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UV radiation and temperature effect on different species of aphids behavior and mortality in Uttarakhand

Sunil Kumar*, Deepa Saini
[1] Gurukul Kangri University Haridwar, Haridwar, Uttarakhand, India
[2] Department of Zoology, D.A.V (PG) College Dehradun, Dehradun, Uttarakhnd, India

Abstract
The potential threat of rising ultraviolet (UV) radiation levels at the Earth's surface due to ozone depletion has led to the demand for worldwide measurement of UV radiation. Ultraviolet radiation directly regulates insect life processes and indirectly affecting changes in insect chemistry and morphogenesis. Aphids are the pest of many vegetables, fruits, ornamental plants and crops. They feed plant nutritive sap and affects the plant growth and productivity. Increasing temperature and UV-B radiation is a critical abiotic stressors affecting insect biology. Measurement of solar ultraviolet radiation was performed in Uttarakhand. Morphological, behavioural changes, fecundity and mortality rate was observed in different aphids species after exposure of different temperature and intensity of Ultraviolet- B irradiation in this communication.

UV- B radiation show seasonal, diurnal and altitudinal variations in uttarakhand. Ultraviolet-B radiation exposure in aphids show stunted growth, morphological changes, low reproduction and high mortality up to 51%. Change in catalase and superoxide dismutase enzyme level was observed. UV-B was found more harmful with increasing temperature. Results indicate that high intensity of UV-B radiation and increase in temperature show toxic effect on aphids population diversity and dispersal. Mustard aphid (*Lipaphis erysimi*) and cabbage aphid (*Brevicoryne brassicae*) was found more sensitive than pea aphid (*Acyrthosiphon pisum*) and rose aphid (*Macrosiphum rosae*). Climate change and temperature increase affect the aphids development and population growth. High intensity of UV radiation exposure at high temperatures significantly lowered the aphids population. Increasing temperature directly affect small insects like aphids, by altering their behaviour, metabolic rate and physiological processes. UV-B radiation alters biochemical cellular integrity in aphids, which also affect their life cycle.

Keywords: UV-B, catalase, aphids, photosensitivity, climate change, agriculture pest

Introduction

Climate change is predicted to cause a global increase in temperature due to the thinning of the ozone layer leading to higher UV-B radiation reached to the earth surface. Aphids show a dynamics of complex associations with increasing UV radiation and they may be show decline respond to long term environmental changes, high temperature and high intensity of UV radiation (Hance *et al*., 2007) [21]. In recent years solar Ultraviolet radiation (UV) has received higher attention due to ozone depletion and increase in temperature at the earth surface. UV- B radiation represents a small but important part of the solar spectrum, it notably affects many biological and photochemical processes, being quite harmful to organisms (Neale *et. al*., 2021) [31]. Long-term UV radiation exposure very harmful to humans, that causes skin cancer, cataracts and a dangerous weakening of immune functions (Diffey, 1991).

Ultraviolet radiation, which composes a small part (8.03%) of the incoming solar light at the earth surface (Iqbal, 1983), is usually divided into three bands according to its biological effects: UV-C (100–280 nm), completely absorbed by the ozone layer and oxygen before reaching the Earth's surface, UV-B (280–315 nm) partly absorbed by the ozone, and UV-A (315–400 nm), weakly absorbed by the ozone and mostly arrives at the Earth surface (Lee *et. al*., 2020) [29]. UVB is the most detrimental band contributes less than 10% to total UV irradiance at ground level (Diffey, 1991). This effect is due to the high sensitivity of living organisms to radiation with a wavelength lower than 315 nm (Serrano *et. al*., 2006) [37]. Temperature is also a critical abiotic factor affecting insect biology. Temperature-based reaction are most essential analytical tools for evaluating, understanding, and predicting the phenotypic variation in insects (Baker, 1991; Jarvis & Baker, 2001) [3, 25]. The increasing temperature increase the metabolic activity of aphids, *B. brassicae* (Govindasamy, *et. al*., 2003; IPCC, 2014) [23]. Environmental factors modify the insects physiology and behavior this response termed as the phenotypic plasticity (Pigliucci, *et. al*., 2006) [33] controlled by several physiological mechanisms (transcription, translation, enzyme, and hormonal regulation) that produce local or systemic responses (Whitman & Agrawal, 2009) [43]. The primary challenge Global warming, faced by ecologists is to predict variation that occurs on the biology of ectothermic organisms (Brodeur *et al*., 2013). UV-B radiation impact herbivorous insects through host plant interaction. Infestation of aphids in high number can change plant biochemistry. High numbers of aphid progeny on low-UV-B plants led to decreased indolyl glucosinolate concentrations. Induced change in indolyl glucosinolates depend on the threshold infestation. UV-B radiation impacts on plant traits and also affect phloem feeding aphids, whereas high growth of aphid forces some plants to generate specific defense responses (Kuhlmann and Müller, 2010) [28].

