness, slower number and flower size as well as fruits colour and shape (Runkle & Heins 2003).

Powdery mildew on tomato also depends on light intensity. This is reported that light intensity from 1000 lux to 5000 lux reduces conidial germination of *O. neolycopersici*. The same study also report tomato powdery mildew has optimal development at 25ºC under at light intensity 3500 lux and more than 90% conidia germinate and can be seen moderated lobed appressoria (Kashimoto et al. 2003).

2.6.3 Light Quality

Various wavelengths have various effects on the germination of conidia. It is reported that conidia germination reduce under red or blue light, while the highest conidial formation as recorded in full spectrum white light (Purschwitz et al. 2008). Severity of powdery mildew was highest in cucumber plants grown under white light (300-800 nm) compare to red light (Schuerger, Andrew C & Brown, Christopher S 1997). Reduced severity of cucumber powdery mildew caused by *P. fucusa* was also observed under polythene films that block far red and UV light (Elad, Y. 1997). However, cucumber powdery mildew caused by *P. xanthii* showed highest number of powdery mildew under halide lamp, an intermediate number of colonies under red light or red to blue whereas lowest number colonies under red light (Schuerger, Andrew C & Brown, Christopher S 1997). In addition far-red light induced cucumber powdery mildew while red light reduced conidia formation and release. But it was observed that the far red followed by red light can neutralize the effect of red light on conidial release (Suthaparan et al. 2010b). Powdery mildew in cucumber caused by *P. xanthii* was low in red, high in red to blue or red to far-red and highest under full spectrum (Schuerger, Andrew C & Brown, Christopher S 1997).

2.6.4 Light Period:

Photoperiod refers to the amount of time a plant is exposed to light during the 24 hours cycle. Light period can affect plants growth in two ways: 1) short light period provides less total energy to plants than long light period at the same light intensity, 2) the length of the photoperiod may induce specific physiological cycle response in many plants species independent of the light intensity, a phenomenon known as photo periodisms. Control of powdery mildew depends upon the length of light (period). The first time carbon arc lamps were used for growing plants in 1860 by Siemens (Siemens 1879)

2.7 The Effect of Light on Powdery Mildew Development

Light plays important role on fungal development. It has been found that the powdery mildew on the Strawberry leaves are not affected by light (Peries 1962) and another study on powdery mildew has found that powdery mildew grow completely in the darkness. It has been found that conidia formation rose powdery mildew is independent; however, maximum growth occurs during dark periods and maturation and release occurs only in day time (Frinking 1977). It is reported that the increase in the length of day from to 20- 24 by using supplementary light reduces significantly sporulation of *p. pannosa* and severity of powdery mildew in greenhouse roses (Suthaparan et al. 2010a). Some growers supply continuous light to cut rose in order to increase yields, but also maintaining minimum heat on greenhouse by the help of heat producing lamp. This help to reduce powdery mildew in rose with comparison to switch off light to make dark condition (Carver & Carr 2008). UV radiation is known to suppress or kill a variety of fungi. Powdery mildew may be suppressed with relatively short exposure to low intensity UV-B.

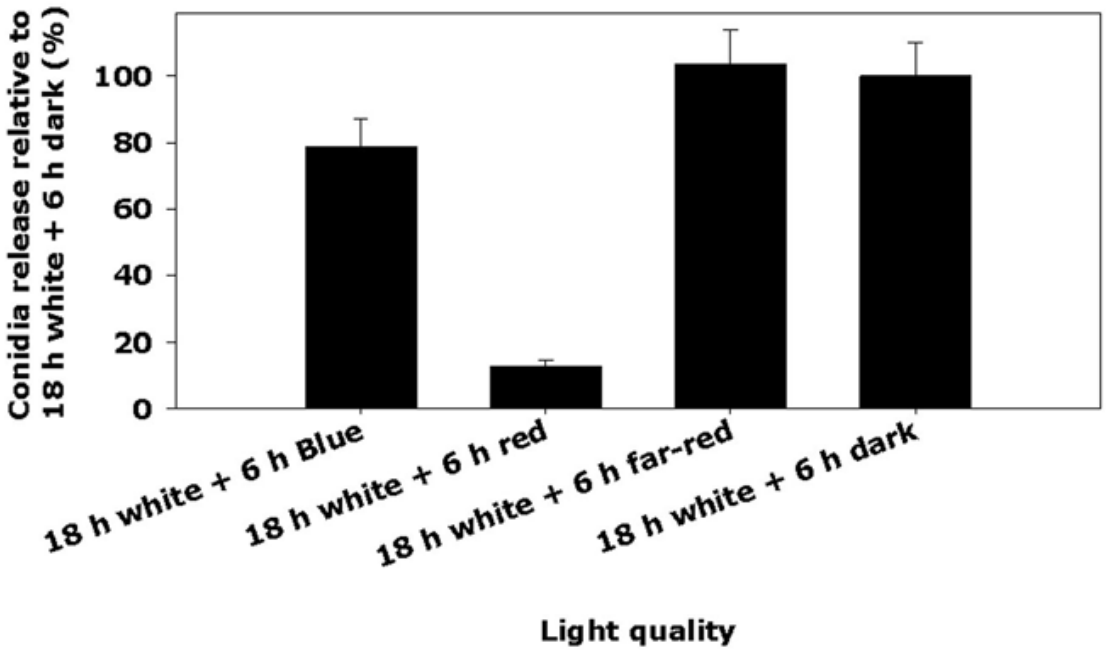


Figure 1 : Effect of extension of day length using different light qualities on productivity (formation and release) of conidia by *Podosphaera pannosa* on whole plants of Rosa × hybrida. Inoculated plants (kept at 18 hours of day length) bearing 12-day-old c colonies were exposed to 4 cycles (days) of 18 hours of white light followed by 6 hours of either blue, red, or far-red light or darkness in wind tunnels (experiment was repeated three times). Treatment means are reported as percentages relative

to 18 hours of white light plus 6 hours of darkness control. Bars indicate one standard error of the mean (Suthaparan et al. 2010b)

In above figure, the effective combination of light:18 hours white light followed by 6 hours blue, red , far-red and dark was observed in the powdery mildew by Suthaparan et al. (2010b) showed that the reduced germination of conidia of powdery mildew followed by 6 hours of red light.

3. Materials and Methods

The experiment was based on manipulation of light intensity and duration to control of powdery mildew in close chamber. The experiments were conducted on the SKP (Senter for klimaregulert plant forskning) and Håkonshallen laboratory of Norwegian University of Life Sciences (UMB). Experiment was started from February, 2011 and it was completed during six months. The experiment was repeated three times with same condition and method. Plants for these experiments were set in closed chamber with control environment. These chambers were facilitated by artificial supplementary light, air humidity, and temperature and wind speed. Day temperature and night temperature were set as 20^0C± 2 respectively. The relative humidity of all chambers were maintained at 70% ± 5% and wind speed was maintained constant , which helped to transmit disease from inoculated plants to healthy plants. Wind speed was maintained by using an electric wind blower. Irrigation on chamber was done manually through complete nutrient stock solution on the regular time basis at nine o'clock morning. Powdery mildew free tomatoes were grown in lime and fertilized peat and pertile (25% by volume) in greenhouse compartment. Six chambers have different light intensity and different light duration.

3.1 Closed Chamber at Håkonshallen

Closed chambers were situated at Håkonshallen at Norwegian University of Life Sciences. These chambers were in an artificial environment. Relative humidity of all chambers was maintained at 70% and wind speed was maintained constant, which helped to transmit disease from inoculated plants to health plants. Wind speed was maintained through electric wind blower.

All chambers has provided through the following light. Round LED lamps and HPS lamps were used. High-pressure sodium lamps (HPS) (Lucalox LU400/XO/T/40, GE lighting, Budapest, Hungary). Red light was supplied by 162 W high powers LED grow light. The night break was maintained for two hours.

3.2 Greenhouse Chamber

The Greenhouse is a relative isolated unit during the cold season. Most of the vegetable and the ornamental plants are grown in the greenhouse suffer from powdery mildew. The greenhouse is particularly kept clean and free from pest for several months. The greenhouse is used for plant production in the experiment. Three compartment of the greenhouse are used to plants growth for closed chamber experiment. These greenhouses were supplied with artificial light and relative humidity. The heating is done through sun light as well as supplying heating pipe around the chamber. The light break also maintains thorough time-regulated system. Light is controlled through the automatic time secludes using sensor PRIVA which monitors the relative humidity and temperature in every five minutes and sends to the data centre for analysis. When temperature goes up, ventilator activates heat is lost to cool the system. All chambers are fitted with CO_2 enrichment system. The level of CO_2 was maintained between 400 ppm-700 ppm. The CO_2 was not supplied when ventilation was opened. Irrigation was done thorough closed irrigation system on the regular basis through open irrigation system. The temperature of greenhouse compartment was also set as $20^{\circ}C \pm 2$.

3.3 Production of Plant for Experiment

Plants for this experiment were grown on greenhouse compartment. Tomato species *Esperio* was selected for this experiment. Plants are propagated into 12 cm diameter plastic pots containing a standard lime fertilized peat medium (veksttorv, Ullensaker Almening, Nordkisa, Norway). Mercury lamp (Powerstar HQI-BT 400W/D day light (OSRAM GmbH, Augusberg, Germany) with photon flux densities 400- 700 nm of 200 $\mu mol/m^2/s$ are used as supplementary light source at 18 hour per day. Light are atomically switched off when it was more than 200 $\mu mol/m^2/s$. Plants are maintained at a minimum temperature at $20 \pm 2^{O}C$ and with minimum relative humidity 70± 5%. Irrigation was done thoroughly with complete nutrient solution (Superba^{TM}Rød ,YaraNorges As , Oslo Norway). About 20 disease free plants were grown on the greenhouse compartment. From those 20 plants, 12 uniform plants (height) were selected when they reached two–leaves stages (after two week) and were ready to transform into a closed chamber. These plants were shifted to a closed chamber on putting

insulating box, which helped to maintain the same room temperature in the plants. Two plants were shifted to each chamber. These plants were grown in closed chambers until they reached to four leaves stage. Two leaves were detached for water-agar and Petri disc experiment. Leaf Petri dish was prepared by inoculated mildew by using small painting brush. These entire Petri discs were kept in all the chambers for 24 hours and 48 hours. From this agar experiment and Petri disc experiment, conidia germination was observed by the help of electric microscope in the laboratory Bioforsk.

