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Ultraviolet-B, end of day light and exclusion effect on photosynthetic efficiency of sweet potato (*Ipomoea batatas* L.) based on altitude

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ABSTRACT

Purpose: herbaceous dicot plants mainly sweet potato is highly affected by UV-B and light quality based on altitude. Therefore, this study will give insights on the effect of UV-B and light quality on photosynthetic efficiency of sweet potato based on Altitude. **Research method:** The experimental design was laid out in split plot design with factorial arrangement. The treatments consist of +UV-B or control, UV-B exclusion, UV-B+end of day light exclusion, and the two sweet potato cultivars such as Kulfo and Hawassa-83. **Main findings:** highest UV-B (1693.0mw/m^{-2}s^{-2}) was recorded at highland (2230m.a.s.l) and the lowest (1107mw/m^{-2}s^{-2}) was recorded at lowland (1400m.a.s.l). The result shows that photosynthetic rate increased by 2.41% in Kulfo compared with Hawassa83 cultivar. Also altitude has a highly significant effect on photosynthetic efficiency; the highest stress level 0.68 and 0.72 was recorded at UV-B + EOD exclusion and highland. This indicate UV-B +EOD exclusion cause light quality and intensity stress at highland also UV-B was inducing high stress at highland area and affecting sweet potato productivity but exclusion increase Fv/Fm and stomata conductance it has no effect on photosynthesis and transpiration rate. **Limitations:** The research has a limitation due to Altitude difference it's difficult to control factors other than UV-B and light Quality that may cause a difference. **Originality/Value:** This research tries to assess UV-B and end of day time light quality effects due to altitude difference and encourages new research on UV-B, its adaptation and light quality on crop productivity.

INTRODUCTION

Currently, UV radiation incident increase and these shortest UV waves are the most harmful to plants, humans and animals. Typically, UV radiation is divided into three such as UV-A (315 to 400 nm), UV-B (280 to 315 nm) and UV-C (100 to 280 nm) spectral ranges (Hollosy, 2002). UV-C radiation is totally absorbed by the stratospheric ozone layer, UV-B radiation partially absorbed by the ozone layer and it's the most harmful but UV-A radiation is unaffected, such radiation does not harm to plants (Caldwell & Flint, 1997). However, the UV-B radiation intensity is mostly affected by the thickness of the stratospheric ozone layer across altitude (Helsper et al., 2003; Björn, 1996). Lower thickness of the atmosphere, closeness of the sun to the earth surface, solar angle, and lower reflectivity at highland resulted high incident of Ultraviolet-B radiation at highland area (Caldwell et al., 1980). Through experiment impacts of UV-B on plants was documented such as reduction of photosynthesis, biomass, impaired chloroplast function, decreased the relative growth rate, and damage DNA (Robson et al., 2014; Coleman & Day, 2004; Kakani et al., 2003 & Zhao-Go et al., 2004). This effect of UV-B directly or indirectly reduce photosynthetic efficiency and also it produces oxidative stress arising from the injurious effects of reactive oxygen species which reacts with lipids, pigment, proteins and nucleic acid that cause reduction of photosynthesis (Costa et al., 2002). However, as altitude increase light intensity and quality increases irrespective of many other climatic differences; altitude influences both intensity and quality of radiation. Especially, there is high light quality and intensity during day time at highland when we compare with lowland but end of day time after 4:00 pm light quality and intensity may vary based on altitude that may affect sweet potato growth and productivity by affecting photosynthesis (Blom & Ingratta, 1983). Therefore, exclusion of ambient Ultraviolet-B and end of day time light quality from the solar radiation increases photosynthesis rate and Co_2fixation (Kataria et al., 2013; Agrawal, 1992). Half of the total agricultural land in Ethiopia was located at highland area with elevation higher than 1500 m.a.s.l (Adugnaw, 2014). Since, sweet potato productivity was low on such highland areas of Ethiopia. Therefore, this study aims to asses and depict the impact of ambient UV-B, end of day light quality and its combined exclusion on photosynthetic efficiency of two sweet potato cultivars on different altitude.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in two agro ecological zone of southern Tigray, Ethiopia. The sites are i.e. Gerjele and Simert.

Table 1. Climatic condition and elevation of the study area

Sites	Average daily max. T (◦c)	Average daily min. T (◦c)	Annual total rainfall (mm)	Elevation (m.a.s.l)	Soil type
Gerjile	31.29	15.91	792.4	1400	Sandy loam
Simert	22.4	9.05	737.5	2230	Clay loam

Source: Ethiopian Metrological agency and Bureau of agriculture and rural development (BoARD).

