INTRODUCTION

Nowadays, global food security is being haunted by the rapid increase in population and severe climate changes which have the potential to threaten global food security, according to the latest edition of FAO’s flagship annual report, ‘The State of Food and Agriculture’ (FAO, 2016). Changes in climate condition is mainly attributed to the tremendous increase in greenhouse gases, including carbon dioxide (CO₂), methane, fluorinated gases and nitrous oxide, which causes changes in rain fall, temperature and negative effects on water and land resources (Kreft et al., 2017). Even though climate change is a global phenomenon, its impacts are more affected in the developing countries as reported by Stockholm International Peace Research Institute (Bremberg, 2018). Because most of the developing countries have agriculture-based economies, their agricultural zone is highly affected by climate change. Moreover, the variability in climate change becomes a major challenge to agricultural production, as it affects approximately 2.5 billion people who are partially or completely dependent on agriculture (Ali et al., 2017).

Climate change affects various crops and areas differently, but it is generally expected that agricultural productivity will decline. As climate change will negatively affect the crop productivity, it causes food security problems worldwide (Tripathi et al., 2016). World population is growing day by day and by 2050 it is expected to reach 9.1 billion, but agricultural production is not rising at a parallel pace. To feed the world population, productivity must be increased by 70% for an additional 2.3 billion people by 2050 (Rosenzweig et al., 2014). As far as India is considered, the country is highly sensitive to changes in climate because of high physical exposure to climate related parameters and also the India’s economy and population depends on climate sensitive sectors like agriculture, forests and fisheries.
Low productivity is the main problem of Indian agriculture. Moreover, to meet India’s growing food demand, there is an acute need for increasing productivity in all sectors of agriculture. Agricultural policy should focus on improving crop productivity and developing safety nets to cope with the risks of climate change to feed the overall population (Chakrabarty, 2016).

Agriculture production is dwindled mainly due to various biotic and abiotic stresses resulting in 30-60% yield losses globally each year. The major abiotic stresses like temperature (heat, cold chilling/frost), water (drought, flooding), chemicals (heavy metals/pesticides, gaseous toxins), radiation (UV, ionizing radiation), mineral deficiency/excess, light (high/low), mechanical (wind, soil movement, submergence) are responsible for over 50% reduction in agricultural production (Pereira, 2016). In the world only 9% of the total land area is useful for crop production, while 91% is under stress. The area under stress is likely to increase further due to land degradation, climate change and urbanization. It is anticipated that if present scenario persists, 50% of current cultivated land will be lost by 2050 (Gomiero, 2016). Added pressure to the above is that global population is likely to reach 7 billion by 2025 and 10 billion by 2050, whereas the area of cultivable land is diminishing and the necessity for enhancing the crop production is increasing (Wani and Sah, 2014). Therefore, the whole world is on the lookout for developing various technologies to enhance crop production and also to counter various abiotic stresses, so that achievements out of these attempts will help to cope up with the food demand of the increasing population (Gimenez et al., 2018).

Sunlight fuels plant growth and development through a process called photosynthesis, which converts light energy into chemical energy in plants. In natural conditions, plants have to respond to diurnal change in the light
environment due to their sessile character (Darko et al., 2014). Sunlight is an electromagnetic spectrum with an array of visible and non-visible energy with different wavelengths and it consists of packages of light (photons). Visible light to human’s eye is only a small portion of the electromagnetic spectrum that includes radiation wavelengths ranging from gamma rays to TV and radio. Photons travel directly through space as long as nothing obstructs them, but different particles such as aerosols, clouds, gases, dust and other particles present in the atmosphere affect the quantity and quality of incoming radiation. Photons are absorbed, scattered and reflected by the ozone layer in the stratosphere and the particles present in the troposphere. As a result, the portion of the total solar radiation reaching Earth’s surface is different (Munawwar, 2006).

