Summary

Agriculture has been a way of life and continues to be the single most important livelihood of the masses in India. Agricultural policy focus in India across decades has been on self-sufficiency and self-reliance in food-grains production. Considerable progress has been made on this front. Food-grains production rose from 52 million tons in 1951-52 to 244.78 million tons in 2010-11. Without incremental productivity gains and technology diffusion across regions, achieving this higher growth may not be feasible and has implications for the macroeconomic stability given the rising demand of the 1.21 billion people for food. Achieving minimum agricultural growth is a pre-requisite for inclusive growth, reduction of poverty levels, development of the rural economy and enhancing of farm incomes. Improvement in yield, which is key to long term growth, depends on a host of factors including technology, use of quality seeds, fertilizers, pesticides, micronutrients and irrigation. Each of these plays a role in determining yield level and in turn augmentation in the level of production.

But there are concerns among scientists and intellectuals from different fields about growing challenges of climate change, pressures on land, air, water, forests and loss of plant and animal habitat. The 2009 State of the Environment Report by the Ministry of Environment and Forests clubs the issues under five key challenges faced by India, which are climate change, food security, water security, energy security, and managing urbanization. Environmental degradation is impacting the natural ecosystems and is expected to have substantial adverse effects in India.

One dimension of this environmental degradation may be increased concentration of CFCs and other toxicants which may potentially harm stratospheric ozone layer allowing the solar UV-B radiation to come on the earth surface. Elevated UV-B radiation has pleiotropic effects on plant development, morphology and physiology. Ultraviolet-B
affects plants including cyanobacteria from the molecular level to the ecosystem level. UV-B responses can be summarized as low and high fluence rates responses either by stimulating protection mechanisms or by activating repair mechanisms to cope with different types of stresses. There is strong evidence from studies based on gene expression profile that the low-fluence UV-B responses are not mediated by DNA damage signaling. Low UV-B fluence rates (<1 µmol m\(^{-2}\) s\(^{-1}\)) cause no or very low amount of cyclobutane pyrimidine dimers (CPDs, oxidation product of DNA) that are below the limit of detection and stimulate protective and photo-morphogenetic responses. It has been reported that low UV-B fluence rate is capable of promoting metabolic and developmental changes such as biosynthesis of secondary metabolites and photomorphogenesis. Further, it has been shown that responses to low UV-B fluence rates are in part due to transcriptome changes.

On the other hand, high fluence rates (>1 µmol m\(^{-2}\) s\(^{-1}\)) of UV-B produce excess ROS and may damage DNA, proteins, lipids and membranes. These higher fluence rates of UV-B can also initiate the expression of genes characteristic of stress responses via signaling pathways which are not specific to low fluence rates of UV-B. Besides this, high fluence rate of UV-B may also enhance the formation of CPDs. Thus, it is clear that on one extreme, UV-B can initiate protective responses while on the other extreme it can initiate damaging responses based on its fluence rates.

In oxygenic photosynthetic organisms including cyanobacteria reactive oxygen species (ROS) i.e. O\(_2^\cdot\)\(^{-}\), H\(_2\)O\(_2\), \(\cdot\)OH, \(^1\)O\(_2\) are inevitably generated by various electron transport systems and their concentrations are under tight control. However, presence of toxic factors such as pesticide and high UV-B radiation enhances the generation of ROS through the same electron transport systems and thus accelerate chance of biomolecule damage. In order to control the amount of ROS so that they participate only in signaling rather than causing damage to macromolecules, a full-fledge antioxidant system has evolved in cellular system. Antioxidant system consists of enzymatic and non-enzymatic antioxidants. Among antioxidants superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), glutathione-S-transferase (GST) and components of ascorbate-
glutathione (AsA-GSH cycle) cycle play prominent role to control/detoxify ROS. Components of AsA-GSH cycle are comprised of three independent redox couples: reduced to oxidized ascorbate ratio (AsA/DHA), reduced to oxidized glutathione ratio (GSH/GSSG), and NADPH/NADP; and enzymes *i.e.* ascorbate peroxidase (APX), glutathione reductase (GR), monodehydroascorbate reductase (MDHAR) and dehydroascorbate reductase (DHAR). These enzymes are responsible for redox cycling of AsA, GSH and NADPH. Proper operation of the AsA-GSH cycle maintains reduced and active forms of ascorbate and glutathione on optimal level. Thus, any alteration in AsA-GSH cycle may affect the proper scavenging of ROS which could have adverse effect on growth and over-all physiology of the organism.