After two weeks of plants shift to chamber, when they reached four -leaves stage; plants were inoculated by powdery mildew solution by using hand spray. In the same day of inoculation of powdery mildew, three plants in two leaves stage were transformed to each chamber, which were grown in the greenhouse compartment. About 25 tomato plants were seedling in the greenhouse chamber that was grown until they reached two-leaf stage (about two week older plant). Among 25 plants, 18 uniformed (height and growth) plants are separated which were shifted to the closed chamber by the help of an insulating box.

Plants at chambers were inoculated at every nine o' clocks, which were at four leaves stage. At the same day three small plants were shifted at two leaves stage for each chamber. After 9 days of inoculation, disease was observed by counting lesion on the plants leaves. The infected disease area in percentage was also calculated. Plants leaves were marked number from bottom to up with number 1, 2, 3, 4 and so on. Powdery mildew lesions were counted every alternate day. Five observations were taken from each experiment

3.4 Pathogen Isolates

For tomato powdery mildew, *O. neolycopersici* was isolated from young diseased leaves of tomato plants grown in a commercial greenhouse (Vårsolgartner, Tananger). Clean mildew colonies were produced as described (Suthaparan et al. 2010a). Disease free tomato plants cv. *Espero* were spray inoculated by conidial suspension with hand held spray at the rate of 20 ml per plant. Inoculated plants were kept in an isolated growth chambers throughout the experiment, with diurnal lighting of 14 hours supplied by mercury lamps (Power star HQI-BT 400 W/D day light, OSRAM GmbH, Augsburg, Germany) at photosynthetic photon flux of

150±10 µ mol m^{-2} s^{-1}, 20 ± 2 °C and 70% RH. The inoculums were renewed by the replacement of healthy plants inoculated by similar method in weekly interval.

3.5Effect of Night Interruption Light (EXP 1, 2&3)

Growth chamber experiments were conducted with the air temperature and relative air humidity of 20 ± 2 °C and 70 ± 5% respectively. Artificial lighting of 16 hours photoperiod was provided to each growth chamber by high-pressure sodium lamps (HPS) (Lucalox LU400/XO/T/40, GE lighting, Budapest, Hungary) Photosynthetic photon flux (PPF) of the light sources was 15 µmol $m^{-2}s^{-1}$. Lamps were set to switch on at 09:00 and switched off at 01:00. Night interruption light of either 25 µmol $m^{-2}s^{-1}$ or 50 µmol $m^{-2}s^{-1}$ supplied with either HPS or custom made red (peak at 635 nm) light emitting diodes (LEDs) (SoLa-Co, People's Republic of China) for 2 hours as described in treatments as follows.

i) 16 hours light supplied by high pressure sodium lamps (HPS) plus 8 hours Dark;
ii) 16 hours light supplied by high pressure sodium lamps (HPS) plus 2 hours Dark plus 2 hours HPS (25 µ mol $m^{-2}s^{-1}$) plus 4 hours Dark;
iii) 16 hours light supplied by high pressure sodium lamps (HPS) plus 2 hours Dark plus 2 hours HPS (50 µ mol $m^{-2}s^{-1}$) plus 4 hours Dark;
iv) 16 hours light supplied by Red LEDs (630-635 nm) plus 8 hours Dark;
v) 16 hours light supplied by high pressure sodium lamps (HPS) plus 2 hours Dark plus 2 hours Red (25 µ mol $m^{-2}s^{-1}$) plus 4 hours Dark; and
vi) 16 hours light supplied by high-pressure sodium lamps (HPS) plus 2 hours Dark plus 2 hours Red (50 µ mol $m^{-2}s^{-1}$) plus 4 hours Dark.

Plants produced in the Greenhouse; at two unfolded leaves stage; were moved to each treatment (two plants per treatment). At four leaves stage, plants were inoculated by spraying 20 ml of spore suspension per plant as described above. The concentrations of spore suspension were 60 x 10^3 to 66 x 10^3 per ml of water in experimental repeat in one and two. Immediately after inoculation of these plants, another group of 18 healthy plants at two unfolded leaves stage were moved as three for each of the lighting treatment and allowed for the natural infection.

Percentages of leaf area diseased in inoculated plants were assessed visually for each leaves and average diseased leaf area was calculated at 6, 9, 12 and 15 days after inoculation (DAI).

For non-inoculated plants, number of diseased leaves among the unfolded leaves (disease incidence), percentage of diseased leaf area and number of lesions per leaf (average values of the unfolded leaves) were assessed at 9, 12, 15 and 18 days after exposure (DAE) to light treatments. In addition, leaf area, fresh and dry weight of the unfolded leaves and stem was also assessed for non-inoculated plants at the end of the experiment (18 DAE).

3.6 Different Combination of HPS and Red Light (Spectral Balance) (EXP 4).

Four growth chambers with temperature and RH of 20 ± 2 °C and 70 ± 5% were lightened with 16 hours of photoperiod in combination with HPS and red LED. Total numbers of photons of 150 µ mol $m^{-2}s^{-1}$ were supplied with the light sources of:

i) 150 µ mol $m^{-2}s^{-1}$ HPS;
ii) 125 µ mol $m^{-2}s^{-1}$ with HPS and 25 µ mol $m^{-2}s^{-1}$ with red LED;
iii) 100 µ mol $m^{-2}s^{-1}$ with HPS and 50 µ mol $m^{-2}s^{-1}$ with red LED; and
iv) 50 µ mol $m^{-2}s^{-1}$ with HPS and 100 µ mol $m^{-2}s^{-1}$ with red LED.

Plants were moved at two unfolded leaves stage (six plants per treatment) and the leaf area was measured at 3 days interval during 3 DAE-12 DAE by non-destructive length and width method. Hundred leaves of the same variety at different age were used to develop the correlation between leaf area and its length and width. Plants were inoculated with powdery mildew inoculums at five leaves stage as described above. Shoot tips were pinched before inoculation. Concentration of the spores was 58.4 x 10^3 per ml of water.

3.7 Recording Environmental Conditions.

Light intensity was recorded at the level of plant height, with a Lambda LI-185B photometer (LI – COR Inc., Lincoln, NE, USA) containing a quantum sensor. A PRIVA greenhouse computer was connected for recording, control and storage of air temperature and relative air humidity data for five minute interval (Priva, De Lier, The Netherlands).

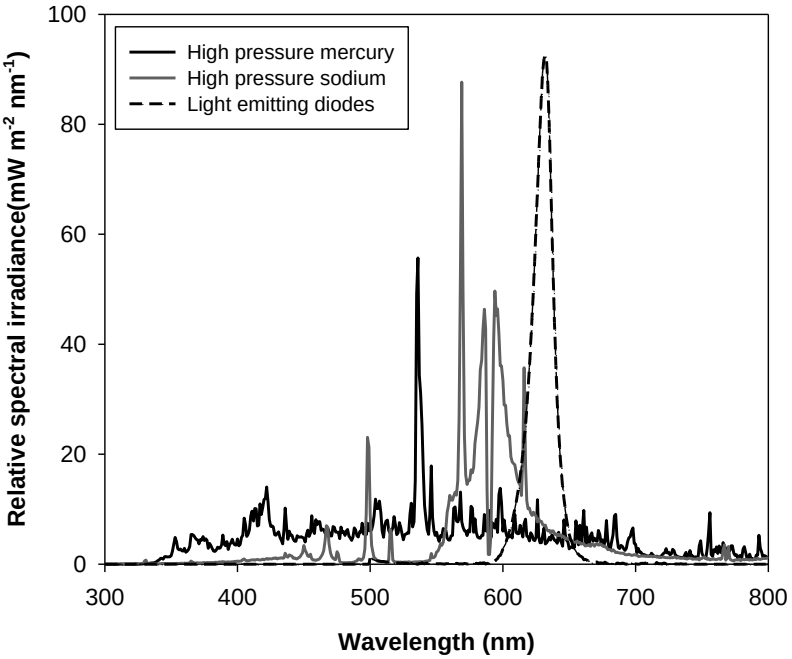
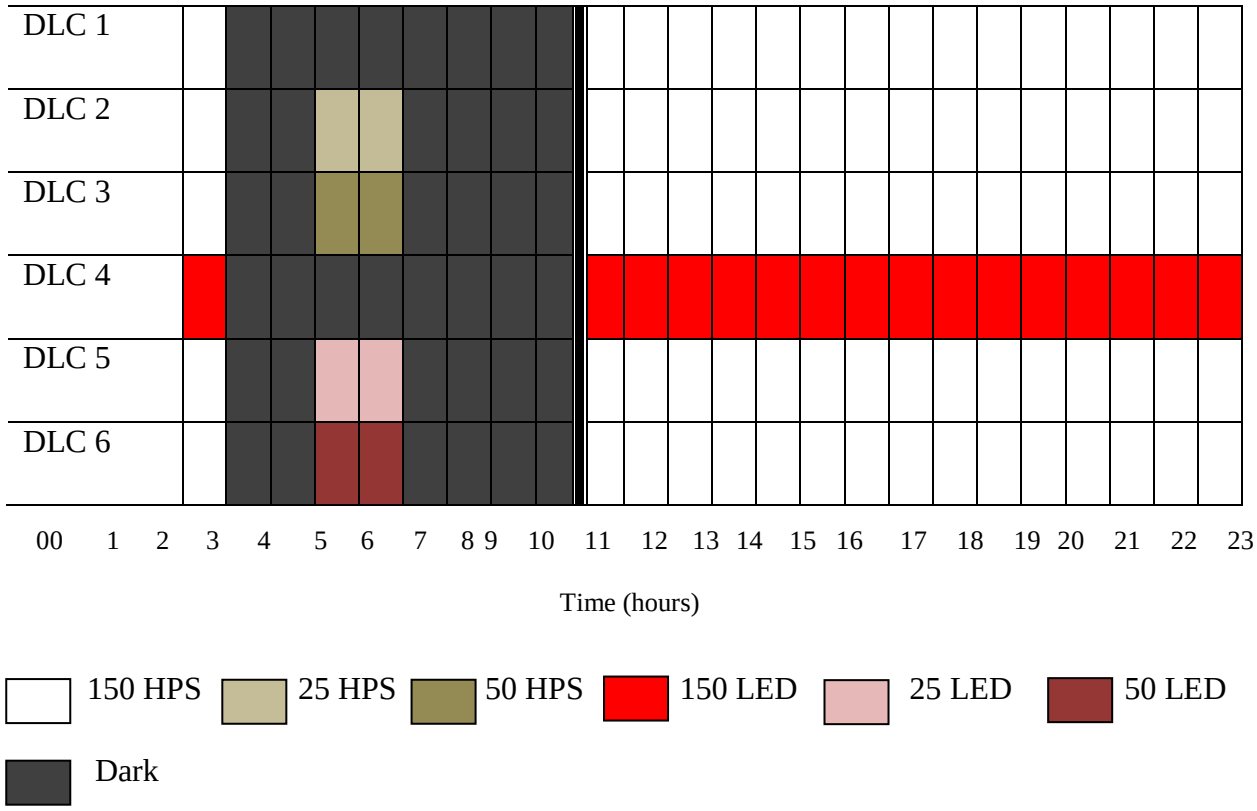


