Impact of Solar UV-B on Tropical Ecosystems and Agriculture. Case Study: Effect of UV-B on Rice

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Abstract

The Sun is essential for sustaining the life on the Earth, via the process of photosynthesis. However a small proportion of solar spectrum contains short-wavelength ultraviolet-B light (280-320 nm), which is deleterious to life. The depletion of stratospheric ozone layer by man made pollution has substantially increased UV-B light impinging on the earth surface. UV-B affects living organisms by damaging cellular metabolism in several ways, such as dimers formation in the genetic material DNA, inactivation of enzymes, disruption of membrane structure and generation of highly reactive "free radicals". Elevated UV exposure also causes temporary or irreversible damage to process of photosynthesis. Therefore, increased UV-B radiation would affect the stability of ecosystems and genetic health of living organisms. The increased UV-B radiation can lead to altered food supply, as many crops including staple crops such as rice have been shown to be adversely affected by increases in UV-B radiation. Many species of plants have evolved mechanisms for protection against deleterious effects of UV-B radiation. Accumulation of the UV-B absorbing pigments such as flavonoids is one of the ways by which plants alleviate the harmful effects of UV-B light. Examination of photoinduction of anthocyanin in different rice cultivars showed that few of them like purple puttu show UV-B mediated induction of anthocyanin formation, a colored flavonoid. *In vitro* experiments revealed that anthocyanin can also complex with DNA and protect it against oxidative damage. It is highlighted that there is an urgent need to breed new varieties of crop plants, which are tolerant to UV-B radiation.

Introduction

The solar energy from sun is essential to support the life on our planet. However, the sunlight also contains a small amount of short wavelength ultraviolet (UV) light irradiation, which harmful to the life on the planet. Fortunately most of this harmful UV irradiation is filtered out by the stratospheric ozone layer, which strongly absorbs UV light. Unfortunately this protective shield is being continually damaged by human activity. During the past sixty years the ozone layer has been damaged by release of ozone depleting substances (ODSs), such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl bromide (MeBr) and other industrial compounds containing halogens (Kerr, 1988). These ODSs which are stable molecules are carried up to the stratosphere where they decompose under UV light and sets a chemical chain reaction leading to ozone layer destruction. The depletion of ozone layer has reduced its ability to absorb UV-B radiation, particularly that of UV-B (280-320 nm), and consequently there has been a significant increase in the UV-B radiation impinging on earth.

UV-B exposure to living organism has several harmful effect, among which its capacity to induce the genetic mutations is the foremost. Therefore the increase in UV-B radiation would affect the genetic health of all living organisms in the biosphere. In addition the photochemical damages caused by it would also affect quality of the air, nature of the weather to name a few. In brief the increase in UV-B would endanger all forms of life and could have devastating effect by reducing the yield of crops and fisheries. Inspite of the concern raised about the damaging effect of UV-B radiation on the quality of life on the planet, the information of its impact on overall ecosystem is limited.

Effect of UV-B on Human Health

Most concern about the increased incidence of UV-B in the biosphere has come from its impact on human health, particularly with increased chances of skin cancer (Lefell and Brash, 1996). Increase UV-B radiation would increase the frequency of malignant as well as non-malignant skin cancers. It has been reported that occurrence of non-melanoma a common form of skin cancer has increased by about 10% in Northern Hemisphere between 1979 to 1993. The UNEP has forecasted that a 1% depletion of ozone layer may increase skin cancer by 2%. UV-B can also potentiate the malignant melanomas, which effect the pigment cells in the skin. These malignant cells can spread throughout the body via blood and lymphatic system. It is believed that the darker skinned individuals are less susceptible to UV-B radiation. However, dark skin does not completely protect against UV-B radiation, only dark skin requires a greater dosage of UV-B than white skin to trigger immune suppression. In addition the increase UV-B radiation is also linked to elevated risk from diseases caused by the herpesviruses, contact dermatitis and toxic photodermatitis etc. The pentrance of UV-B radiation in lower layers of the atmosphere sets off a chain of chemical reactions particularly over the major cities or industries, where incidence of air pollution is high. In lower strata of atmosphere UV-B interacts with the pollutants causing a photochemical smog. The smog also includes the acidic compounds formed from emissions of sulfur and nitrogen oxides. These compounds eventually fall to earth as acid precipitation and also responsible for causing and enhancing respiratory diseases.