Soil and water pollution due to pesticides have also become a common concern among environmentalists. Pesticide contamination to aquatic ecosystem including paddy fields is a serious global environmental concern. Use of pesticides became indispensable and an integral part of modern agriculture and their usage under Integrated Pest Management Programme to save the crop losses have become quite decisive in countries like India in wake of second green revolution likely to be experienced in next few years. Use of pesticides in our agricultural fields cannot be ruled out because of steady and continuous rise in population and lesser availability of agricultural fields. But, excessive and imprudent use of pesticides may severely affect metabolic functions and overall growth performance of non-target microorganisms like cyanobacteria which add nitrogen to paddy fields by their microbial activity and indirectly augment the paddy production. Various pesticides such as atrazine, butachlor, malathion and trichlorfon have been reported to cause adverse effects on growth and physiological responses of cyanobacteria and green algae.

Chlorpyrifos (IUPAC name: *O, O*-diethyl *O*-3, 5, 6-trichloro-2-pyridyl phosphorothioate) is a crystalline organophosphate and broad spectrum insecticide which is applied on a large scale in rice fields for the control of brown plant hopper, green leaf hopper, whorl maggot gall, midge stem borer. Chlorpyrifos remains biologically active in agricultural fields for variable time periods. The half-life of chlorpyrifos ranges from 10
to 120 days and its initial concentration, soil type, soil microflora, pH and moisture of the surroundings cumulatively decide its dissipation. Due to the immense usage of chlorpyrifos, the toxic effect of chlorpyrifos has been extensively investigated on aquatic as well as terrestrial animals such as zooplanktons, earthworm, amphibians, fish etc., showing variable range of LD$_{50}$ – 0.7 ng l$^{-1}$ to 8.4 mg l$^{-1}$.

Hormesis is a dose-response phenomenon of an organism against a toxicant/environmental factor characterized by low dose stimulation and a high dose inhibition. As stated above that UV-B may play dual role based on its fluence rates. Similarly, chlorpyrifos may also have dose dependent stimulatory or inhibitory impact on cyanobacteria. It has been shown that chlorpyrifos inhibits acetylcholinesterase activity by its oxygenated metabolites (oxons) due to the phosphorylation of the serine hydroxyl group located in the active site of the molecule. Besides this, chlorpyrifos has also been reported to cause toxic effects on animals by disrupting antioxidative system. Besides damaging effects, ameliorating effect of chlorpyrifos has also been reported on animal as well as plant systems. Chlorpyrifos has been reported to affect carbon fixation and nitrogenase activity in the cyanobacteria. Accounting the risk of chlorpyrifos to non-target organisms, especially cyanobacteria, there is still not much known about impact of chlorpyrifos on biochemical responses particularly the extent of oxidative stress posed by chlorpyrifos and the existing defense mechanism in the cyanobacteria. Impoverished knowledge of chlorpyrifos on cyanobacteria is also due to its insecticidal nature.

Cyanobacteria are an important component of aquatic ecosystems. Any damage to their biodiversity may lead to a non-recoverable damage to the ecosystem. They are also an integral component of the rice fields and contribute significantly to soil fertility through their capacity to fix atmospheric nitrogen and enrich the paddy field with humus after their death and decay. Any damage to cyanobacterial population will also lead to the loss in crop productivity, particularly paddy.

Considering importance of cyanobacteria to aquatic ecosystem especially in paddy fields where they increase fertility of soil, in the present study, effects of low and high doses of chlorpyrifos together with low and high fluence rates of UV-B radiation on
growth responses, physiology and biochemistry including nitrogen metabolism, ROS generation and their possible harmful impact on biomolecules, related defense strategy encompassing enzymatic and non-enzymatic antioxidants and components of AsA-GSH cycle of the two cyanobacteria—*N. muscorum* and *P. foveolarum* were studied. Present work is also focused to find out the tolerant genera between the two, against the high doses of the twin stresses. *Nostoc muscorum*, a heterocystous cyanobacterium is capable to fix molecular nitrogen under aerobic condition while *Phormidium foveolarum*, a non-heterocystous strain can fix nitrogen under microaerobic condition particularly in darkness.