Aphid species found all over the world and specifically in all the temperate regions. Species variation is higher in temperate regions, than tropical regions. They migrate over long distances. The lifespan of aphid species is only about 20 to 40 days. Their excessive reproduction rate compensates for the short lifespan and maintains their population. The life cycle of various aphid species varies widely. Reproduction involves asexual as well as sexual reproduction. Aphids are ectothermic organisms; all their physiological processes largely depend on several climatic variables that include temperature (Brodeur *et al*., 2013). Aphid pests occurs throughout the temperate region of the world, causes direct damage by sucking plants sap which affects growth and yield of the crops (Gulidov & Poehling, 2013) [20]. Aphids are feed on plant sap. Plants exhibiting aphid damage have variety of symptoms, such as decreased growth rates, mottled leaves, yellowing, stunted growth, curled leaves, wilting, low yields and death. Lack of sap creates lack of vigour in the plant, and aphid saliva is toxic to the plants. Aphids frequently transmit disease causing organisms like plant viruses to their hosts (Nichols, 2007) [32].

Temperature directly affects small insects like aphids, drosophila, and mosquito by altering their behaviour, metabolic rate and downstream cellular and physiological processes (Bale *et al*. 2007) [4]. Aphids have a complex life cycle and feed on different plants species. Some of aphid species are host alternating species while others live and multiply on particular host. Complex life cycle of aphids involves morphologically distinct forms and parthenogenesis generation alternating with asexual generation and about 10% is associated with host alternation (Foottit *et al*, 2008) [18]. Aphids formed colonies on the stems, petioles, and leaves of their host plants and causes different damages (Christelle, 2007 and Eaton, 2009) [7, 15] and that damaged grouped into two categories: (a) direct damage due to the host sap absorption; and (b) indirect damage: associated with the transmission phytopathogenic viruses (Blackman & Eastop, 2000) [5] and the ejection of honeydew causing fumagine formation that affects photosynthetic activity. Under severe infestation, reduces the production of plant productivity from 70% to 80% (Khattak, *et. al*., 2002) [27]. Continuous increases in atmospheric CO2 and global air temperature are directly to influence insect plant interactions. Plant traits important to insect, such as nitrogen content, directly affected by elevated CO2 and temperature, while insect are directly affected only by temperature. Direct UV-B radiation and increased temperature formed abiotic stress that alters cellular integrity and damages DNA in most living organisms, which also affect aphid life cycle (Rathore and Tiwari, 2017) [35]. This study was designed to impact of increasing UV- B radiation and temperature on different aphids species behavior, fecundity and mortality. Rose aphid (*Macrosiphum rosae*), Mustard aphid (*Lipaphis erysimi*), Cabbage aphid (*Brevicoryne brassicae*) and Pea aphid (*Acyrothosiphon pisum*) were selected for different intensity of UV-B radiation in Garhwal range (400 msl- 2000 msl) of Uttarakhand.

Study Area and Methodology

Different altitudinal region of Uttarakhand 400 msl to 2000 msl (Haridwar to Tehri) situated between 29 -94' to 31°-28' north latitude and 78 -16'to 78°-32' east longitude was selected for the study. Aphid samples were collected from different altitudes and reared in the laboratory and also the monitoring of UV radiation was done by using Kipps and Zonen Radiometer, Netherland having 312 nm spectral sensitivity. Data recorded were stored in Kipps and Zonen data logger (Logbox- SD). Altitude and longitude measurements were done with the help of GPS Garmin USA. Data from different altitudinal sites keeping in view of various environmental factors such as season, altitude, latitude, weather condition and monthly variations were collected.