Effect of UV-B on Food Supply

While the effect of UV-B radiation on human health is widely researched and acknowledged, its effect on the other components of the ecosystem also needs similar attention. Its effect on the crops can be of more dreadful consequences in view of the research showing that the UV-B radiation reduces the economic yield of crop plants. Moreover it can also affect the quality of nutrition which would have indirect impact on human population through alterations in the food supply. Several agricultural crops including varieties of important crops such as rice (Hidema *et al.,* 1997) have been shown susceptible to increases in UV-B radiation. The UV-B effects on these varieties are manifested as losses in yield and higher susceptibility to stress and damage from drought and disease. The loss of yield of the crops would of serious consequences in developing counties where the food supply is already in shortfall due to increasing population. It is predicted that every 1% increase in UV-B radiation would similarly reduce the crop yield by 1% (Coohill, 1991). Moreover in many rural economy the people are dependent on local plants and animals for their food sources, where reduction in food supply would put considerable strain on the society.

Impact of UV-B on Tropical Ecosystem

The role of UV light as disinfectant is well known, which results from its capacity to induce the mutations in the genetic material DNA. It is known that increased UV-B radiation alters the metabolism of living organisms in many ways such as destruction of the DNA, inactivation of enzymes, disruption of membranes and the generation of highly reactive "free radicals". Even though the DNA damage can be repaired by the existing repair mechanisms not all the organisms are endowed with an efficient repair system. There is always a possibility to retain few mutations, which may be passed on to the next generation, thereby affecting genetic health of the organisms. Most often the cellular damage caused by the free radical generation is irreversible and causes an enormous harm to the organisms. Moreover the interaction between these processes can induce a range of adverse effects on living organisms.

In an ecosystem the effects on plants in the marine, freshwater and terrestrial terrain is of paramount fundamental importance because plants are primary producers in the food chain (Williamson, 1995; Dunne and Brown, 1996). The plant structure is optimized to perform photosynthesis, which needs direct exposure to the sunlight. Consequently, plants are also simultaneously exposed to harmful UV-B exposure. It is known that the increased UV-radiation causes reduction in the photosynthetic efficiency (Nogu and Baker, 1995) and can also damage the genetic material present in nuclei and organelle (Taylor et al., 1996). In addition UV-B radiation disables the processes of cell division and alters the pattern of plant growth and development such as dormancy and flowering. The reduction in the yield of plants has a cascading effect on food supply of entire food chain endangering the balance of entire ecosystem. The defense responses of the plants are also weakened and there is evidence that UV-B radiation can enhances the pathogenicity of the organisms such as fungus. Investigations on the photosynthetic rate of Loblolly pine have shown that decrease in ozone levels results in reduction in its productivity (Sullivan and Teramura, 1989). Additionally the effect of UV radiation on the microbes present in forest litter, soil and associated with other organism can also alter the delicate balance of ecosystem (Klironomos and Allen, 1995) The information on possible impact of UV-B radiation on animals is more limited. The impact is likely to be two prong first one on the genetic health of the organism and second one an indirect effect on food chain. Similar to human beings the primary target is the skin, but it is believed that the animals are more susceptible in their juvenile stages.

The consequences of these changes in the ecosystem merit a detailed study but several of the effect can be foreseen in advance. For example the reduced yield of plants would reduce the food supply of the ecological niche, which would in turn affect the distribution of species within a given ecosystem. The potentially harmful effect of enhanced UV-radiation has been first noticed with reference to amphibian populations particularly of frogs.

UV-B Radiation and Population of Frogs

In many parts of the world the frog population is rapidly declining which have triggered an intensive study on its causes. Several factors have been attributed to these phenomena such as modification and destruction of habitats like forests and wetlands, excessive runoff of fertilizers and pesticides in the water bodies etc. However, one of the major reason for the decline of certain species could be the fact that the eggs of these species are susceptible to UV-B mediated genetic damage. Normally the DNA of living organisms is protected from UV-B damage by action of an enzyme called DNA photolyase, which repairs the damages in the DNA. However, in the species prone to UV-B damage, they produce little DNA photolyase. Consequently a large number of eggs are destroyed resulting in falling population. In addition it is speculated UV-B also impairs defense mechanism of eggs and embryos thereby allowing pathogens such as *Saprolegnia*, to infect the eggs. Likewise, UV-B by killing insect larvae on which frogs feed further accelerates the decline by reducing food supply.