After a series of screening experiments, low fluence rate for UV-B was decided as 0.1 µmol m$^{-2}$ s$^{-1}$, denoted as UV-B$_L$. At this dose no adverse effect was observed on the tested organisms. Similarly, low dose of chlorpyrifos was decided as 1 µg ml$^{-1}$ and denoted as CP$_L$. This dose was inhibitory after 24 h of experiments, but after 72 h of experiments becomes stimulatory.

High fluence rate for UV-B was decided as 1.0 µmol m$^{-2}$ s$^{-1}$, denoted as UV-B$_H$. At this dose marked adverse effect was noticed. High dose for chlorpyrifos was decided as 2 µg ml$^{-1}$ and denoted as CP$_H$. These doses remained inhibitory even after 72 h of experiments.

Present study profusely investigates impact of non-damaging (low fluence rate; UV-B$_L$, 0.1 µmol m$^{-2}$ s$^{-1}$) and damaging (high fluence rate; UV-B$_H$, 1.0 µmol m$^{-2}$ s$^{-1}$) dose of UV-B radiation on physiological and biochemical responses of *N. muscorum* and *P. foveolarum* with special emphasis on oxidative stress and their mitigation strategies under low (CP$_L$: 1µg ml$^{-1}$) and high (CP$_H$: 2µg ml$^{-1}$) doses of chlorpyrifos (*O*, *O*-diethyl O-3, 5, 6-trichloro-2-pyridyl phosphorothioate) insecticide.

Growth is the resultant of metabolic processes occurring in the cell thus it can be used as an indicator for testing sensitivity of an organism under stress. Growth behavior was measured as change in absorbance ($A_{750}$ nm), relative growth rate (RGR), dry mass and protein content. These parameters decreased by CP doses and UV-B$_H$ treatments,
after 24 h of experiment. \( CP_L \) was inhibitory after 24 h of measurements but after 72 h of experiment, not only an apparent recovery was seen in \( CP_L \) treated samples but also it surpassed the control samples. Despite of marked recovery after 72 h experiments, high dose of CP (\( CP_H \)) remains inhibitory for growth parameters. Furthermore, results revealed that when UV-B\(_H\) combined with any of the CP doses significantly exacerbated the decrease in these growth parameters in comparison to their individual treatment. However, under similar treatments, reduction in growth was more prominent in \( N.\ muscorum \) than \( P.\ foveolarum \). The low dose of UV-B which individually could not able to cause any significant change in these parameters, after combining with CP doses brought about significant positive changes in these parameters. After 72 h of experiment, growth parameters were improved in all samples irrespective of amount of stress posed. This suggests that both organisms exhibited adapting behavior against the twin stresses.

Photosynthetic pigments \( i.e. \) chlorophyll \( a \), carotenoids and phycocyanin were measured in both cyanobacteria under similar experimental condition. Results revealed that \( CP_L \) and \( CP_H \) significantly decreased photosynthetic pigments content in both the cyanobacteria but after 72 h of experiment \( CP_L \) treated cyanobacteria not only recorded improvement but surpassed the control cells. UV-B\(_L\) improved the pigments level after combining any of the CP doses. Similarly, UV-B\(_H\) worsened the pigments level singly as well as after combining with any of the CP doses. CP and UV-B\(_H\) induced decrease in photosynthetic pigments was higher in \( N.\ muscorum \) than \( P.\ foveolarum \). Among photosynthetic pigments, phycocyanin was highly affected by the twin stresses and their different combinations, followed by chlorophyll \( a \) and the least effect was noticed on carotenoids.