For the experimental protocol and study the impact of temperature on aphids morphological, behavioural changes and mortality or fecundity rate was designed using stock culture method for established the aphids colonies on potted plants (Hughes and Woolcock, 1965) and as modified by Tisher and Songlake (2001) [41]. Mesh netting cages were used for culture of aphids leaf cages and leaf clip cages also used for monitoring the changes in aphids in a different time interval. Experiment was conducted in Dehradun. Rose aphid (*Macrosiphum rosae*), Mustard aphid (*Lipaphis erysimi*), Cabbage aphid (*Brevicoryne brassicae*) and Pea aphid (*Acyrothosiphon pisum*) were divided into different groups with replicates. Group one was kept control, group two was exposed to UV-B low dose with low temperature, group three exposed with UV-B high dose with low temperature, group four was exposerd with high UV dose with low temperature, group five was exposed with high UV dose with high temperature. UV- B radiation of low intensity 0.600 mw/cm^2 and high intensity 900 mw/cm^2 was given during experimental period in the months of March by Philips UV-B lamps. UV-B radiation was measured using Kipps and Zonen Radiometer. Experiment was performed for 20 days at different temperatures 15 and 25˚C. Exposure time was daily 3 hour per day UV -B radiation exposure. Morphological, behavioural changes, fecundity rate and mortality rate were recorded by the method (Borowiak *et. al*., 2016). Catalase is an oxidoreductase enzyme activity in the aphids was determined by breakdown of H_2O_2 using titration method (Takahara *et. al*.1960). Superoxide dismutase is oxygen metabolized primary antioxidative enzyme present in the cells. Superoxide dismutase convert Superoxide radicals into O_2 and H_2O_2. SOD activity was assayed by methods of (Sun *et. al*., 1988). Absorbance was recorded at 412 nm with the help of UV spectrophotometer. Statistical inferences were drawn by using Students 't' test (Fisher, 1963) [17].

Results and Discussion

The results indicated the monitoring of solar UV- B radiation recorded at altitudinal range at 400 msl - 2000 msl (Haridwar to Tehri). The values of UV- B radiation was highest in the months of May to July 0.899 and 0.968 mw/cm^2 at high altitude. Minimum values in the month of December (400msl- 0.364 mw/cm^2 and 2000 msl- 0.479 mw/cm^2) and January (400msl- 0.312 mw/cm^2 and 2000 msl- 0.443 mw/cm^2) (Fig.-1). The natural solar UV- B radiation levels were recorded minimum at low altitudes and increases with high altitudes. Results on mortality indicate highest upto 51% in cabbage aphid at high temperature and high intensity. Non significant changes were observed at low UV-B and Low temperatue in pea aphid (Table -1). Impact of temperature had a significant role on the life and fecundity of different aphids species. The longest longevity period of aphids was recorded at 20 temperature and the shortest at high temperature. The optimal fecundity was recorded from moderate temperature 20 °C. Decrease in Catalase level and Superoxide dismutase level was observed in all groups in comparison to control. Non-significant changes was observed in group 2. Maximum decrease in level of catalase was observed at high temperature and high intensity of UV-B in Cabbage aphid (Table: 2). Maximum increase in level of superoxide dismutase was found in cabbage aphid with high temperature and high intensity of UV-B exposure (Table - 3).