Mainly sunlight is composed of three most important parts; ultraviolet radiation (UV), visible light and infrared radiation. Among them, photosynthetically relevant solar energy that reaches the surface of Earth is divided into two main spectrums; photosynthetically active radiation (PAR) (400 to 700 nm) and UV (100 to 400 nm). Because of the short wavelength, UV radiation has high energy and frequency. In biological research, UV band has been divided as UV-A (320 to 400 nm), UV-B (280 to 320 nm) and UV-C (100 to 280 nm). Among these UV-A and PAR radiation are affected by light scattering. In contrast, UV-B region is selectively absorbed by the ozone layer present in the stratosphere (Tarasick et al., 2003). UV-C, the most biologically damaging wavelength, is not a significant factor for biological processes under natural conditions since it is completely absorbed by atmosphere (Bais et al., 2018).

The main role of sunlight in plant’s life is to provide the energy for photosynthesis and for the regulation of plant growth and development at different stages, now termed as photomorphogenesis (Folta and Childers,
The majority of developmental processes throughout the entire life cycle of plants are influenced by light: seed germination, vegetative growth, sensing neighboring plants, circadian rhythm, de- etiolation, shade avoidance, stomatal development, phototropism and induction of flowering (Franklin et al., 2005). Plants are able to detect the quality, quantity and direction of light and respond to it as an external signal, even though both intensity and duration of light have an additive relationship in plants. Light intensity is the total amount of light received each day, each hour or each minute and the duration is the period of time that light strikes the plant’s leaves each day, generally measured in hours and termed as day length (Franklin and Quail, 2010).

Light stress in plants is defined as the exposure to insufficient/excess levels of light that negatively affect plant growth and development. Exposure to insufficient light limits photosynthetic activity, whereas exposure to excess light energy can damage the photosynthetic apparatus in plant system. The type of stress response in plant system induced by light is depend on the factors like fluence rate, intensity, exposure time, age of the plants and whether plants have been acclimated by prior exposure to light (Gururani et al., 2015). High intensity light (HL) or excessive light can reduce photosynthetic activity and efficiency known as photoinhibition (Adir et al., 2003; Fiorucci and Fankhauser, 2017). In HL situations, plants absorb more light than can be used for photosynthesis, resulting in over-excitation of the photochemical reaction centers in the chloroplast, which can lead to serious damage to the photosynthetic apparatus and ultimately causes plant growth reduction (Derks et al., 2015). This excess energy has the potential to be transferred to oxygen, leading to formation of reactive oxygen species (ROS), which can cause damage to cells and inhibit growth. Since photosynthetic CO₂ assimilation is a major sink for absorbed light energy, the difference in
photosynthetic capacity depends on light intensity and plant type (Kami et al., 2010).

The stratospheric ozone layer is a high altitude expanse of oxygen molecules that protects life on Earth from damaging solar UV radiation. During the last few decades, stratospheric ozone has been catalytically broken down due to high concentration of greenhouse gases and halogenated species, resulting in significantly decreased ozone levels (Shanklin, 2010). Depletion of the stratospheric ozone layer has occurred mainly by emissions of chlorofluorocarbons (CFCs), methyl bromide, nitrogen oxides, sulphur oxides and some other substances released by human activities (Portmann et al., 2012). The depletion of the ozone layer has been on the recovery for the past decade or so. But industrial emissions of chemicals commonly used in solvents, paint removers, and the production of pharmaceuticals have doubled in the past few years, which could slow the healing of the ozone layer (Hossaini et al., 2017).

Bais et al. (2015) assessed the factors that determine the intensity of UV radiation reaching at Earth’s surface and found that stratospheric ozone, which absorbs UV radiation, is of considerable importance, but other constituents of the atmosphere, as well as certain consequences of climate change, can also be major influences. In addition to ozone effects, the UV changes in the last two decades have been influenced by changes in aerosols, clouds, surface reflectivity and solar activity. The main reason for positive trends of UV radiation observed after the mid-1990s over northern mid-latitudes are decreases in clouds and aerosols. Since the beginning of the 1980s, an ozone hole has developed over Antarctica resulting in a decrease in ozone level up to 70% during the southern spring season. Ozone depletion is more severe in Antarctica than at the North Pole because high wind speeds cause a fast rotating vortex of cold air, resulting to low temperatures (Harris et al., 2008). Over the Arctic, the
northern hemisphere’s irregular landmasses and mountains normally prevent the build-up of strong circumpolar winds and so the effect is far less pronounced. Ozone depletion over the southern hemisphere means that people living there are more exposed to cancer-causing UV radiation (Cerrone et al., 2017).