Photosynthesis is the only physiological process that provides organic matter for existence of life on the earth. Results related to photosynthetic activity as whole cell \( O_2 \) evolution showed that \( CP_H \) significantly decreased photosynthetic activity in both the cyanobacteria; however, reduction in photosynthetic rate was higher in \( N.\ muscorum \). UV-B\(_H\) alone also decreased photosynthesis and together with CP doses exacerbated decrease in photosynthetic rate over their individual treatments. On the other hand,
exposure of UV-B_L dose together with CP doses led to a better photosynthetic activity compared to the CP treatments alone.

To understand the mechanism of inhibition on photosynthetic oxygen yield the PS II, PS I and whole photosynthetic chain mediated electron transports activities were measured in spheroplasts prepared from *N. muscorum* and *P. foveolarum* cells grown under low and high doses of CP with UV-B_L and UV-B_H alone and together. Data related to photosynthetic electron transport activities showed that CP_H significantly inhibited PS II, PS I and whole photosynthetic chain reaction in both the tested cyanobacteria but inhibition was greater in *N. muscorum*. UV-B_H also significantly decreased photosynthetic electron transport activities in both the organisms. Among PS II, PS I and whole chain, it was the whole chain which was the most affected followed by PSII while PS I was least affected which is due to its resistant nature against stresses. In contrast to UV-B_H, UV-B_L dose together with CP doses alleviated CP-induced inhibition of photosynthetic electron transport chain reaction.

In order to find out possible site of damage in photosynthetic electron transport chain (PS II) caused by CP and UV-B_H, the DCPIP photoreduction was measured in the presence of various exogenous electron donors– DPC, NH_2OH and MnCl_2 and compared with DCPIP photoreduction in PS II without donor. Results indicated that all the three exogenous electron donors restored PS II activity but DPC was comparatively more effective. This shows that the site of damage lies in between oxygen evolving complex (OEC) and PS II reaction centre.

In contrast to photosynthetic activity, respiration rate was increased by CP and UV-B_H. Further results showed that as the amount of stress increased, increase in respiration rate might have been an arrangement to meet the demand of ATP for carrying out the basic life processes in the cell.

Cyanobacteria absorb nitrogen as nitrate or nitrite. These are important sources of macronutrient for their growth and development. Any alteration in the process of absorption of macronutrients may cause subsequent loss in growth and development of
cyanobacteria. A considerable inhibition was noticed following the exposures of CP_L and CP_H in case of *N. muscorum* cells and *P. foveolarum* and these inhibitions were partially overcome by simultaneous exposure of UV-B_L, while UV-B_L alone could not succeed in altering NO_3^- and NO_2^- uptake rates in any of the tested cyanobacteria. CP_H, whether alone or in combination with either doses of UV-B, always showed detrimental effects on NO_3^- and NO_2^- uptake rates of both the organisms after 24 h of experiments but after 72 h, the uptake rates were substantially improved in *N. muscorum* as well as in *P. foveolarum*.

Nitrogen is a quantitatively important bio-element which is incorporated into the biosphere through assimilatory processes carried out by microorganisms and plants. Nitrate assimilation is carried out by successive action of nitrate reductase (NR) and nitrite reductase (NiR) and results into the formation of ammonium. In cyanobacteria, ammonium (either taken up from the outer medium or produced intracellularly) is incorporated into carbon skeletons (glutamate) mainly through the glutamine synthetase-glutamate synthase cycle (GS-GOGAT cycle). However, recent studies showed that ammonium may also incorporate into glutamate by the action of aminating glutamate dehydrogenase.

Nitrogen assimilating enzymes—nitrate reductase (NR), nitrite reductase (NiR), glutamine synthetase (GS) and glutamate synthase (also known as glutamine 2-oxoglutarate aminotransferase; NADH-GOGAT) were severely affected when treated either singly with CP_H or/and exposed to UV-B_H. CP_L also inhibited all the parameters (except GDH activity) when measured after 24 h, but after 72 h of measurement, this dose became stimulatory. Whenever, UV-B_L combined any of the CP doses, it either reduced the inhibitory effect of CP_H or enhanced the concerned enzymatic activities (except GDH activity). However, GDH which is of course, a bypass route for NH_4^+ assimilation in stress condition is affected reversibly as those of GS and GOGAT. Further, between the two cyanobacteria, *P. foveolarum* was found to be more tolerant against either of the two environmental factors.
Phosphorus is considered as growth limiting factor for growth of cyanobacteria. CP_L decreased PO_4^{3-} uptake rate substantially in *N. muscorum* and *P. foveolarum*, CP_H dose inhibited the rate more vigorously in both the tested cyanobacteria. When UV-B_L combined with any of the CP doses, substantially improved the CP induced inhibitions in PO_4^{3-} uptake rates.