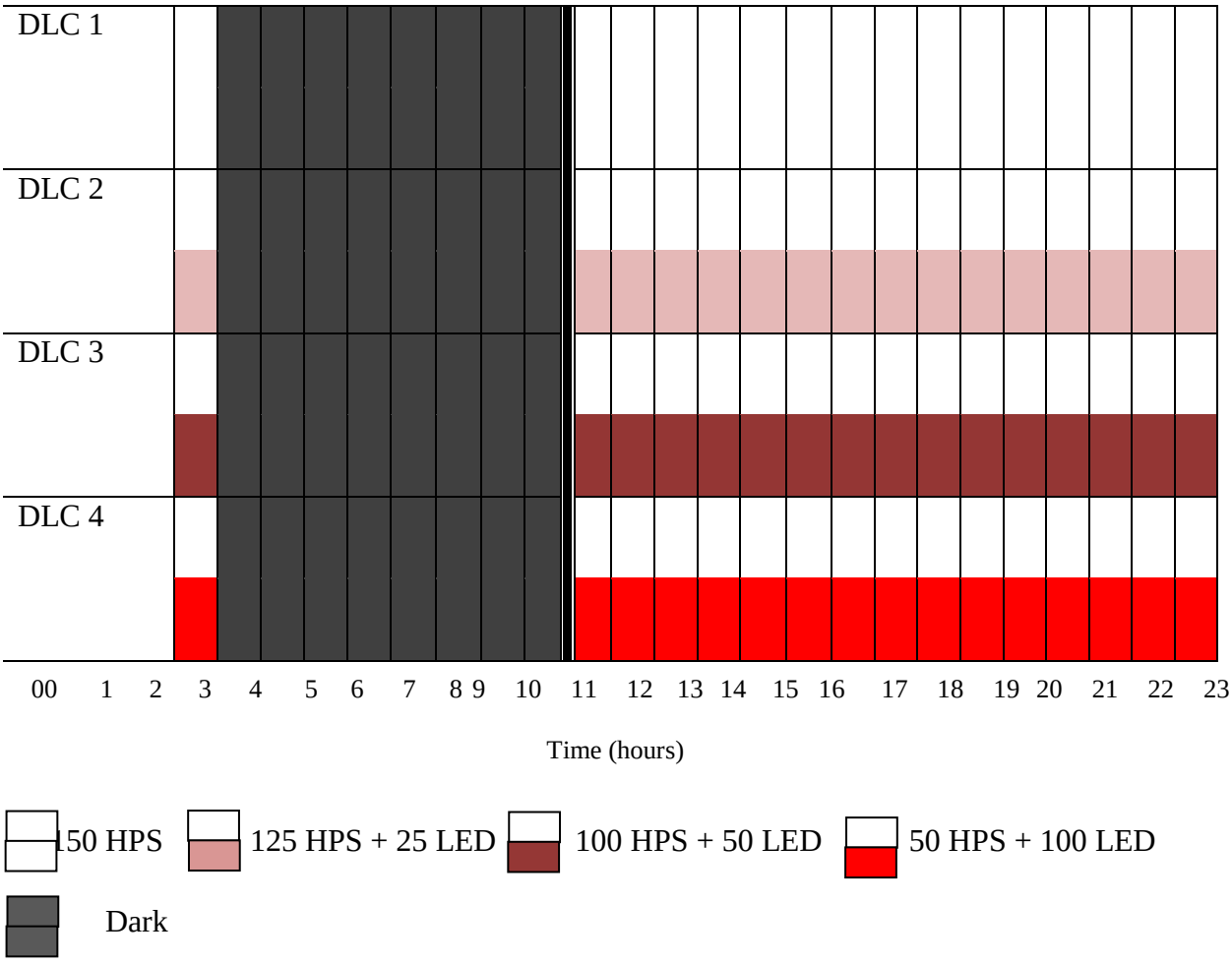
Fig. 2 Spectral distributions of the light sources used during the experimental period

Experiment (1, 2& 3)



Treatment	16 h W- Intensity	Night break intensity
DLC 1	152 ± 5 µ mol $m^{-2}s^{-1}$	0
DLC 2	166 ± 5 µ mol $m^{-2}s^{-1}$	25 ± 3 µ mol $m^{-2}s^{-1}$ (White)
DLC 3	147 ± 5 µ mol $m^{-2}s^{-1}$	50 ± 3 µ mol $m^{-2}s^{-1}$ (White)
DLC 4	150 ± 5 µ mol $m^{-2}s^{-1}$	0
DLC 5	157 ± 5 µ mol $m^{-2}s^{-1}$	25 ± 3 µ mol $m^{-2}s^{-1}$ (Red)
DLC 6	162 ± 5 µ mol $m^{-2}s^{-1}$	50 ± 5 µ mol $m^{-2}s^{-1}$ (Red)

Experiment 4



Treatment	16 h W- Intensity	16 h Red- intensity	Total Intensity (W +R)
DLC 1	152 ± 4 µ mol $m^{-2}s^{-1}$	0	152 ± 4 µ mol $m^{-2}s^{-1}$
DLC 2	123 ± 2 µ mol $m^{-2}s^{-1}$	24 ± 2 µ mol $m^{-2}s^{-1}$	148 ± 7 µ mol $m^{-2}s^{-1}$
DLC 3	97 ± 9 µ mol $m^{-2}s^{-1}$	48 ± 3 µ mol $m^{-2}s^{-1}$	154 ± 11 µ mol $m^{-2}s^{-1}$
DLC 4	54 ± 5 µ mol $m^{-2}s^{-1}$	95 ± 9 µ mol $m^{-2}s^{-1}$	155 ± 5 µ mol $m^{-2}s^{-1}$

3.8 Preparation of Inoculums

The inoculums were prepared from collection of spores from one-week old powdery mildew by washing spores by distilled water. We collected spores from the Food laboratory, which is

situated at Norwegian University of Life Science. Spores that were used for inoculation were one week old. Spores of powdery mildew were collected in distilled water with volume 250 cubic centimetres. Numbers of spore were counted with help of electronic microscope by using haemocytometer. Solution, which was prepared, was sprayed to all plants by help of hand sprayer. Each plant was sprayed by 20 ml solution.

3.9 Assessment of severity and plant development

Disease severity was assessed by counting white powdery mildew and the percentage of leaf area covered by powdery mildew. It can be seen in small amount disease after nine days of inoculation. White lesions of powdery mildew were counted one by one starting from the bottom leaves. Bottom leaf was marked as number 1. Each leaflet was taken as individual unit for counting white lesion. Five observations were taken from each treatment. At end of each treatment (18 days after inoculation), fresh weight was taken by using digital electronic weighing machine. Leaf areas were calculated by using leaf area meter Model 3100 (Li- COR Inc. Lincoln, NE, USA). All plants were set on drier for 10 days at the temperature of 60º C. Dry weight was taken after 10 days.

4. Result

4.1 Experiment 1

4.1.1 Effect of Light Quality and Duration on Development of Powdery Mildew

Table 1: Effect of light quality and duration on disease severity as percentage in leaf area of inoculated tomato plants with 16 hours white(w) base light (16 hours). W (HPS) and R (LED) with 2 hours night- interruption with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25mol $m^{-2}s^{-1}$ W	16hw+ 50µ mol $m^{-2}s^{-1}$ W	16hR	16hw+ 25µ mol $m^{-2}s^{-1}$ R	16hw+ 50µ mol $m^{-2}s^{-1}$ R
6	19.2±3.8	18±3.8	14.3±2.5	0±0.0	10.8±2.1	15.7±3.3
9	35.3±5.9	39.3±7.0	27.8±4.1	1.7±0.4	30.6±2.8	29.2±5.1
12	55±7.3	58.1±9.1	61.6±6.4	9.8±1.8	60.6±5	63.5±8.7
15	62.8±7.6	64.4±8.8	60.8±4.7	13.1±2.5	63.1±3.6	65.5±8.5

4.1.1.1 Effect of Light Duration on Severity of Inoculated Plants

The severity was found with significant difference between the duration of light in between 16 hours white with no night interruption with 16 hours red (LED) light without interruption. Disease was highest in case of 15 days after inoculation which was found average value 62%. Disease severity after 15 days after inoculation seems reduced by 1/4 times on red light treatment with no night interruption. The disease was on the plants after 6 days but there was no disease found in case 16 hours red light treatment. It was found that the disease increased rapidly in 16 hours white light (Table 1).