Continuous observations since the 1980’s have shown that ozone content of stratospheric zone have decreased by 3 to 6%, resulting in a 6 to 14% increase of UV-B radiation at Earth’s surface. The stratospheric ozone depletion in southern hemisphere is dangerous, where an annual reduction in ozone density occurs in each spring, than high latitudes of the northern hemisphere where it is less pronounced (Rowland, 2006). Each CFCs molecule may cause the destruction of many molecules of ozone as the half life of CFCs ranges from 50 to 150 years. Therefore it is expected that decreased ozone levels will only recover to pre-1970 levels after several decades as the occurrence of CFCs will remain in the upper atmosphere for a long time. The generally expected forecast is that the stratospheric ozone layer will recover by 2050, even though the interactive effects of global climate change will remain (McKenzie et al., 2011). International agreements on protecting the ozone layer - particularly the Montreal Protocol - have stopped the increase of ozone depleting substances mainly CFCs, and a drastic fall has been observed since the mid-1990s. However, the progression of the ozone layer is affected by the interplay between atmospheric chemistry and factors like wind and temperature. Unfortunately, the ozone hole formed over Antarctica grew to about 8.9 million square miles in 2016 before starting to recover, according to scientists from NASA and the National Oceanic and Atmospheric Administration (NOAA) who are monitoring this annual phenomenon.
Scenarios based on chemistry-climate models shows that in the middle of 21st century, UV-B radiation at ground level is enhanced and resulted in alteration of the normal spectral UV composition reaching the surface of Earth, which is predicted to continue in the future (Taalas et al., 2000; McKenzie et al., 2007). It has been found that thinning of the stratosphere ozone layer has caused significant increase in the UV-B radiation and change in the spectral UV composition that reaches Earth’s surface. Since 1980s and 1990s, increases in UV-B due to decreasing ozone were observed, where ozone depletion was more pronounced, particularly at high latitudes (>60°) (Caldwell et al., 1998). Though, only a small part of the total solar spectrum (0.5%), it has the potential to cause photobiological damage in biological system in the case of not only major increases, but also minor increases in its content, due to its high energy. It is mandatory to understand the mechanisms of biological processes such as negative effects, repair or protection caused by UV-B, in order to understand the eco-physiological role of UV-B radiation. This is of special importance in plants which have sessile and photosynthetic characters. Plants monitor changes in their environment and are able to memorize and respond to these changes (Hollósy, 2002).

The UV-B range of solar spectrum is absorbed by many components of the cell which leads to harmful consequences. UV-B radiation is cytotoxic, at the cellular level it initially causes an increase in ROS levels, which subsequently oxidizes proteins, lipids, photosynthetic pigments and other biomolecules, and thus damages the structural integrity and functionality of enzymes and membranes in the cell (Schuch et al., 2017). UV-B induced pyrimidine dimer formation in DNA strands becomes mutagenic and genotoxic by blocking the action of DNA polymerase. As a result, the exposure of plants to UV-B can lead to cell damage and often cell death also may occurs (Robson et al., 2015; Köhler et al., 2017).
HL and UV-B irradiation is expected to be adverse on plant growth and development even at relatively small doses and it can induce several plant photomorphogenic responses. HL and UV-B induces various morphological, physiological and biochemical stress responses in plants, which are species specific and different, even for closely related cultivars (Cramer et al., 2011). The morphological effects of HL and UV-B in plants includes many changes, such as the reduction of biomass, plant height, root growth and leaf area, curling of cotyledons and leaves, increased auxiliary branching, chlorosis and necrotic spots, shortened internodes, altered flowering, etc. Decreased plant height was mainly due to shorter internodes rather than reduction in number of nodes (Kakani et al., 2003a; Fedina et al., 2010).