Cyanobacteria assimilate phosphate at a much faster rate and accumulate large amounts of reserve phosphate for an extended growth period at low phosphate concentrations. The characteristic feature of cyanobacteria is the production of phosphatases. When the level of phosphate declined, the cyanobacterial cells induced formation of alkaline phosphatase (ALP; in periplasm) and acid phosphatase (ACP; in cytoplasm) and their activity provide soluble form of phosphate for growth of cyanobacteria.

ALP and ACP activities were increased following CP_L or CP_H treatments individually. While UV-B_L could not able to alter ACP activity significantly, it substantially enhanced ALP activity. After 72 h of experiment, uniform reduction was recorded in ALP and ACP activities in all samples (except UV-B_H treated tested cyanobacteria and UV-B_L induced ACP activity in *N. muscorum*). Low dose of UV-B whenever combined with any of the CP doses, an enhanced ALP and ACP activities were obtained. Contrary to UV-B_L, when UV-B_H was given along with any of the CP doses, ALP and ACP activities were lowered appreciably.

Cyanobacteria are exposed to different types of stresses such as metal toxicity, UV-B, pesticides, temperature, ozone etc. A common feature of different stress factors is their potential to increase the production of ROS such as singlet oxygen \( (^{1}\text{O}_2) \), superoxide radical \( (\text{SOR}; \text{O}_2^{-}) \), hydrogen peroxide \( (\text{H}_2\text{O}_2) \) and hydroxyl radical \( (^{\cdot}\text{OH}) \) in cells by altering metabolic processes. Although some of them may function as important signaling molecules that alter gene expression and modulate the activity of specific defense proteins, however, all ROS can be extremely toxic to organisms at high concentrations which result into oxidative stress. Besides, photosynthetic electron transport chain,
respiratory electron transport chain has also been reported to be a major source of ROS production. Oxidative stress may occur either due to the overproduction of ROS or due to the decrease of cellular antioxidative levels. Oxidative stress is essentially a regulated process, the equilibrium between oxidative and antioxidative capacities determines the fate of aerobic organisms. It has been shown that production of ROS during environmental stresses such as excessive usage of pesticides and exposure of UV-B radiation is one of the main causes for decrease in productivity, injury and death. Thus, considering important role of ROS in physiology and cell biology of organisms including cyanobacteria, the impact of low and high fluence rates of UV-B on the generation of ROS i.e. SOR and H$_2$O$_2$ and their consequent damages to lipids and proteins have been investigated in detail.

The amount of H$_2$O$_2$ and SOR progressively increased after the treatment of CP$_L$ or CP$_H$ doses of chlorpyrifos, which decreased significantly after the simultaneous exposure of UV-B$_L$, but after the simultaneous exposure of UV-B$_H$ it got increased considerably. While UV-B$_H$ alone was able to generate the substantial amount of H$_2$O$_2$, any notable increase was not noticed with UV-B$_L$. SOR and H$_2$O$_2$ contents showed similar trends, however, H$_2$O$_2$ level was too higher than SOR. Further, results revealed that SOR and H$_2$O$_2$ contents were higher in N. muscorum than P. foveolarum.

Lipids and proteins are integral components of biological membranes and discharge wide array of functions in cells. Therefore, peroxidation of lipids and oxidation of proteins by ROS may alter their functions. Alterations in ROS production/accumulation were manifested in the form of increased amount of lipid peroxidation and protein oxidation. Malondialdehyde (MDA) which is an indicator of lipid peroxidation and reactive carbonyl group (RCG) which is an indicator of protein oxidation were significantly raised by CP treatments. UV-B$_H$ alone also significantly enhanced MDA and RCG levels. Furthermore, combined treatments of CP and UV-B$_H$ further accelerated accumulation of MDA and RCG compared to their individual treatments. Results revealed that MDA and RCG levels were higher in N. muscorum.
contrast to UV-B\(_H\), UV-B\(_L\) dose alone did not significantly influence MDA and RCG levels in both the cyanobacteria but together with CP significantly lowered MDA and RCG contents when compared to CP treatments alone.