4.1.1.2 Effect of Light Quality and Night Interruption on Severity of Inoculated Plants

With comparison in between the light quality and the night interruption (16 hours white with 25 µ mol HPS and 16 hours white with 25 µ mol LED) the disease severity was found difference but not significant. The ratio between the treatments was found that 1.8 times greater in the 16 hours white light with 25 µ mol HPS than the 16 hours white with 25 µ mol LED on 6 days after inoculation. But it was found almost similar in both cases on 15 days after inoculation.

Similar result was also observed on the 16 hours white with 50-µ mol white and 16 hours white with 50-µ mol LED light treatment. It was found that there was not difference in these treatments. It was found that average disease severity in case 6 days after inoculation were 14% and 15% respectively and 60% and 65% after 15 days inoculation respectively (Table 1).

4.1.1.3 Effect of Light Intensity on Disease Severity of Inoculated Plants

We compared the disease severity in between the light intensity. We compared the treatment in between the 16 hours white with 25 and 50 µ mol $m^{-2}s^{-1}$ HPS with night interruption. Light intensity has small effect on disease severity. It was found that the small effect on reduced powdery mildew in case of 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS light. We can see on table disease severity after 6 days inoculation was found, 18% and 14% respectively and 15 days after inoculation 64% and 60% respectively.

Similar with comparison in between the 16 hours red with 25 and 50 µ mol $m^{-2}s^{-1}$ red with night interruption was found small effect of intensity in the case of disease severity in 25 µ mol . It was found that average disease severity were 10% and 15% after 6 days inoculation and 63% and 65% after 15 days inoculation (Table 1).

4.1.2 Effect of Light Quality and Duration on Lesion Formation in Non-inoculated Plants.

Table 2: Effect of light quality and duration on lesion formation in leaf area of inoculated tomato plants with 16 hours white(w) base light (16h). W (HPS) and R (LED) with 2 hours night- interruption with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$).

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}$W	16hw+ 50µ mol m-^{2}s-^{1}W	16hR	16hw+ 25µ mol $m^{-2}s^{-1}$	16hw+ 50µ mol $m^{-2}s^{-1}$ R
9	3.0±1.1	3.0±1.7	1.0±0.5	0±0	1.3±0.3	3.0±2.5
12	3.0±1.15	3.0±1.5	1.3±0.3	0±0	1.3±0.3	3.7±2.7
15	31.0±1.1	29.0±3.6	31.7±8.3	0±0	45.7±9.8	38.7±11.0
18	313.3±14	380.7±42.8	379.0±71.7	0±0	283.0±40.5	440.0±20.7

4.1.2.1 Effect of Light Duration on Lesion Formation on Non -inoculated Plants

We compared the effect of light duration on formation of lesion in plants leaves. it was found no lesion was formed in the 16 hours red light treatment whereas the 16 hours white light had great effect on the formation of lesion. It was found that only three lesion after 9 days inoculation and 313 lesions after 18 days of inoculation (Table 2).

4.1.2.2 Effect of Light Quality and Night Interruption on Lesion Formation on Non - inoculated Plants.

We compared the lesion formation in between the two paired of light treatment. Light treatment 16 hours white with 25 µ mol $m^{-2}s^{-1}$HPS and 16 hours white with µ mol $m^{-2}s^{-1}$LED light treatment , we found that average number lesion were 3 and 1.3 after 9 days inoculation and similar average number of lesion formed in 18 days after inoculation were 380 and 283 respectively. There were no differences in between the formation of lesion in these two treatments.

Similarly we observed in between the 16 hours white with 50 µmol $m^{-2}s^{-1}$HPS and 16 hours White with 50 µmol $m^{-2}s^{-1}$ LED light treatments with night interruption, we found that small effect on formation lesion on 16 hours white with 50 µmol $m^{-2}s^{-1}$ HPS than 16 hours white with 50 µmol m^{-2} s^{-1} LED (Table 2).

4.1.2.3 Effect of Light Intensity on Lesion Formation on Non- inoculated Plants.

We compared the light intensity in the formation of lesion in between the treatment 16 hours white light with 25 µmol $m^{-2}s^{-1}$HPS and 50 µmol $m^{-2}s^{-1}$ HPS with night interruption , we found that there were no difference in the formation of lesion. Average lesions counted in the treatment were 3 and 2 after 9 days' inoculation and 380 and 379 after 18 days inoculation

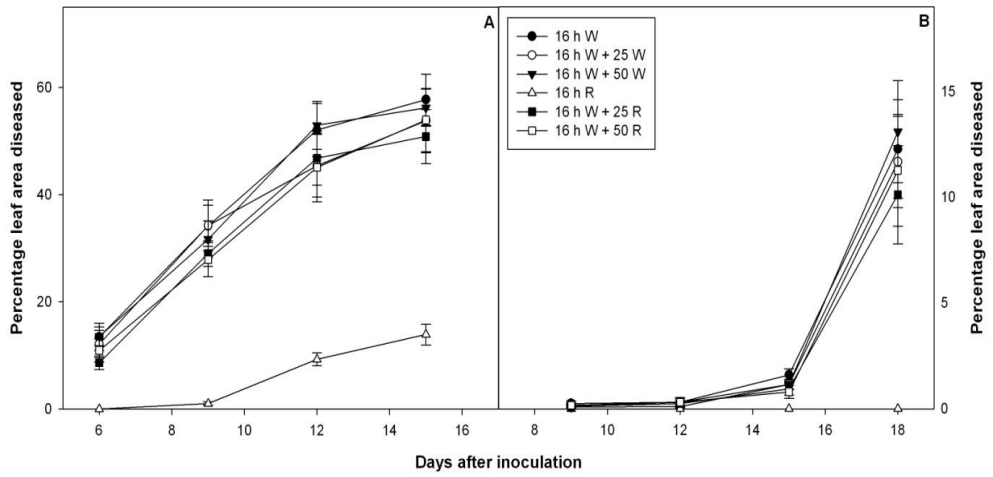


Figure 3

Figure **3** Effect of light quality and low intensity night interruption light quality on percentage leaf area diseased in inoculated (A) (N = 4) and non-inoculated (B) (N = 6) tomato cv. *Espero*. Plants were inoculated with powdery mildew inoculum by spraying one week old powdery mildew spore suspension. Values are the means of two repeated experiments with error bar (P = 0.05)

The figure showed that, there was significance difference to the disease severity after 6 days after inoculation. The below line represents the disease severity with inoculated plants in graph A. Similar result was found in case of non-inoculated plants. The disease in the red light treatment seems no disease 9 days after inoculation without night interruption which is significance difference. But the rest treatment had not significance difference.

4.1.3 Light Effect Quality and Duration on Disease Percentage on Non- inoculated Plants Leaf

Table 3: Effect of light quality and duration on disease severity as percentage in leaf area of non-inoculated tomato plants with 16 hours white base light(16h), W (HPS) and R(LED) with 2 hours night interruption with 25 and 50 µ mol $m^{-2}s^{-1}1$ respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
9	0.5±0.2	0.3±0.1	0.16±0.1	0±0	0.2±0.1	0.3±0.2
12	0.6±0.2	0.6±0.3	0.2±0.1	0 ±0	0.5±0.1	0.6±0.4
15	1.6±0.2	1±0.3	1.2±0.2	0±0	1.6±0.2	1.4±0.6
18	14.2±0.5	14.1±1.4	16.2±2.9	0±0	12.5±1.3	16.5±1.5

4.1.3.1 Effect of Light Duration on Disease Severity Percent on Non-inoculated Plants

We compared the disease severity percentage in two treatment 16 hours white (HPS) light and 16 hours red (LED) light without no night interruption, we found that no disease were found in 16 hours red light treatment where as there is disease noticed in 16 hours white light treatment. The minimum average disease was 0.5% after 9 days inoculation and maximum average disease severity was 14.2% after 18 days inoculation (Table 3).

4.1.3.2 Effect of Light Quality and Night Interruption on Disease Severity Percent on Non- inoculated Plants

We compared the disease severity in two different quality of light 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and µ mol $m^{-2}s^{-1}$ LED light. We found that similar average disease severity percentage in both case. The average disease severity were 0.3% and 0.2% after 9 days inoculation respectively and highest average disease severity were 14 and 12 after 18 days inoculation.

Similarly, we observed disease severity in 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS and LED light treatment, we found that no difference in between the treatment. Here we observed that minimum average disease severity were 0.1% and 0.2% after 9 days inoculation and maximum average disease severity were 16.2% and 16.5% after 18 days inoculation respectively (Table 3).

4.1.3.3 Effect of Light Intensity on Disease Severity Percent on Non- inoculated Plants

We compared disease severity percentage in two different light intensity which were 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$HPS, result showed no difference in between the treatment. We found that minimum average disease severities were 0.3 and 0.16 respectively and maximum disease severity percentage were 14.2% and 16.2% respectively after 18 days of inoculation.

Similarly we observed in between 16 hours white light with 25 and 50 µ mol $m^{-2}s^{-1}$LED light treatment, that there were similar results obtained as above. The average minimum disease severity was 0.2% and 0.3% respectively and maximum were 12.5% and 16% respectively after 18 days inoculation (Table 3).