In a study conducted by Andrew R. Blaustein (1995) of Oregon State University, hatching of the embryos of long-toed salamanders was compared with or without UV-B exposure. The embryos were exposed to UV-B free radiation by filtering light through Mylar filters, while the second group was exposed directly to UV-B light. It was found that while the 95% of the shielded embryos hatched, only 14.5% of embryos survived UV-B exposure. Moreover 91.9% of UV-B exposed embryos had morphological deformities compared to a meager 0.5%, of the shielded embryos. Since many amphibian species lay their eggs in open, shallow water they are highly susceptible to UV-B damage. The survival of amphibian species has been linked to *in vivo* levels of DNA photolyase. The species with the high DNA photolyase activity show lower mortality rates of embryos.

Effect of UV-B on Crop Plants

The farmers are normally concerned with the economic yield and take steps to optimize the yield of the planted crops, by taking measures against pathogen, pests and drought etc. However, such measures can not be applied to omnipresent stress such as UV-B, which is the part of the sunlight itself. Increased solar UV-B lead reduction in photosynthesis (Jansen et al., 1996) and production of some crop species (Teramura and Murali, 1986). More serious threat to crops is due to the indirect effect UV-B radiation that can alter the competitive balance in many pairs of competing species (Caldwell *et al.*, 1989). Comparative studies with wheat and its weedy competitor, wild oat revealed that UV-B altered competitive balance between the two species by inducing changes in plant morphology which changed the competition for light (Barnes *et al.,* 1988). In soybean two cultivars under enhanced UV-B light showed differing sensitivities with reductions yield by 19-25% for Essex, while another cultivar Williams was unaffected (Teramura and Murali, 1986). The effectiveness of UV-B radiation was also affected by microclimatic factors such as precipitation and temperature.

UV-B Effects on Forests

The information on effect of UV-b on forest species is very limited. In one study the effect of exclusion of UV-B radiation was studied on growth of four broadleaf species. The removal of UV-B radiation enhanced the growth but additional UV-B irradiation to natural light had no effect on growth of Spruce or pine (Kaufmann, 1978). The studies conducted supports the view that the UV-B radiation is deleterious to tree growth and physiology (Sullivan and Teramura, 1988). A study on 15 species of conifers showed that, 7 were deleteriously affected, 5 were resistant, and for 3 growth was stimulated by UV-B radiation (Sullivan and Teramura, 1988). However, a leading commercial species Loblolly pine was found to be one of the most susceptible species.

Little information exists on effect of UV-B on natural plant communities, such as annuals and other perennials. Moreover the UV-B dose in places such as tropical mountains can be six-fold greater than at arctic (Caldwell *et al.*, 1982). It is expected that the plants on higher altitudes, which receive high UV-B radiation, would be more adapted to protect them from the deleterious effects of UV-B. Barnes *et al.* (1987) showed that plants from tropical mountains were resistant to UV-B by having more flavonoids in epidermis, which protects plants from UV-B radiation. In addition they also possessed a more resistant photosynthetic apparatus to UV-B.

In a study on seeds collected for 132 species growing over a 3,000 m elevational gradient in Hawaii it was found that the UV-B tolerance was markedly higher in species which grew on higher elevations. Interestingly all species growing above 2,000 m were found to be tolerant of UV-B radiation, indicating that the higher exposure to UV-B make the plant resistant.

Effect of UV-B on Rice

Rice is one the world's most important food crop and grown mostly in tropical and subtropical countries. It is known that UV-B radiation is highest in tropical regions where rice is grown, because the stratospheric ozone layer is high latitudes, and solar angles are higher. Rice is the staple food for over half the humanity and at least for 3 billion people in Asia depend on rice for their daily food, which consists mostly of developing countries (Singh, 1993). Eventhough rice is a staple food crop, and the reduction in its yield by UV-B can have adverse consequences in developing countries, there are only few studies on the effects of UV-B radiation on this species (Olszyk *et al.*, 1995). The current information on rice is insufficient to conclude the potential risks of UV-B exposure to rice production. UV-B radiation would also have indirect effects on rice production through indirect effects on other components of rice ecosystem such as weeds, diseases and nitrogen-fixing cyanobacteria. The competition from weeds can reduce rice yield and it is known that UV-B alters the competitive balance between crops and weeds (Barnes *et al.*, 1988).