Experimental design and treatments

The experiment consists of three treatments such as (–UV-B), means UV-B exclusion,(-UV-B+EOD) UV-B + end of day time light quality exclusion and (+UV-B) or control, the two sweet potato cultivars are (Kulfo and Hawassa-83) in a split plot design with factorial arrangements. The main plot factors are UV-B exclusion, UV-B + end of day time light quality exclusion and +UV-B or open as a control, the two sweet potato cultivars as sub plot factors with three replications. There are 6 factor combinations in each altitude and the experiment totally has 12 factor combinations.

Pre- cultivation and growth condition

The two sweet potato cultivars such as Kulfo and Hawassa83 was collected from Hawassa agricultural research center and then propagated in tissue culture to get disease free planting materials and after they reached a transplanting stage they transferred to a structure made of UV-blocking plastic covers and end of daylight blocking plastics covers. That selectively cut-off UV-B below 350 nm radiation; solar eva-5 high diffuse opaque polyethylene film with 0.20 mm thick and 2 m wide, revora plastic, the Netherlands, and open as a control. The structure was 2 m wide and 4 m high with the bottom and top sides (1m above ground south and 90 cm in north) left open to allow air ventilation. It was constructed in the north–south direction over the treatment plot to ensure the solar radiation reaching the plants only after passing through the filter as the sun moves from east to west. The main climatic factors recorded inside the structure during growth are temperature, relative air humidity (RH), UV-A intensity, UV-B intensity, PAR, RED, FAR RED and RED TO FAR RED light ratio at each site. Photosynthetically active radiation (PAR) passing through the UV-blocking, UV-B + end of day light blocking and control was measured respectively, compared with unfiltered radiation. End of day time light quality exclusionwas done from 4:00 to 6:00pm within each day and UV-B blocking throughout the growing season.

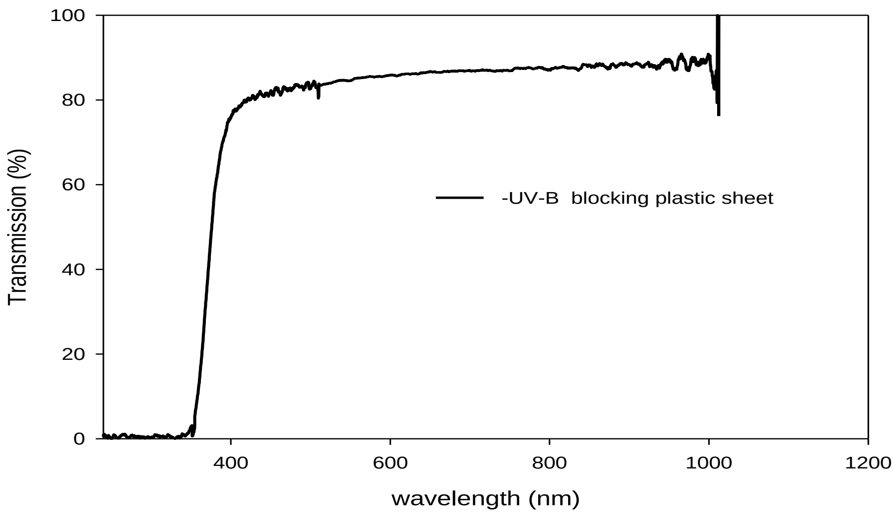

Fig. 1. UV-blocking polyethylene film (-UV) (solid line) blocks UV-B light spectrum (280-315) and the short wavelengths of UV-A spectrum 315nm (Solar EVA-5 0.20 mm thick high diffuse opaque polyethylene film, Revora plastic, The Netherlands).

Table 2. Average UV-B and light quality recorded throughout the growing season in the experimental site in (MW/M-^{2}-S^{2})

Lowland							Highland					
Treat-ments	UV-B	UV-A	PAR	RED	FAR-RED	R:FR Ratio	UV-B	UV-A	PAR	RED	FAR-RED	R:FR Ratio
-UV-B	156.5a	2636a	542.5b	64.18b	62.95b	1.01b	131.6a	2310b	875.8b	94.91b	92.61b	1.02b
+UV-B	1107.1b	18717b	1201.0c	136.22c	122.52c	1.12c	1693.0b	24143c	1841.5c	162.07c	144.55c	1.08c
-UV-B + EOD	48.6c	973c	40.5a	1.82a	2.27a	1.75a	6.3c	107a	8.6a	1.08a	1.59a	0.62a

Table 3. Main effect of altitude, exclusion and cultivar on photosynthetic efficiency