4.1.4 Effect of Light Treatment Germination of Conidia in Water -Agar and Leaf

Table 4: Effect of light quality and duration on germination of conidia in leaf tomato and water agar with 16 hours white base light (16h). W (HPS) and R (LED) with 2 hours night - interruption with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$).

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}$W	16hw+ 50µmol $m^{-2}s^{-1}$W	16hR	16hw+ 25µmol $m^{-2}s^{-1}$R	16hw+ 50µ mol $m^{-2}s^{-1}$R
24 HRS in water agar	34.5±2.3	24.7±1.8	30.5±2.8	24.2±4.8	30.7±2.6	22.7±2.3
48 HRS in Leaf	25.7±1.1	12.7±1.7	10.0±2.3	10.2±1.7	16.7±0.9	11±1.2

4.1.4.1 Effect Of Light Duration On Germination Of Conidia In Water Aga And Leaf Detach.

We compared the germination of conidia with respect of light duration in 16 hours white light (HPS) treatment and 16 hours red (LED) light treatment; we found that there were small effects on germination. The average germination 34 and 24 respectively in case of water agar and 25 and 10 in case leaf detached after 48 hours inoculation. The difference was noticed on the germination of conidia in detached leaf reduced highly in case of 16 hours red light treatment (Table 4).

4.1.4.2 Effect of Light Quality and Night Interruption on Germination of Conidia in Water Agar and Leaf Detached.

We compared germination on treatment on 16 hours white with 25 µ mol $m^{-2}s^{-1}$ HPS and 25 µ mol $m^{-2}s^{-1}$ LED, we found that small reduction of germination in case of 25 µ mol red in water agar but similar to tomato detached leaf.

Similarly we compared effect on the 16 hours white with 50 micro mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ LED ,we found that similar result as above reduction in water agar and same as tomato leaf (Table 4).

4.1.4.3 Effect of Light Intensity on Germination of Conidia in Water Agar and Leaf Detached.

We compared two paired treatment, which are 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ and 50 µ mol $m^{-2}s^{-1}$ HPS, we found that no difference on germination of conidia. The average germination on water agar were 24 and 30 whereas in leaf detached were 12 and 10 respectively.

Similarly comparison in between 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ and 50 µ mol $m^{-2}s^{-1}$ LED, we found that small effect on germination in water agar but similar effect on plant leaf. The average growths on plants leaf were 16 and 11 respectively (Table 4).

4.1.5 Effect of Light Quality and Light Duration on Plants Growth.

Table 5: Effect of light quality and duration on plants growth with 16 hours white base light (16h). W (HPS) and R (LED) with 2 hours night- interruption with 25 and 50 µ mol $m^{-2}s^{-1}$respectively. The mean values are in column with standard error ($p<0.05$)

Plant growth	16hw	16hw+ 25µ mol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
Leaf area	751.1±6.4	974.1± 21.6	1043.1± 4.52	493.1 ±72	991.2 ±40.6	818.8± 7.5
Leaf fresh wt.	20.3±0.4	27.8± 0.8	28.1± 0.1	16.3±1.6	25.5± 1.4	22.2± 0.2
Leaf dry wt.	2.1± 0.1	2.9± 0.1	2.83± 0.1	1.4± 0.2	2.6± 0.13	2.2±0.1
Stem fresh wt.	9.9± 0.1	13.7± 0.6	14.5± 0.4	10.1±0.5	12.9±0.3	10.3±0.1
Stem dry wt.	0.5± 0.1	0.7± 0.1	0.8± 0.1	0.4±0.1	0.6± 0.1	0.5±0.1

The plants growth depends upon the light treatment. (Here N=18) With p-value 0.001, there is significance difference in growth. The highest leaf area mean is 1043 in 16 hours white light with 50 µ mol $m^{-2}s^{-1}$ HPS which is 2.1 times greater than 16 hours red light treatment.

4.1.5.1 Effect of Light Duration on Plants Growth

We compared two light duration on plants growth which were 16 hours white light (HPS) and 16 hours red (LED) light treatment without night interruption, we found that there were reduction of leaf area, leaf fresh weight, leaf dry weight, but stem fresh weight and stem dry weight were not affected. The average leaf area was 751 cm^2 and 493 cm^2 respectively and average stem dry weight were 0.5 and 0.4 in both cases (Table 5).

4.1.5.2 Effect of Light Quality and Night Interruption on Plants Growth

We watched the effect of light quality and night interruption in the treatment by 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and 25 µ mol $m^{-2}s^{-1}$LED light treatment. We found that similar in leaf area, leaf fresh weight, leaf dry weight, stem fresh weight and stem dry weight.

Similarly we compared between the 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ LED light treatment, we have found that effect on the leaf area was greater in 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS, leaf fresh weight was also greater than 50 µ mol $m^{-2}s^{-1}$ LED light treatment. But leaf dry weight, stem fresh weight and stem dry weight were found same in both cases (Table 5).

4.2 EXPERIENT 2

4.2.1 Effect of Light Quality and Duration on Development of Powdery Mildew.

Table 6: Effect of light quality and duration on disease severity as percentage in leaf area of inoculated tomato plants with 16 hours white (w) base light (16h), W (HPS) and R (LED) with 2 hours night interruption with 25 and 50 µ $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$).

Days after inoculation	16hw	16hw+ 25µmol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
6	13.4±2.5	12.1±2.5	13.5±1.7	0±0	8.6±1.2	10.9±2.2
9	34.2±3.8	34.3±4.7	31.7±3.5	1.0±0.3	29.0±2.4	27.8±3.2
12	52±5	45.4±5.9	52.9±4.5	9.3±1.2	46.8±5.1	27.9±6.4
15	57.8±4.8	53.8±6.1	56.2±3.5	13.8±1.9	50.8±5.1	53.9±5.9

4.2.1.1 Effect of Light Duration on Disease Severity of Inoculated Plants

We compared the disease severity percentage of inoculated plants in two different durations of 16 hours white light (HPS) and 16 hours red light (LED) treatment. We noticed that diseases were reduced in red light treatment. We found no disease in the 6 days after the inoculation whereas minimum an average severity was found to be 13% in case of 16 hours white light treatment. The highest recorded disease severity was 57% and 13% respectively which was significant (Table 6).

4.2.1.2 Effect of Light Quality and Night Interruption on Disease Severity on Inoculated Plant.

We compared the two light quality and night interruption effect on the disease severity of inoculated plants. We took 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS light with 2 hours night interruption, we found that there is difference which are not significant. Although

average minimum disease severities were 13% and 8 % respectively and the maximum severity were 53% and 50 % respectively after 15 days inoculation.

Similarly we compared in between the 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ LED, we recorded that there were no significant differences in the treatment. They show small difference in minimum average disease severity which were 13 and 10 after 6 days' inoculation whereas the maximum were 56% and 53% after 15 days of inoculation (Table 6).

4.2.1.3 Effect of Light Intensity on Disease Severity on Inoculated Plant

We recorded disease severity in case of light intensity with night interruption. We took, 16 hours white light with 25 and 50 µ mol $m^{-2}s^{-1}$ HPS, we found that, there is not significant different between the treatment. They have almost similar type of effect on severity. The minimum severities were 12% and 13% after 6 days' inoculation. The highest average disease severities were 53 and 56 respectively.

Similarly we compared the two different light treatments which were 16 hours white with 25 and 50 µ mol $m^{-2}s^{-1}$ LED light with 2 hours night interruption, no significant difference was observed. The minimum disease severities were 8% and 10% after 6 days inoculation and maximum were 50% and 53 % after 15 days inoculation in both cases (Table 6).

4.2.2 Effect of Light Quality and Duration Disease Severity in Non-inoculated Plants.

Table 7: Effect of light quality and duration on disease severity as percentage in leaf area of non-inoculated tomato plants with 16 hours white (w) base light (16h). W (HPS) and R (LED) with 2 hours night- interruption with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$).

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
9	0.3±0.1	0.12±0.1	0.08±0.1	0±0	0.1±0.1	0.2±0.1
12	0.3±0.2	0.3±0.2	0.1±0.1	0±0	0.3±0.2	0.3±0.2
15	1.6±0.3	1.1±0.2	1.2±0.2	0±0	0.9±0.3	0.8±0.3
18	12.3±2.3	11.7±2.2	13.2±2.4	0±0	10.12±2.3	11.3±2.7

4.2.2.1 Effect of Light Duration on Disease Severity of Non- inoculated Plants.

Two Light durations were compared on the severity of non-inoculated plants which were 16 hours white (HPS) light and 16 hours red (LED) light without night interruption; we found that there is no disease in case of 16 hours red light treatment after 15 days inoculation. There were significant differences in between the treatment. The white light treatment had 13 % highest disease severity percentage after 18 days after inoculation (Table 7).

4.2.2.2 Effect of Light Quality and Night Interruption on Disease Severity of Non - inoculated Plants.

The comparison were made between the two different quality light which were 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and LED light, we found that there was no significant difference between these treatment. The minimum disease severities were 0.12% and 0.2 % and highest were found to be 11% and 10% respectively.

Similarly we compared in between 16 hours white with 50 µ mol $m^{-2}s^{-1}$ HPS and LED light treatment. We found no significant difference. The minimum average disease severities were 0.08 and 0.2 and highest average disease severities were 13% and 11% (Table 7).

4.2.2.3 Effect of Light Intensity and Night Interruption on Disease Severity of Non - inoculated Plants.

We observed the disease severity in two different light intensity, which were 16 hours white with 25 and 50 µ mol $m^{-2}s^{-1}$ HPS. We found that, no significant difference on disease severity. Although, we found small difference in between the treatment the minimum were 0.12% and 0.08% and maximum disease severities were 11% and 13% after inoculation.

Similarly we compared in between the 16 hours with 25 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol $m^{-2}s^{-1}$ LED with night interruption, there is no significant difference in disease severity. The

minimum disease severities were 0.1% and 0.2% after 9 days inoculation. Similarly the highest disease severities were 10% and 11% respectively after 18 days inoculation (Table 7).