The physiological effects of HL and UV-B include reduction in photosynthetic and respiratory efficiency, destruction of chlorophyll and carotenoids pigments and the effects on stomatal activity. Reduction in the photosynthetic activity due to HL exposure was found in several plant species which ultimately reduced the crop yield (Zlatev et al., 2012; Tian et al., 2017). UV-B inhibits photosynthesis at several levels, including photosystem I (PSI) and photosystem II (PSII) photochemistry, maximum net photosynthetic rate, the activity of carbon fixing enzymes and electron transport (Rousseaux et al., 2004; Sztatelman et al., 2015). Many components have been summarized as primary targets of HL and UV-B action on photosynthesis, including the reaction centre itself, oxygen evolving Mn cluster, quinone acceptors and other components on the donor and acceptor sides of PSII (Kataria et al., 2014).

The biochemical effects of HL and UV-B include anthocyanin and flavonoids accumulation and they function as UV absorbing compounds by providing a shield to protect plants from harmful radiation and excess visible light (Guo et al., 2008; Zoratti et al., 2014). In order to reduce the impact of
ROS generated by HL and UV-B exposure, plant produces non enzymatic antioxidants such as glutathione, ascorbic acid, α-tocopherol and evokes antioxidant enzymes such as catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR) and guaiacol peroxidase (GPOX). Moreover, leaf surfaces of higher plants develop an epicuticular wax coating which provides the first line of outermost defence against external influences such as air pollutants, UV and HL irradiation, restriction of the water vaporization and attack by pathogens together with some other leaf surface structures such as glandular hairs or trichomes (Yeats and Rose, 2013; Biswas et al., 2017).

Cereals are the most important source of calories to humans. According to Khush (2001), rice, wheat and maize are globally offer 23%, 17% and 10% calories respectively. Rice is a well known cost-effective cereal; also staple food included in the diet of humans which is feeding more than 2.7 billion people worldwide. More than 28% of the world’s population live in Asia-Pacific region, where, the current 524 million tonnes of rice produced annually will have to be increased to 700 million tonnes by the year 2025, which is an immense task (Papademetriou, 2000). It is a chief and most vital source of food for more than half of the population and more than 90% of the world’s rice is grown and consumed in Asia, where 60% of Earth’s people live. It is expected that we will have to produce 25% more rice by the year 2030 (Khush, 2012).

As the 21st century unfolds, global rice production has showed signs that it may no longer be stable in the future. Globally, the traditional agricultural practices are not enough to produce rice for the needs of an ever-increasing population. Thus, the global population continues to increase, although with lower growth rate, while the resources for rice production are diminishing (Papademetriou, 2000). There are many challenges to reduce rice food shortage and poverty within the rice-based systems. Climatic change casts a huge shadow in the horizon of agricultural productivity. A variety of
factors including shrinkage of arable land, declining yields and labour, scarcity of irrigation water, effects of economic growth, pressure on land use, climate change and the related abiotic stress situation, environmental pollution etc. make threats to future rice production (Korres et al., 2017).

Based on the facts stated above, the focus of the present study is on thirteen rice varieties (Aathira, Aiswarya, Annapoorna, Harsha, Jyothi, Kanchana, Karuna, Mangalamahsuri, Mattatriveni, Neeraja, Swarnaprabha, Swetha and Varsha) which are the commonly cultivated high yielding rice varieties in Kerala with an emphasis on the effects of HL and UV-B radiation on the physiological, biochemical processes and the mechanisms of its tolerance which can aid in distinguishing the tolerant and sensitive rice varieties towards these two environmental stresses. Therefore, the present study was designed for fulfilling the following objectives.

1) Screening of thirteen commonly cultivated high yielding *Oryza sativa* varieties grown in nutrient solution for analyzing the effect of HL and UV-B irradiation.

2) Evaluation of the effect of HL and UV-B irradiation on the photosynthesis of selected *O. sativa* varieties.

3) Revealing the physiological and biochemical adaptations in the seedlings of selected *O. sativa* varieties towards HL and UV-B irradiation.

4) Identify the HL/UV-B stress tolerant and sensitive *O. sativa* varieties based on their HL/UV-B stress tolerance potential.