To mitigate ROS induced damage to macromolecules, organisms have naturally been equipped with diverse array of antioxidants. Antioxidants are of two types \textit{i.e.} enzymatic antioxidants such as SOD, CAT, POD, GST, APX, GR, DHAR etc. and non-enzymatic antioxidants such as ascorbate, glutathione, non-protein thiols, cysteine etc. Thus, considering their important role in mitigating negative consequence of ROS, in the present study, the impact of low and high fluence rates of UV-B on antioxidant capacity of both the cyanobacteria under low and high doses of chlorpyrifos has been investigated in detail.

The increase in SOD and POD activity was noticed in both the organisms exposed to CP doses and UV-B\(_H\) alone and together after 24 as well as 72 h of experiments. As evidenced from data of MDA, RCG and different growth parameters, increase in SOD and POD might not be sufficient to scavenge ROS properly. In contrast to above, GST activity reduced significantly in CP\(_H\) treated \textit{N. muscorum} cells and was recovered only after 72 h. UV-B\(_L\) was also not successful to overcome the decrease in these samples. UV-B\(_H\) dose produced significant decline in CAT activity. Combined treatments of CP\(_H\) and UV-B\(_H\) further deteriorated CAT activity when compared to their individual treatments. In contrast to UV-B\(_H\), UV-B\(_L\) dose alone significantly stimulated CAT activity and with CP\(_H\) alleviated CP\(_H\)-induced inhibition in CAT activity. Thus, it can be presumed that UV-B\(_L\) induced up-regulation of CAT activity may be one of the reasons for alleviation of CP stress through proper scavenging of H\(_2\)O\(_2\). Results also revealed that inhibition in CAT activity was higher after 24 h of experiment than that recorded after 72 h of experiment which indicated CAT activity is playing a prominent role during acclimation of both the cyanobacteria to CP\(_H\) and UV-B\(_H\) stresses.

CP\(_L\) and UV-B\(_L\) both significantly stimulated AsA-GSH cycle enzymes. On the other hand, CP\(_H\) and UV-B\(_H\) posed inhibitory effects by inhibiting AsA-GSH cycle
enzymes. Inhibitions in CPH or UV-Bt treated samples were significantly prevented when they were additionally supplemented with UV-BL and CP2 (after 72 h), respectively enhancing AsA-GSH enzymes and related metabolites which manifested in terms of biomass accumulation. However, AsA-GSH cycle enzymes were more affected in N. muscorum. Further, results also revealed that under CPH and UV-Bt treatments, APX, GR and DHAR activity were higher after 72 h than recorded after 24 of experiments which indicated that these enzymes help in acclimation of the organisms to CP and UV-Bt stress by scavenging H\textsubscript{2}O\textsubscript{2}, providing GSH and AsA, respectively.

Ascorbate is a crucial non-enzymatic antioxidant involved in defense against oxidative stress. Ascorbate can directly scavenge 'O\textsubscript{2}, O\textsubscript{2}•– and •OH and protect organism against oxidative stress. Reduced ascorbate acts as a substrate for APX in removing H\textsubscript{2}O\textsubscript{2} and this system of ROS removal has been regarded as the most precious strategy for photosynthetic organisms to avoid oxidative stress. Glutathione is also a powerful non-enzymatic antioxidant involved in redox regulation and directly scavenging of various ROS. Glutathione is the most abundant low-molecular-weight thiol in cells and it constitutes a redox buffer which keeps the intracellular environment reduced. Glutathione may assist in scavenging ROS by providing electrons to ROS scavenging enzymes such as glutathione peroxidase, GST, peroxidases of peroxiredoxin family etc.