4.2.3 Effect of Light Quality and Duration on Plants Growth.

Table 8: Effect of light quality and duration on plants growth with 16 hours white (w) base light (16h),W (HPS) and R (LED) with 2 hours night interruption with 25 and 50 µ mol $m^{-2}s^{-1}$respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
Leaf area(cm^{2})	1004±120	1067.9±43.9	1115.6±55.6	827±166	1195±94	1065±126
Total dry weight(gm.)	4.5±0.9	5.1±0.8	5.1±0.6	2.8±0.5	4.8±0.7	4.1±0.6

4.2.3.1 Effect of Light Duration on Plant Growth

The plants growth was absorbed in two light differences which are 16 hours white (HPS) and 16 hours red light (LED), we found significant difference. The leaf area is reduced by 21% in red light treatment. Total dry weight also was found significantly different over the treatment. The dry weight was observed 4.5 gram and 4.8 gram respectively (Table 8).

4.2.3.2 Effect of Light Quality and Night Interruption on Plant Growth

In the comparison of plants growth in two different light quality and night interruption in between 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and 25 µ mol $m^{-2}s^{-1}$ LED light

treatment we found differences that were not significant. The dry weights were found 5.1 gram and 4.8 gram.

Similarly in between 16 hours white light with 50 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ LED treatment, we found small differences but that were not significant. The weights were found 5.1 gram and 4.1 gram respectively (Table 8).

4.2.3.3 Effect of Light Intensity and Night Interruption on Plant Growth

We compared light intensity and night interruption effect on plants growth, which are 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ and 50 µ mol $m^{-2}s^{-1}$ HPS light, we found the difference but not significant. We found 5.1 gram in both case.

Similarly we compared with 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol m^2 s^{-1} LED. We found there is no significant difference in plants' growth. The dry weight 4.8 gram and 4.1 gram was found (Table 8).

4.3. Experiment 3

4.3.1 Effect of Light Quality and Duration on Powdery Mildew on Inoculated Plants

Table 9: Effect of light quality and duration on disease severity as percentage in leaf area of inoculated tomato plants with 16 hours white (w) base light (16h) W (HPS) and R (LED) with 2 hours night interruption were with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$).

Days after inoculation	16hw	16hw+ 25µmol $m^{-2}s^{-1}W$	16hw+ 50µmol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
6	7.6±1.7	6.25±1.9	12.7±2.5	0±0	6.4±1.21	6.1±1.52
9	33.4±5.2	29.1±6.25	35.5±5.5	0.25±0.2	27.4±3.9	26.5±4.2
12	49.1±7.1	34.3±5.3	46.4±5.4	8.6±1.6	33.6±5.2	28.8±.9
15	52.6±5.6	44.5±7.09	52.7±4.8	14.6±3.2	33.6±3.5	42.4±5.8

4.3.1.1 Effect of Light Duration on Powdery Mildew on Inoculated Plants

The disease severity was compared with two light duration treatments which are 16 hours white light and 16 hours red light without night interruption. We found significant differences in between the treatment; we observed that 7.6% and 0% disease after 6 days inoculation where as 52% and 14% disease after 15 days inoculation (Table 9).

4.3.1.2 Effect of Light Quality and Night Interruption on Disease Severity on Inoculated Plants

The effect of quality and night interruption was compared to the disease severity in inoculated plants, which are 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ HPS and 25 µ mol $m^{-2}s^{-1}$ LED light treatment, we found small difference that was not significant. The minimum disease severities were observed 6.2% and 6.4% respectively. The highest disease severities were 44% and 33% respectively. Similarly we compared in between the 16 hours white light with 50 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ LED light treatment, we found that no significant difference in disease severity (Table 9).

4.3.1.3 Effect of Light Intensity and Night Interruption on Disease Severity on Inoculated Plants

The light intensity effects were compared in disease severity in the inoculated plants. We compared two light intensity in between the 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ and 50 µ mol $m^{-2}s^{-1}$ HPS light , we found that there was no significant difference after 6 days inoculation and 15 days after inoculation. We found the minimum average disease severity were 6.25% and 12% and the maximum disease severities were 44% and 52%. Similarly we observed in between the 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol $m^{-2}s^{-1}$ LED, we found the difference between them but they are not significant. The average severities were 6.4% and 6.1% after 6 days of inoculation, and 33% and 42% after 15 days after inoculation (Table 9).

4.3.2 Effect of Light Quality and Duration on Formation of Lesion on Tomato Leaf.

Table 10: Effect of light quality and duration on formation of lesion in leaf area tomato non-inoculated plants with 16 hours white (w) base light (16h), W (HPS) and R (LED) with 2 hours night interruption with 25 and 50 µ mol m^{2} s^{-1} respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25µmol $m^{-2}s^{-1}W$	16hw+ 50µmol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
15	29±2.6	23±8.1	15.3±2.8	0±0	2.6±1.2	1.3±0.8
18	351±32.4	239.7±30.7	270.7±62.3	0±0	81.3±6.3	58.3±10.4

4.3.2.1 Effect of Light Duration on Formation of Lesion

The effect of light duration was observed in two different light duration which are 16 hours white light (HPS) and 16 hours red (LED)light treatment without night interruption we found no lesion formation in 9 days and 12 days after inoculation. The highest lesion formation after 18 days inoculation was 351 and 0 respectively (Table 10).

4.3.2.2 Effect of Light Quality and Night Interruption on Formation of Lesion

We compared effect of light quality with night interruption in between 16 hours white light with 25 µ mol $m^{-2}s^{-1}$HPS and 25 µ mol $m^{-2}s^{-1}$ LED light, we found reduction in these case. The average lesion formations were 239 and 81 respectively.

Similarly we compared that 16 hours white light with 50 µ mol $m^{-2}s^{-1}$HPS and 50 µ mol $m^{-2}s^{-1}$ LED light, we found reduction in 50 µ mol m^{2} s^{-1} LED light treatment (Table 10).

4.3.2.3 Effect of Light Intensity with Night Interruption on Formation of Lesion

The effect of intensity of light was observed with two different light intensity which are 16 hours white with 25 µ mol $m^{-2}s^{-1}$ HPS and 50 µ mol $m^{-2}s^{-1}$ HPS, we did not find the difference of the treatment. Similar effect was observed in between 16 hours white with 25 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol $m^{-2}s^{-1}$ LED (Table 10).

4.3.3 Effect of Light Quality and Duration on Disease Severity of Non- inoculated Plants.

Table 11: Effect of light quality and duration on disease severity as percentage in leaf area of non-inoculated tomato plants with 16 hours white (w) base light (16h), W (HPS) and R(LED) with 2 hours night interruption with 25 µ mol $m^{-2}s^{-1}$and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25µmol $m^{-2}s^{-1}$W	16hw+ 50µmol $m^{-2}s^{-1}$W	16hR	16hw+ 25µmol $m^{-2}s^{-1}$R	16hw+ 50µ mol $m^{-2}s^{-1}$R
15	1.6±0.1	1.3±0.3	1.1±0.2	0±0	0.2±0.1	0.2±0.1
18	6.7±0.7	5.6±0.3	6.4±1.2	0±0	3.4±0.2	2.4±0.3

4.3.3.1 Effect of Light Duration on Disease Severity of Non -inoculated Plants

In two different light duration in 16 hours white (HPS) and 16 hours red (LED) light treatment, we found disease severity highest (6.7%) percentage in 16 hours white light treatment where as there is no disease found after 9, 12, 15 and 18 days after inoculation (Table 11).

4.3.3.2 Effect of Light Quality and Night Interruption on Severity of Non -inoculated Plants

The effect of light in between 16 hours white light with 25 µ mol $m^{-2}s^{-1}$ and 25 µ mol $m^{-2}s^{-1}$ LED light treatments, we found similar results in both case. The average disease severities were 1.3 and 0.2 respectively.

Similarly comparing the 16 hours white with 50 µ mol $m^{-2}s^{-1}$HPS and 50 µ mol $m^{-2}s^{-1}$ LED light treatment are also found as the above result. The result was observed 6.4% and 2.4% respectively (Table 11).

4.3.3.3 Effect of Light Intensity and Night Interruption on Disease Severity of Non -inoculated Plants

In the two light intensity with 16 hours white light with 25 µ mol $m^{-2}s^{-1}$and 50 µ mol $m^{-2}s^{-1}$ HPS light treatment, we found that there is no significant difference in the between the treatment. The average mean disease severities were 1.3% and 1.1% after 15 days inoculation and 5.6% and 6.4% in after 18 days inoculation (Table 11).

4.3.4 Effect of Light Quality and Duration on Plants Development

Table 12: Effect of light quality and duration on plants growth with 16 hours white (w) base light (16h), W (HPS) and R (LED) with 2 hours night interruption with 25 and 50 µ mol $m^{-2}s^{-1}$ respectively. The mean values are in column with standard error ($p<0.05$)

Days after inoculation	16hw	16hw+ 25µ mol $m^{-2}s^{-1}W$	16hw+ 50µ mol $m^{-2}s^{-1}W$	16hR	16hw+ 25µmol $m^{-2}s^{-1}R$	16hw+ 50µ mol $m^{-2}s^{-1}R$
Leaf area(cm^2)	1257.3 ±91.6	1161.7±19.6	1188±101	1160±147	1400±30.6	1311±135
Leaf fresh wt.(gm).	47.7±4.7	47.8±2.9	40.8±2.5	32.43±5.4	43.1±1.5	33.3±5.6
Leaf dry wt(gm)	5.3±0.4	5.4±0.3	5.1±0.3	3.1±0.5	5.1±0.2	4.4±0.4
Stem fresh wt(gm).	15.6±0.9	16.9±1.3	17.7±0.4	12.4±1.6	16.9±0.3	14.3±1.6
Stem dry wt(gm).	1.2±0.1	1.3±0.1	1.3±0.01	0.6±0.1	1.3±0.1	1.1±0.1

4.3.4.1 Effect of Light duration on Plant Growth

Two different light duration were observed on plants growth which were 16 hours white light (HPS) and 16 hours red (LED) light without night interruption, we found that there were no significant differences in leaf area, leaf fresh weight, stem fresh weight but we found significant difference in case of leaf dry weight and stem dry weight. The leaf areas were found 1257 and 1160 respectively (Table 12).