Developmental times of *Brevicoryne brassicae* and *Lipapis erysimi* immature stages significantly decreased with the increase in temperature ranging from 20-25 days at low temperature range (10°C or below) and 5-6 days at high temperature (above 25°C). At higher temperature, No development occurred for nymph stage at the high temperature range aphids cannot survive. Aphids species *Macrosiphum rosae* (Rose aphid) and *Acyrothosiphon pisum* (Pea aphid) are show slightly tolerate to high temperature as compare to *Brevicoryne brassicae* (Cabbage aphid) and *Lipapis erysimi* (Mustard aphid). Aphids are sensitive for UV -B radiation. Due to increasing temperature and high UV -B radiation exposure aphids die at nymph stages. The intrinsic rate of natural increase (rm) is a good indicator of the temperature at which the growth of a population is most favorable. It reflects the overall effects of temperature on development, reproduction and survival characteristics of a population (Satar *et. al*., 2004). Increasing temperature induce thermal stress in both insects and plants. The effect of thermal stress on organisms is disrupt the homeostasis of ROS production, which lead to oxidative damage and antioxidative enzyme catalase indicated decrease in antioxidant potential. A decrease level of catalase was observed in all the groups as compared to control. Significant changes were observed in groups with exposure to High and Low artificial UV-B with high temperature. Maximum decrease level of catalase was observed in high dose of artificial UV with high temperature. Superoxide dismutase (SOD) function is to help breakdown harmful oxygen molecules in cells which prevents damage to tissue. An increase level of SOD was observed in all groups in comparison to control. Significant changes in enzyme activity was observed in groups with High and Low dose of artificial UV-B with high temperature level. Behind the worldwide crop losses there are a number of biotic stresses, among which insect pests are play high. Despite the extensive use of insecticides, the loss of crops is high estimated (García-Lara and Saldivar, 2016).

Temperature is a crucial factor that influences the development of insects Temperature influence wing development indirectly and directly acting on the aphid physiology. (Angilletta, Steury, & Sears., 2004; Brown, et.al., 2004; Porter, Parry, & Carter, 1991) [2, 6, 34]. Temperature influence wing development indirectly and directly acting on the aphid physiology. Wing development in aphids is usually governed by some interacting factors like: crowding, photoperiod, plant quality and temperature (Kawada, 1987) [26]. (Sharpe & DeMichele, 1977 and Janisch, 2001) [38] applied the relationship between increased temperature and the developmental rate of B. brassicae. The temperatures below 20°C and above 30°C retarded the development of aphids. (Fathipour *et al*., 2005 and Satar *et al*., 2005) [16, 36] showed that *B. brassicae* optimally developed at 20°C and the alternating temperature of 25/30°C, respectively. (Abdel-Rahman *et. al*., 2011) [1] reported that 28°C reported the highest fecundity per day at 25°C (4.2 nymphs). Mostly aphids species causes direct damage to the plants and crops, resulting from searching for food, which may induce plant deformation, and indirect damage caused by honeydew and transmission of viruses and viral disease (Oatman and Platner, 1969). Plants exhibits aphid damage have variety of symptoms decreased plant growth rates mottled leaves, yellowing, stunted growth, curled leaves, wilting, low yield and death removal of sap creates lack of vigour aphid in the plant, and aphid saliva is toxic to the plants. Temperature play the major effect on the biology and life cycle of aphids.

Plant responses to abiotic challenges, UV-B radiation and their interactions with aphid species were explored in a multifactor approach transmission of high UV-B or low UV-B to ambient UV-B on aphid species. Plant quality and growth increases rapidly with increasing temperature, while the population of aphids decreases with increasing temperature. Over feeding of aphid on plants reduces plant quality. Aphids also affect plant chemistry (Guay *et. al*., 2009) [19]. The higher numbers of aphid on plants grown in the presence of low-UV-B resulted in decreased indole glucosinolate concentrations in plants. This deficiency-induced alteration of glucosinolates may depend on a transition threshold. UV-B radiation affects herbivorous insects through changes in host plants. Plants grown under high-UV-B intensity are smaller and have higher flavonoid concentrations. These plants had reduced cuticle wax coverage, with amino acid concentrations of phloem sap slightly affected by varying UV-B intensities (Kuhlmann and Mullar, 2010) [28]. The reproductive rates of aphids were higher on plants grow under low UV-B and Less on plants grown under high UV -B. UV-B radiation significantly affects plant traits and subsequently affects phloem-feeding aphids. High temperature suppresses late wing production of aphids (Dader *et*, *al*., 2017).