Treatment	FV/FM	gs (mol-m^{2}s^{1})	Pn (mol-m^{2}s^{1})	E (mol-m^{2}s^{1})
Cultivar				
Kulfo	0.77	0.13	13.87	3.79
H83	0.77	0.12	11.45	3.82
Altitude				
Lowland	0.82	0.20	20.98	5.39
Highland	0.72	0.05	4.35	2.22
Exclusion				
-UV-B	0.80	0.12	13.7	3.82
+UV-B	0.76	0.10	11.84	4.77
-UV-B +Eod	0.74	0.15	11.45	2.82
P-^{Value}				
Cultivar	0.74	0.67	0.01	0.88
Exclusion	0.04	0.04	0.67	0.08
Altitude	0.001	0.01	0.001	0.001

Key abbreviations: Fv/Fm- Chlorophyll florescence or quantum efficiency, gs-stomatal conductance, Pn- photosynthesis rate, E-transpiration rate, -UV-B=UV-B exclusion, +UV-B =control or open and –UV-B +EOD= UV-B and end of day time light quality exclusion.

Climate and Radiation at the Field Site and Its Measurements

An instrument called Mini data loggers (TESTO 174, VERSION 5.0.2564.18771, MICRO DAQ COM, LTD., and SOUTH BURLINGTON, USA) was used to recoded temperature and RH of the tested treatments. additionally, UV-B (W M^{-2}),UV-A (W M^{-2}), RED and FAR-RED and photosynthetic active radiation (PAR) (µmol m^{-2} s^{-1}) were also measured from 8:30am–12:30pm on randomly selected four clear sky days using SKYE SPECTROSENSE 2 (SKYE INSTRUMENT LTD, LLANDRINDOD WELLS, UK) as detailed in the below Figure 1.

Data Collection

Photosynthesis, stomatal conductance and transpiration rate

Measurements was made during the vegetative on fully developed intact leaves at the 5th node stage using an open system (LCA-4 ADC portable infrared gas analyzer (Analytical development company, Hoddeson, England).these measurements was made from 12:00 to 15:00 h with the following specifications/adjustments: Leaf surface area was 6.25 cm^{2}, ambient carbon dioxide concentration (Cref) 340 µmol mol^{-1}, temperature of the leaf chamber (Tch) varied from 34 to 47°C, leaf chamber molar gas flow rate (U) was 410 µmol s^{-1}, ambient pressure (p) 828 mbar and par (Q) at the leaf surface was maximum up to 1500 µmol m^{-2}. data was collected every five minutes for 15 minutes using three leaves in each of 3 plants per treatment.

Chlorophyll fluorescence measurement (Fv/Fm)

To evaluate the performance of the plants, chlorophyll fluorescence of well-developed leaves at the 5th node from randomly selected plants was measured in the middle of the day at vegetative stage using a so called plant efficiency analyzer Handy-*PEA* (Hansatech, Kings Lynn, UK) following the methodology of Strasser et al. (2004).

Statistical Data Analysis

All the collected data were subjected to statistical analysis by using GenStat 18th edition software package. The significant difference was determined by LSD tests at ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

Main and Interaction effects of altitude, exclusion and cultivar on photosynthetic efficiency