4.3.4 .2 Effect of Light Quality and Night Interruption on Plant Development

The plants growth was observed in two different quality with night interruption which are 16 hours white light with 25 µ mol $m^{-2}s^{-1}$HPS and 25 µ mol $m^{-2}s^{-1}$LED light treatment, we found that no significant difference is in the leaf area, leaf dry weight, stem fresh weight stem dry weight. Similar result was found in case of 16 hours white with 50 µ mol HPS and 50 µ mol $m^{-2}s^{-1}$ LED light treatment (Table 12).

4.3.4.3Effect of Light Intensity with Night Interruption on Plant Growth

The light intensity effect was observed on plants growth which are 16 hours white light treatment with 25 µ mol $m^{-2}s^{-1}$HPS and 50 µ mol $m^{-2}s^{-1}$ HPS and 16 hours white light treatment with 25 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol $m^{-2}s^{-1}$ LED, we found no significant difference in plants growth for all case (Table 12).

4.4 Experiment 4

4.4.1 Effect of Combination of HPS and LED Light with Different Intensity on Powdery Mildew Severity on Inoculated Tomato Plants.

The diseases were observed after 6 days after inoculation in 6 days after inoculation we did not find any significance. After 9 days inoculation, we found there is significance difference in between the 100 µ mol HPS with 50 µ mol $m^{-2}s^{-1}$ LED and 50 µ mol $m^{-2}s^{-1}$ HPS and 100 µ

mol $m^{-2}s^{-1}$ LED light treatment. But 12 days after inoculation there is no significance difference was observed.

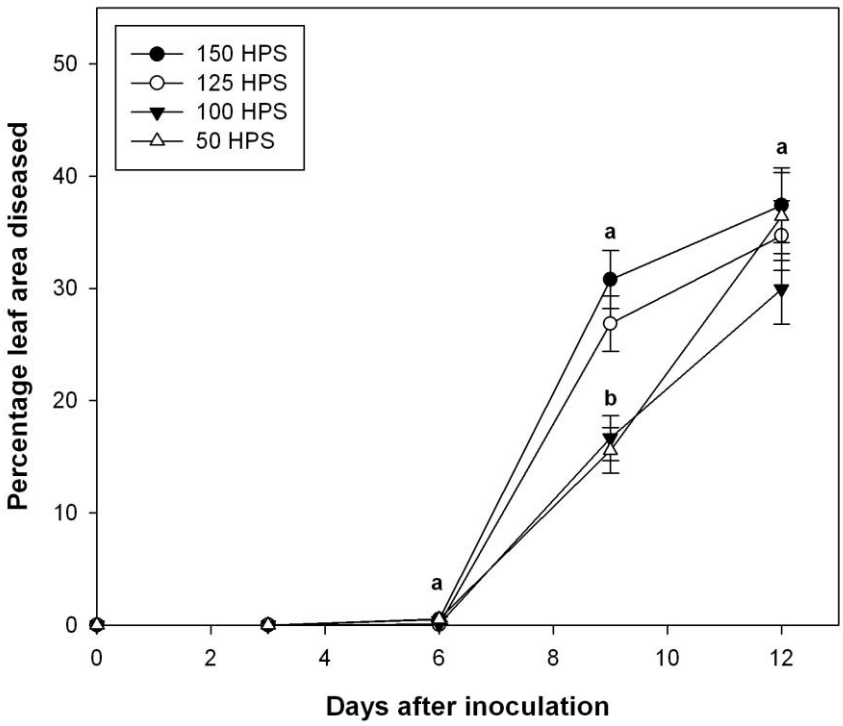


Figure 4. Effect of different combination of HPS and red LED light on severity of powdery mildew in tomato cv. *Espero*; inoculated by spraying 20 ml spore suspension per plant. Values are the means and standard error of the six assessments. Means that do not share a letter are significantly different.

4.4.2 Effect of Combination of HPS and LED Light with Different Intensity on Germination of Conidia Powdery of Mildew Severity on Tomato Detached Leaf.

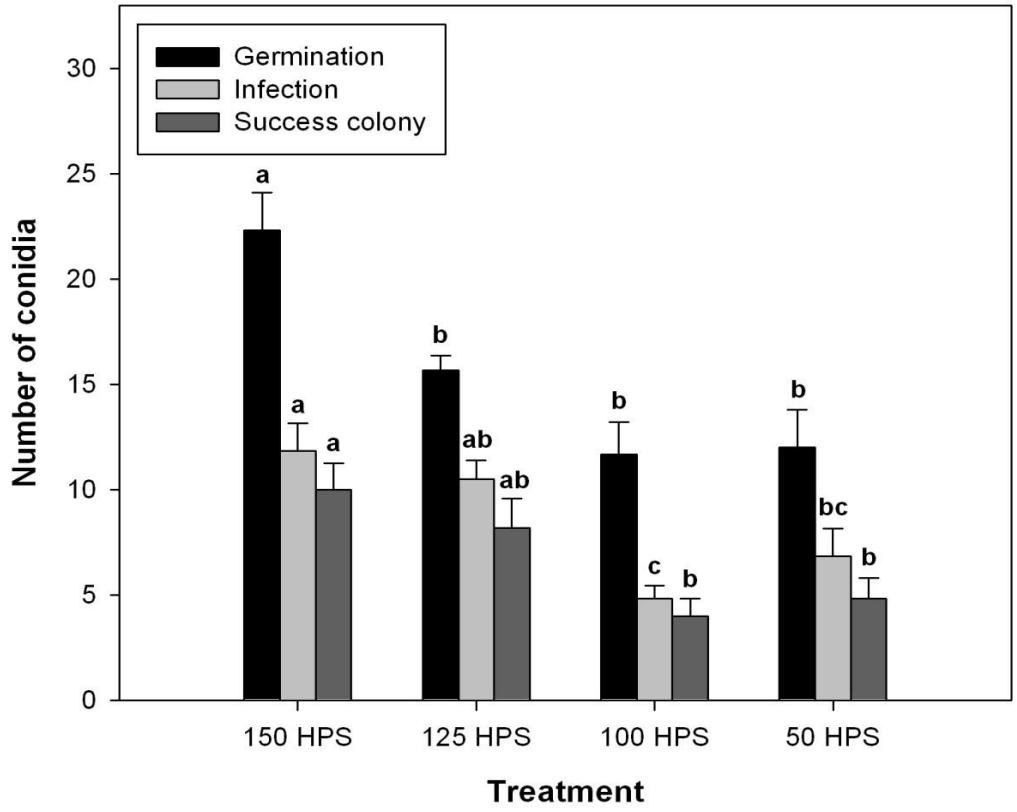


Figure 5: The effect of different combination of HPS and red (LED) light on germination, infection and development of success colony of *o. neolycopersici* at three days after inoculation. Leaf disc were treated with absolute ethanol: glacial acetic acid (3:1) for 6 hours and stained with cotton blue. Samples were observed under LM and fifty conidia were assessed. Values are mean and standard error of the six assessments. Mean that do not share letter are significant different.

Germination of powdery conidia were found significant difference with treatment of 150 µ mol $m^{-2}s^{-1}$HPS with other treatment where as other treatment were found no significance difference (p=0001). But the infection seems significance with treatment 150 µ mol HPS and 150 µ mol $m^{-2}s^{-1}$LED. Similar significance difference was observed in between 125 µ mol $m^{-2}s^{-1}$ HPS with 25 µ mol $m^{-2}s^{-1}$ red (LED) and 100 µ mol $m^{-2}s^{-1}$ HPS with 50 µ mol $m^{-2}s^{-1}$ LED.

Similarly we observed light effect on formation of success colony of conidia, 150 µ mol HPS light had significant difference with 100 µ mol HPS with 50 µ mol $m^{-2}s^{-1}$ LED and 150µ mol $m^{-2}s^{-1}$ LED but not significant with 125 µ mol $m^{-2}s^{-1}$ HPS with 25 µ mol $m^{-2}s^{-1}$ LED.

5. Discussion

5.1 Effect Light Quality and Duration on Development of Powdery Mildew

5.1.1 Effect of Light Duration on Development of Powdery Mildew

Growing inoculated and infected tomato plants in growth chambers in 16 hours red (LED) light seems to reduce powdery mildew in inoculated and null in non-inoculated plants. This reduction can be seen in all part of the plants in term of multiple level, conidial germination and infection severity. 16 hours HPS light without night interruption significantly has more powdery mildew than 16 hours red (LED). This result suggests that powdery mildew is more sensitive to red light. There is clearly and significance difference of disease severity in the plant grown at 16 hours red (LED) light treatment without night interruption. One of the study conducted by Pettersen et al. (2010) reports that significant increase of rose powdery mildew under lighting 18 hours with 6 hours dark period with compare to continuous with HPS. Cole and Geerligs (1976) study reports that conidia developed faster in light than the dark period and released in the light period in tobacco powdery mildew. This result supports the current finding of powdery mildew in tomato that HPS light has positive effect in development while the same experiment explains red light (LED) reduced the powdery mildew (0 %) after 18 days of inoculation in table 3, 7, 10, 11 and figure 4 in non-inoculated plants. However, we found small percentage of disease (13%, 13.8% and 14%) in the plants that are grown under 16 hours red (LED) treatment to inoculated plants. It is clearly showed that the day length of 20 to 24 strongly suppressed the powdery mildew development in rose(Suthaparan et al. 2010a). In the same study, it is also found that the significance reduction of conidia when day length is increased from 18 to 24 hour.