Ultraviolet-B (UV-B) radiation directly affects the growth and development of aphids. Effects of thermal stress is excessive ROS generation which causes oxidative damage (Zhang *et. al*., 2015) [45]. SOD is involved in the transformation of the toxic induction of superoxide dismutase activity that catalyzes O2 and H2O2 dismutation. There is no significant change in SOD activity at low temperature but at high temperature increases the amount of SOD in aphid tissues. Catalase enzyme (CAT) catalyzes the H2O2 reduction reaction to water in tissues. The activity of SOD and CAT enzymes in aphids tissues changed at high temperature. Reactive oxygen species (ROS), rapidly accumulate in the aphids body to response the abiotic stresses UV radiation intensity and temperature. High levels of ROS damage the bodies of living organisms. SOD is catalyze the dismutation of O2-to H2O2 and O2. To prevent the oxidation burst, due to ROS production every living organisms have a complex protective mechanisms for remove the ROS. Enzymatic removing systems are catalase (CAT) and superoxide dismutase (SOD). Catalase is a major ROS removing enzyme, functions mainly in the removal of excessive ROS generated during developmental or by environmental stressor into organisms (Zhao *et. al*., 2016) [46]. The differences in SOD activity in aphids resulted from the chemical compositions of the host plants. Quercetin and phenylpropenoic acids correlated with the aphids diet influenced SOD activity (Lukasik, 2007) [30]. The chemical composition of phloem sap in plants changes due to increase in temperature. Due to which the level of glucose in the phloem juice decreases and the aphids start eating the mesophyll cells of the plants rapidly. To release the oxidative stress in insects, anti-oxidative enzymes played a significant role. Increase in temperature affected the increase in antioxidative enzymes SOD and CAT activity. The activity of antioxidant enzymes SOD and CAT in polyphagous aphids tissues is associated with the host plant. CAT is involved in the cell wall resistance and acts as a signal for the induction of defense genes. Superoxide dismutase is an enzyme that helps break down potentially harmful oxygen molecules in cells. This might prevent damage to tissues (Vincent *et. al*., 2021) [42].

Conclusion

Due to the thinning of the ozone layer leading to higher UV-B radiation reached to the earth surface. The present study based on monitoring the UV-B radiation in different altitudinal range between 400 msl- 2000 msl in Uttarakhand. Intensity of UV-B increased with the increased altitudinal range. The highest values of UV- B radiation highest in the months of June - July 0.899 and 0.968 mw/cm^2 and Minimum values in the month of December and January. Environmental factors temperature and UV-B radiation act as critical abiotic stressor and effect the insects physiology and behaviour. Ultraviolet radiation directly regulates aphids species life processes and indirectly affecting changes in biochemistry and morphogenesis. All physiological processes of ectothermic insect Aphids, largely depend on climatic variables i.e. temperature and UV radiation. UV-B radiation and increased temperature formed abiotic stress that alters cellular integrity and damages. The lifespan of aphid species is only about 20 to 40 days. Their excessive reproduction rate compensates for the short lifespan and maintains their population. All immature stages mortality in aphids highest at high temperature and lowest at moderate temperatures. Impact of temperature had a significant on the longevity and fecundity of different aphids species.

The longest longevity period of aphids was recorded at optimum temperature and the shortest at high temperature. The optimal fecundity was recorded from moderate temperatures range between 15 - 20°C. As compare rose and pea aphids, mustard aphids and cabbage aphid are more sensitive for the temperature and UV-B radiation. High intensity UV radiation and temperature can be used to control aphid population. Aphids can be used as the model for the phototoxicity and climate change study.

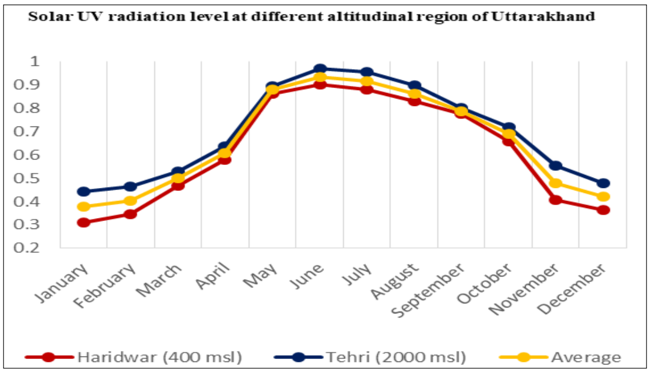

Fig 1: Seasonal Variation in Solar UV radiation level at different altitudinal region of Uttarakhand.