Teramura *et al.* (1991) showed that the in creased UV-B radiation induces a significant reduction in the total biomass in a number of rice cultivars, accompanied by a reduction in tiller number and photosynthetic capacity of plants. The prolonged exposure of UV-B light affects plant height, leaf area, dry weight, net assimilation rate and relative growth rate in some rice cultivars (Ziska and Teramura, 1992; Dai *et al.*, 1992). Accumulation of the UV-B-absorbing pigments is one of the ways by which plants alleviate the harmful effect of UV-B light (Caldwell *et al.*, 1983; Beggs *et al.*, 1986). The UV-B light-absorbing flavonoids are implicated as protective pigments in shoots and leaves exposed to UV-B light, and their specific location in epidermal layer protects internal cell layers by attenuating the impinging UV-B radiation at the epidermis (Tevini *et al.,* 1991; Braun *et al.,* 1993). It has been shown that the photo-induced accumulation of these flavonoids is preceded by an induction of several enzymes of phenylpropanoid biosynthetic pathway such as phenylalanine ammonia lyase and chalcone synthase of flavonoid biosynthetic pathway (Hahlbrock *et al.,* 1989; Schmelzer *et al.,* 1989). Information on the presence of UV-B absorbing pigments and their role in ameliorating the harmful effect of UV light in rice is scanty. A few investigations have reported that UV-B treatment increases the amount of UV-absorbing pigments in some rice cultivars (Ziska and Teramura, 1992; Dai *et al*., 1992). Since an increase in the level of UV-absorbing compounds may offer protection against the potential UV-B damage, information about the presence and regulation of biosynthesis of these pigments is highly valuable in selecting rice cultivars with increased resistance to UV-B radiation.

In a study conducted, we provided evidence for that UV-B mediates photoinduction of anthocyanin synthesis in seedlings of a cyanic rice cultivar, purple puttu, which is associated with PAL biosynthesis (Reddy *et al.,* 1994). We observed that sunlight triggered the photoinduction of anthocyanin in shoots of purple puttu seedlings, whereas seedlings exposed to sunlight filtered through window glass showed little formation of anthocyanin. Since window glass cuts off the wavelengths shorter than 320 nm (Klein *et al.,* 1979), we proposed that the induction of anthocyanin was primarily mediated by the UV-B light present in sunlight. In addition to UV-B receptor the anthocyanin level was also modulated by phytochrome. The exposure of seedlings to far-red light (730 nm) reduced anthocyanin level induced by UV-B, which was reversed by following with a red light (660 nm) exposure. However, the anthocyanin photoinduction was restricted to only a few cultivars of rice (**Table 1**), indicating variability within the cultivars with respect to anthocyanin induction. We also observed that sunlight induced two distinct phases of phenylalanine ammonia lyase, the first one by phytochrome and second one by UV-B receptor.

Table 1.
Classification of some rice cultivars from India on the basis of anthocyanin pigmentation. It is likely that a cyanic variety may be more resistant to UV-B induced damage. The studies on resistance of cyanic varieties to UV-B light may help breeders to generate UV-B resistant rice cultivars (After Reddy *et al*., 1994)

Cyanic	Moderately Cyanic	Acyanic
Purple puttu	TN1013	Black puttu
G2237	Crossa	White puttu
R27(P)	G967	N22
		Hamsa

Although, at the moment, no conclusive data are available on the possible protection of rice seedlings from UV-B radiation by anthocyanin and other UV-B-absorbing compounds, the available information implies such a role (Robberecht and Caldwell, 1986; Tevini *et al*., 1991). For instance, seedlings of certain Arabidopsis mutants deficient in flavonoids including anthocyanins are hypersensitive to UV-B radiation (Li *et al.,* 1993) and exhibit a lethal response, suggesting that the UV-B-absorbing compounds play a protective role. Similarly, the *Rumex patientia* plants are more sensitive to UV-B damage than *Rumex obtusifolius* which have a higher level of UV-B-absorbing compounds in the epidermal layers (Robberecht and Caldwell, 1986). It can be argued that the UV-B-induced anthocyanin pigmentation in rice seedlings may have a role in minimizing the UV-B damage. More direct physiological and molecular genetic data on anthocyanin synthesis and regulation in rice are essential to evolve a strategy to protect this important crop plant from an impending threat of enhanced UV-B radiation in the biosphere.