The role of light in different stage of the conidia production has varied from species to species (Carver & Carr 1978). In the same study, he explain, some grower provides continuous light to increase yield as well as to maintain the heat in greenhouse without night interruption, in such condition they find that fewer mildew in rose plants. The powdery mildew in barely is independent of light can develop continuously in light, dark and shade (Pady et al. 1969). However, the conidia formation is totally dependent in light in case of *Erysiphe polygon* (Pady et al. 1969). Germination of conidia (76%) is found highest at the 36 hours after inoculation in growth chamber (Celio & Hausbeck 1998). In my result average germination of conidia is found 24% red (LED) with compare to 34% in white (HPS) which

are not significance difference. It seems highest lesion (440) in case of 16 hours red light with 50 µ mol $m^{-2}s^{-1}$ LED with night interruption. Germination conidia of *Oidium neolycopesici* is affected by the presence of water. It is found that germination of conidia of *Oidium species* has positive relation with water whereas conidia from the *Er ysipphe species* varied from germination capacity in water (Gottlieb 1950). Germination of conidia remains unaffected by light in my result in water agar and detached leaf. This might be effect of water.

Powdery mildew formed lesion on the plants that causes the necrotic on leaves in greenhouse. During severe epidemic entire foliage may be destroyed which is usually surrounded by bright halo. Elad (1996) reports a high number of lesion in the petiole which causes defoliates. My finding is similar to defoliation of leaves in severe case.

5.1.2 Effect of Light Quality on Development of Powdery Mildew

Low energy emitting diodes (LED) can be possible tools the supress sporulation. In my result, we compared to two different quality of light which are 16 hours HPS plus 25 µ mol $m^{-2}s^{-1}$ HPS and 25 µ mol $m^{-2}s^{-1}$LED, it is not found significance difference. The same result is also observed in others two quality which are 16 hours HPS plus 50 µ mol $m^{-2}s^{-1}$HPS and 50 µ mol $m^{-2}s^{-1}$ LED (red). Light quality plays vital role in development of powdery mildew. The study conducted by Suthaparan (2010) documents that the 18 hours full spectrum white light followed by low intensity red light significantly reduced the conidia formation and release of rose powdery mildew. In the same study, he found that the red light strongly reduced powdery mildew and reduced formation of conidia in *P. pannosa* in greenhouse rose production compared to the white light. In my result in red (LED) shows the significance reduction of powdery mildew development as well as transmitted disease. The similar result to my result also reported by Wang, Hong et al. (2010) in cucumber powdery mildew which is reduced significantly under the red light treatment (628.6 nm) compared to purple, blue green yellow and broad spectrum white The report published by Schuerger, Andrew C and Brown, Christopher S (1997) also reports that least rose powdery mildew on the red light treatment. But the study on the rose, the blue light has significant effect on the reduction of germination of conidia with comparison to red, far- red and white light. The germination of conidia is not reduced by red or far red in case *Podosphaera pannosa* with compared to white light (Suthaparan et al. 2010b).

5.1.3 Effect of Light Intensity on Development of Powdery Mildew

In this study, the effect of light intensity on disease severity and germination of conidia did not reveal significant difference between the two treatments of 16 hours white light with 25 µ mol $m^{-2} s^{-1}$ HPS and 50 µ mol $m^{-2} s^{-1}$ HPS. Further, the treatment with night interruption showed germination of powdery mildew in both cases but the difference was not significant. So, dark period is necessary factor for the development of powdery mildew. Suthaparan et al. (2010a) also found more conidia production with exposure to darkness.

However, the effect of light intensity of germination of powdery mildew is rarely reported. One of studies which report increasing light intensity prevents germination of powdery mildew in light with 1750 lux (Jacob et al. 2008). In the same study, the more conidia formation was observed at the 20ºC and 70% RH and higher light intensity at 5150 lux. Further he explains, low light intensity was associated with optimal germination of *O. neolycopersici*. However, Suthaparan et al. (2012) has reported the reduction rose of powdery by apply of UV –B with 0.1 Wm^{-2} for 1 hours and null at 0.2 Wm^{-2} at low intensity.

Amsalem et al. (2006) also found in the case of strawberry powdery mildew. Significant lower levels of disease severity are recorded at the highest light intensity of 7000 lux, compared to those at 1200 and 3800 lux, which are very similar and not significant in value

One of the studies found that the germination of conidia in tomato powdery mildew species is higher in dark filter with comparison to combination of pink and green filter (Elad, Y 1997).

5.2 Effect of light quality and duration on Plant Development

5.2.1 Effect of Light Duration on Plant Development

The present results show that the development of tomato plants in two different photo period that are 16 hours red and white light without night interruption has adverse effect. Plants that are grown in 16 hours red (LED) light seems smaller and weaker than the other treatment. Leaf area (493cm^2) is found in 16 hour red (LED) compare to 16 hours plus 50 µ mol $m^{-2} s^{-1}$ (1043 cm^2). The dry weight is 2.8 gram in 16 hours red (LED) that is 1.8 times smaller than

16 hours HPS with 50 µ mol m^{-2} s^{-1} HPS. Dry weight is reduced by 2.1 times in red light (LED) in experiment 3. That shows that the red (LED) light has negative effect on development of tomato plants where as 16 hours white light has positive affect on leaf area. Dorais et al. (1996) also found that tomato plants grown under supplemental light has higher shoot fresh weight, but plant grown under 24 hours photoperiod decreased stem and leaf fresh weights compared to a 12 and 18 hours photoperiods. It might be effect of continuous red (LED) light tomato plants grown in are not well development in my result. One of the first reports of damaging tomato plants by continuous lighting was reported by (Guthrie 1929). This result was similar to the increase of dry by 30% – 40% weight with the increase of 20 hours lighting period in pot rose (Mortensen & Gislerød 2005). Similar result was found that in case of lettuce increase in the plants biomass with continuous lighting from 16 hours to 24 hours per day. One of the study by Pettersen et al. (2010) reports that the growth of cucumber leaf area decreasing by 20% in the continuous lighting 20 hours per day.

5.2.2 Effect of light quality on Plant Development

Low intensity light that is obtained from LED red light is below the energy levels required for the plants growth. In our present result it is shown that the plants growths in, 16 hours red light treatment without night interruption, leaf area are seen reduced by one half times than the other treatment. The comparison of two different quality 16 hour base light with 25 µ mol $m^{-2}s^{-1}$ LED and 25 µ mol $m^{-2}s^{-1}$HPS, leaf area were found(974 and 991), stem dry weight are 0.7 and 0.6 gram in table 5. These results shows there are not significant difference. Current result only shows that clear and significant effect of continuous red (LED) light without night interruption on plant growth. Dorais et al. (1995) found the negative growth effect of red light in case of eggplants. Murage and Masuda (1997) also report that the peanuts show the negative effect on development when red light was applied. This finding is also similar to McNellis and Deng (1995) that negative effect of red light was found in the plant development and physiology. However, the combination of red and blue light has an effective lighting source to plant development (Wheeler et al. 1991). The absence of one of the two light wavebands (red or blue) creates photosynthetic in efficiencies (Hogewoning et al. 2010). Another study reported that , the dry weight increases under supplementary blue light in cucumber and tomato (Ménard et al. 2005). Kuwar (2010) is also reports reduced leaf area and height by 20 -30% in LED light treatment with compare to mixing of HPS and LED

light. In the same study, significant reduction of leaf area are also observed in “Chrismas Eve” in the LED light with compare to mix light and HPS light. In our result, I found that the dry weight of tomato was reduced in case of LED light treatment with no night interruption is significant difference and same to result of Kuwar (2010) in `Advent Red ` was significantly lowered by LED light than the mix light and HPS. The study conducted by Terfa et al. (2012) also documented leaf area are reduced but dry weight has not significant differences under LED and HPS light in rose.

5.2.3 Effect of light Intensity on Plant Development

In current result clearly shows there is no significant difference between the intensity, this might be minimum light intensity lesser than 50 µ mol $m^{-2}s^{-1}$. The effect of light intensity are observes, in difference of 25 µ mol $m-^{2}s^{-1}$ and 50 µ mol $m^{-2}s^{-1}$, in leaf area (974&1043), leaf dry weight (2.9&2.8) and stem dry weight (0.7&0.8) in table 5, we found no significance effect of light intensity which increased from 25 to 50 µ mol (100%) on development. However, the study conducted by Conover and Poole (1977) reports that low intensity reduce the leaf area and increased fresh that are grown in the shade. Collins and Blessington (1982) found decreased of dry weight of *Ficus benjamina* in high light intensity and increases fresh and dry weight of *S. arboricola*. Powles and Critchley (1980) reports that the fresh and dry weight is found highest in full sunlight on the other hand he found minimum that are grown in 6% sunlight. There are some plants such as tomato and roses cucumber are less affected by high irradiance level of with supplementary light. Normally Europe commercial provides the 20-100 µ mol $m^{-2}s^{-1}$ for the production of tomato (Ehret et al. 1989).

6. Conclusions

From the result of our experiment, the following conclusion could be drawn.

- 16 hours red (LED light treatment without night interruption in growth chamber gives no powdery mildew after18 days inoculation in non-inoculated plants.
- 16 hours red (led) reduces powdery mildew significantly in inoculated plants grown under growth chamber.
- 16 hours white (HPS) in growth chamber gives lots of powdery mildew.
- 16 hours red (LED) also prevent disease transmit from the inoculated tomato plant.
- Night interruption for 2 hours on base lighting of 16 hours gave same infection of powdery mildew as 16 hours HPS in different light quality.
- Different light intensity used as night interruption had no effect on powdery mildew.
- 16 hours red light (LED) had reduced the plant growth.

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