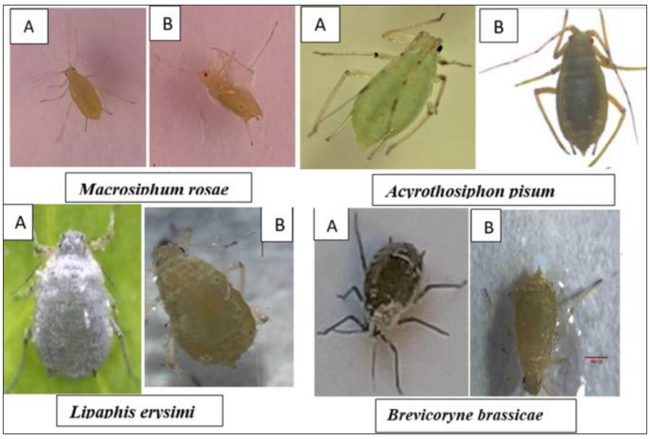

Fig 2: Aphid (A) Before UV exposure (B) After UV exposure

Table 1: Mortality rate in different species of Aphids with low or high dose of UV-B radiation and different temperature exposure.

S. No.		*Acyrothosiphon pisum*	*Macrosiphum rosae*	*Lipaphis erysimi*	*Brevicoryne brassicae*
1.	Control	6.1 ± 1.12	6.2 ± 1.01	6.4 ± 1.04	7.2 ± 1.09
3.	Low UV-B + low temp.	21.6 ± 1.16^{NS}	23.4 ± 1.11 ^{NS}	25.1 ± 1.11 *	26.8 ± 1.28 ^{N*}
4.	Low UV-B + high temp.	28.6 ± 1.28 *	29.8 ± 1.42*	33.6 ± 1.36*	34.8 ± 1.51*
5.	High UV-B + Low temp.	33.4 ± 1.34*	38.6 ± 1.21*	41.8 ± 1.09*	48.2 ± 1.78**
6.	High UV-B + High temp.	39.2 ± 1.82*	44.4 ± 1.57*	49.6 ± 1.24*	51.8 ± 1.19*

Result are mean ± S. E. of 5 observations in each group.

Table 2: Catalase level (mg/100g tissue) in different species of Aphids with low or high dose of UV-B radiation and different temperature exposure.

S. No.	Group	*Macrosiphum rosae*	*Acyrothosiphon pisum*	*Lipaphis erysimi*	*Brevicoryne brassicae*
1.	Control	77.89 ± 1.30	78.49 ± 1.12	76.25 ± 1.20	75.32 ± 1.16
2.	Low UV-B + low temp.	71.02 ± 1.11^{NS}	70.09 ± 1.01^{NS}	76.13 ± 0.91^{NS}	73.21 ± 0.89^{NS}
3.	Low UV-B + high temp.	70.43 ± 1.08*	73.51 ± 1.16*	70.42 ± 1.12*	67.53 ± 1.01*
4.	High UV-B + Low temp.	68.26 ± 2.18*	71.49 ± 2.18*	64.14 ± 2.03*	65.31 ± 2.20*
5.	High UV-B + High temp.	62.32 ± 1.02**	60.43 ± 1.06**	59.13 ± 0.80**	58.19 ± 0.86**

Result are mean ± S. E. of 5 observations in each group.

Table 3: Superoxide dismutase activity (Units/ ml) in different species of Aphids with low or high dose of UV-B radiation and different temperature exposure.

S. no.	Group	*Acyrothosiphon pisum*	*Macrosiphum rosae*	*Lipaphis erysimi*	*Brevicoryne brassicae*
1.	Control	153.81 ± 0.82	153 ± 0.81	152.02 ± 0.91	150.32 ± 0.98
2.	Low UV-B + low temp.	164.43 ±0.56^{NS}	161.21 ±0.49^{NS}	159.21 ± 0.28^{NS}	166.53 ± 0.26^{NS}
3.	Low UV-B + high temp.	169.26 ± 0.96*	167.02 ± 0.91*	165.03 ± 1.02*	169.65 ± 1.12*
4.	High UV-B + Low temp.	172.35± 1.22*	169.25 ± 1.25*	168.24 ± 1.05*	172.34 ± 1.20*
5.	High UV-B + High temp.	176.36 ± 1.07**	174.12 ± 1.10**	172.03 ± 1.01**	176.56 ± 1.11**

Result are mean ± S. E. of 5 observations in each group.

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