The stresses imposed by UV-light (Shibata *et al*., 1991) irradiation can cause reactive oxygen species generation(ROS) such as O_2- and H_2O_2. Though H_2O_2 is an innocuous metabolite present in cells irradiation with UV-light breaks it down to extremely deleterious hydroxyl free radicals ($OH^•$). Since H_2O_2 can easily diffuse through cell membranes it is extremely deleterious to cellular constituents such as DNA. Several studies have indicated that *in vitro* anthocyanins could act as effective antioxidants (Sarma *et al.,* 1997). In rice we examined if anthocyanin can scavenge free radicals by acting as potent antioxidants. It is known that anthocyanin can make complexes with other molecules- copigment (Brouillard, 1983) and such complexation can protect partner compounds against oxidative damages. For example we observed that anthocyanins prevent AsA against metal induced oxidation by forming a stable AsA-metal-anthocyanin co-ordinate complex (Sarma *et al.,* 1997). Above complex protects AsA from H_2O_2 and $OH^•$, but also protects anthocyanins from damage.

We found that purified DNA molecule can make a complex and act as copigment to anthocyanin. When cyanidin-DNA copigment complex was subjected to hydroxyl radical dependent oxidation it showed no bleaching and shoed a 10-15 nm bathochromic shift to longer wavelength . Our results indicated that once cyanidin complexes with DNA, it is no longer accessible to the nucleoplilic attack by the $OH^·$ radical. To test whether cyanidin complexed with DNA can afford protection to DNA from $OH^·$ radical attack, we exposed the free DNA as well as the DNA complexed with cyanidin derivative to the Fenton reaction. We found that the complexation of cyanidin to DNA significantly decreased the DNA damage in vitro. Since in plant cell anthocyanins are predominantly localized in the vacuole their putative role as antioxidant in the cytosol has not been critically examined. Considering the fact that anthocyanins are synthesized in the cytosol and then transported to vacuole (Marrs *et al.,* 1995), it is likely that some amount of anthocyanin may exist in the cytosol In fact, a significant amount of flavonoids has been detected in chloroplast or etioplast isolated from a wide range of plants (Rice-Evans *et al*., 1997).

It has been suggested that under conditions like exposure to high light irradiance, especially, UV light resulted in increased DNA damage measured as decrease in transcription rate and an increase in cyclobutane dipyrimidine dimers. For example, the DNA in *Zea mays* plants that contain flavonoids (primarily anthocyanins) is protected from the induction of damage caused by UV radiation relative to the DNA in plants that are genetically deficient in these compounds (Stapleton and Walbot, 1995). It was proposed that these compounds apparently function as UV filters, since they absorb in the UV region of the spectrum. Thus, results obtained in this study, that both cyanidin and DNA mutually protect each other when present together is a strong indication that in addition to the ability of anthocyanins to function as effective filters for attenuation of ionizing events are also an effective terminator of these events.

Conclusions

The consequences of increase in UV-B irradiation on the growth, productivity of crops in developing nations are largely ignored. UV-B radiation is reported to be harmful to plants in many ways, and the reduction in their yield by UV-B can have adverse consequences in developing countries. One way plants can protect themselves against UV-B light is by induction of DNA photolyase which can repair the UV-B damaged DNA. However, the information regarding the role of the DNA photolyase in protection against the UV-B effect in plants is very limited, but there is an evidence that UV-B sensitive rice cultivars are deficient in DNA photolyase (Hidema *et al.*, 1997). It would be ideal to use biotechnology to generate transgenic plants with high DNA photolyase activity. One of the cost-effective approach to protect plants against deleterious effects of UV-B radiation is to select cultivars with high level of the UV-B absorbing pigments in the epidermal cell layers. These pigments can protect shoots and leaves exposed to UV-B light, and their specific location in epidermal layer would protect internal cell layers by attenuating the impinging UV-B radiation at the epidermis. In addition these pigments can act as an antioxidant and complex with DNA and protect it against oxidative damage. It is highly essential now that the possible strategies to protect important crop plants from impending threat of enhanced UV-B radiation in the biosphere are planned and implemented.

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