CPH and UV-Bt alone and together significantly decreased AsA, and AsA/DHA ratio; GSH and GSH/GSSG ratio. This decrease was more in N. muscorum. In contrast, UV-BL dose together with CP kept high both AsA and AsA/DHA ratio; and GSH and GSH/GSSG ratio compared to CP treatments alone and this might be one of the reasons that UV-BL reduced CP induced oxidative stress. Under CPH and UV-Bt treatments, comparatively higher levels of AsA and AsA/DHA ratio and GSH/GSSG ratio after 72 h of experiment than those recorded after 24 h of experiment further explain reasons for acclimation processes in both the cyanobacteria against CPH and UV-Bt stress.

Cysteine is also an important thiol being constituent of NP-SH and phytochelatins, and plays important role in regulation of oxidative stress. CP2 dose was able to increase the cysteine content in both the cyanobacteria after 24 h as well as 72 h
of experiment, while CP\textsubscript{H} caused inhibition in cysteine level. Contrary to most of the results, cysteine content was badly affected by UV-B\textsubscript{L} in \textit{P. foveolarum}. But, interestingly when UV-B\textsubscript{L} combined with CP\textsubscript{L} dose, the induction in cysteine level was recorded and CP\textsubscript{H} dose induced decrease was recovered in case of \textit{N. muscorum} only. Being inhibitory, UV-B\textsubscript{H} further inhibited CP\textsubscript{H} induced inhibition in cysteine level.

Non-protein thiols (NP-SH) have potential role in mitigating abiotic stresses due to their ability to form complexes with xenobiotics and other peroxidative products of lipids and proteins induced either by pesticides or by UV-B to make them non-toxic. NP-SH level decreased by CP\textsubscript{H} as well UV-B\textsubscript{H} treatments after 24 h of experiment in \textit{N. muscorum}, however, after 72 h of experiment increased level of NP-SH was noticed indicating the important role of NP-SH in mitigating CP and UV-B\textsubscript{H} stress.

In the present study an attempt has been made to understand that how low and high fluence rates of UV-B (UV-B\textsubscript{L} and UV-B\textsubscript{H}) differentially modulated the chlorpyrifos (CP) induced alterations in physiology, biochemistry and overall metabolism of the two tested paddy field cyanobacteria– \textit{N. muscorum} and \textit{P. foveolarum}. UV-B\textsubscript{L} stimulated only protective mechanism. The study physio-biochemically establishes that the low fluence rate of UV-B (UV-B\textsubscript{L}) can have totally different impact in comparison to its higher fluence rate (UV-B\textsubscript{H}). Similarly low concentration of the insecticide chlorpyrifos (CP\textsubscript{L}) also proved to be stimulatory because of inherent capacity of the microorganisms to degrade complex organic compounds into simpler form which may get available to the microorganisms. CP\textsubscript{L} and UV-B\textsubscript{L} treated cyanobacteria showed lesser increment in ROS, thereby either less or no damage to biomolecules– lipids and proteins and enhancements in various enzymes including AsA-GSH cycle enzymes, which ultimately manifested into enhanced biomass accumulation. On the other hand, in response to higher concentration of chlorpyrifos (CP\textsubscript{H}) and higher dose of UV-B (UV-B\textsubscript{H}), the ROS accumulation was much high which caused damage to biomolecules and thus resulted into significant loss in biomass. But, when CP\textsubscript{H} was supplemented with UV-B\textsubscript{L}; or UV-B\textsubscript{H} was supplemented with CP\textsubscript{L}, the stressed condition got alleviated.
significantly by significant lowering in ROS along with considerable improvement in these enzymes and metabolites. Further, the resistant nature of *P. foveolarum* in comparison to *N. muscorum* against CP\textsubscript{H} and UV-B\textsubscript{H} may be attributed to lesser accumulation of ROS and higher inherent level of different enzymes and metabolites along with their activities which are cumulatively translated into biomass.

In fact, in practice, sustainability depends on continually developing new pesticides that keep at least one step ahead of the pests—pesticides that are less persistent, biodegradable and more accurately targeted at the pests. Pesticides and UV-B are notorious for causing oxidative stress, also evident from our results, but on the other hand, as a part of Integrated Pest Management Programme (IPMP), if the pesticides are used prudently under low level of environmental pollution (in the present study, represented by low dose of UV-B *i.e.* UV-B\textsubscript{L}), this will not only prevent our food crops from damage but also the beneficial microbial activity will not be affected.