As shown in Table 3, main effect of cultivar significantly affects photosynthesis but it doesn't affect chlorophyll fluorescence, stomatal conductance and transpiration rate. Main effect of altitude has highly significant effect in all parameters, maximum quantum efficiency, stomatal conductance, transpiration and photosynthesis rate. Exclusion significantly affects only quantum efficiency (Fv/Fm) and stomatal conductance but it has no effect on transpiration and photosynthesis rate. Exclusion by cultivar interaction significantly affects photosynthesis but transpiration rate, chlorophyll fluorescence (Fv/Fm) and stomatal conductance analysis show non-significant result. Altitude by cultivar interaction has no significant effects on (Fv/Fm), stomtatal conductance and transpiration but it affects photosynthesis rate. Exclusion by altitude interaction significantly affects chlorophyll fluorescence (Fv/Fm) and it has no effect on stomatal conductance, photosynthesis and transpiration rate. However, altitude by exclusion by cultivar interaction has no significant effect on chlorophyll fluorescence, stomatal conductance and transpiration rate but according to chlorophyll florescence analysis at highland the all treatments and cultivars show stress but high stress level 0.68 was recorded at UV-B and end of day time light quality exclusion at highland as shown (Table 4). photosynthetic rate increase in Kulfocultivar relative to Hawassa-83 cultivar and this high photosynthesis rate was mainly due to its yellow orange color close to red that may be an indicator of high anthocyanin content that help plants to deter UV-B penetration in to the mesophyll cell and due to that colorkulfo was relatively tolerant to UV-B and low end of day time light quality. The present study was in line with the findings reported by Jansen et al. (1998), Jansen et al. (2012), Jenkins (2014) and Robson et al. (2014); they stated that UV-B protective response in plants such as the biosynthesis of flavonoids and anthocyanin components that synthesized as a response to UV-B. These flavonoids and anthocyanin prevent the transmittance of the UV-B in to the plant cells, thus exclusion of UV-B damage to the plant molecules. Oren-Shamir and Nissim (1997) stated that the increase in anthocyanin content in the leaf in response to the UV-B and light quality resulted in more favorable performance ratings due to color. Plants produce a wide range of flavonoids and related phenolic compounds which tend to accumulate in leaves of higher plants in response to UV radiation. Stapleton (1992) has been suggested that plants developed UV-absorbing compounds to protect them from damage to DNA or to physiological processes caused by UV radiation. However, both cultivars have similar in quantum efficiency, stomatal conductance and transpiration rate but they differ in relative sensitivity to UV-B and end of day time light quality on photosynthesis rate. Altitude has a highly significant effect on all parameters and the lowest record of stomatal conductance, photosynthesis and transpiration rate at highland was due to high UV-B radiation effect at highland and it has severe effect on metabolism this was indicated by chlorophyll fluorescence test (Fv/Fm) as shown in the Table 3 and 4, the healthy plants have Fv/Fm value from 0.83. At highland (Fv/Fm) value was 0.72 and it is highly significant this indicate UV-B was inducing high stress at highland area and affecting sweet potato productivity mainly due to the difference in ozone depletion across altitude which result high UV-B radiation. Similar findings with current study was reported by McKenzie et al. (2003) and Caldwell et al. (1980) they reported that at higher elevations UV-

B levels increase mainly due to a thinner atmosphere, closeness of the sun to the earth surface, solar angle, and low reflectivity at such areas. Pfeifer et al. (2006), reported that UV-B irradiance increase at highland area; this difference is due to change in the level of ozone depletion with elevation change and at highland area there is high seasonal ozone depletion and UV-B radiation. Exclusion significantly affected quantum efficiency (Fv/Fm) and stomatal conductance but it has no effect on photosynthesis and transpiration rate. According to chlorophyll fluorescence (Fv/Fm) analysis (Tables 3 and 4), sweet potato plants grown at UV-B exclusion (–UV-B) are relatively free from stress but stress was detected at +UV-B it may be UV-B and at UV-B + End of day time light quality exclusion it may be light quality and intensity stress. However, there is high stomatal conductance at UV-B + End of day time light quality exclusion and these exclusion increase stomatal conductance by (0.5 mmol-m-2s-1). However, the lowest stomatal conductance at +UV-B is due to the effect of UV-B on stomatal conductance, closure, and density that result ineffective acclimatization. This study was In line with Negash (1987), who reported that UV-B cause stomatal closure in response to reduced demand of co_2 in eragrostistef, and it cause stomatal limitation, i.e. the percentage decrease in UV-B irradiated leaves. These stomatal restrictions in turn affect stomatal conductance and function, Farquhar and Sharkey (1982). Smith (1982) reported that UV-B cause ineffective acclimatization process in sensitive plants by damaging structural and functional elements in plants. Exclusion by cultivar interaction significantly affected photosynthesis rate but transpiration rate, stomatal conductance and chlorophyll fluorescence (Fv/Fm) analysis show non-significant result. The highest photosynthesis rate of Kulfo cultivar at UV-B exclusion was due to avoidance of UV-B effect by exclusion since the main effect of UV-B was reduction of photosynthesis. Similar result with current study was reported by Nogués et al. (1998) which stated that, increasing levels of UV-B radiation currently shown inhibition of photosynthesis in pea Reddy et al. (2003), Zhao-Go et al., (2004) in cotton, and Allen et al. (1998) in Oil seed rape. However, Yao et al. (2006) reported that, ambient and enhanced UV-B decrease the amount of photosynthetic pigments that may affect photosynthesis. As shown in Figure 2, Kulfo was less sensitive to UV-B relative to Hawassa-83 cultivar could be due to its yellow orange color close to red and it may be an indicator of high antocyanin pigment that prevent UV-B entrance in to the plant cells. Similar findings were reported by Briscoe and Chittka (2001), Irani and Grotewold (2005), Chalker-Scott (1998) and Gould (2004), anthocyanin are primarily known for their bright red colors and in plants antocyanin was synthesized in response to excessive UV-B condition. However, altitude by cultivar significantly affected photosynthesis rate, the highest photosynthesis rate was recorded from Kulfo cultivar at lowland but altitude by exclusion by cultivar has no significant effect on all parameters but exclusion by altitude significantly affected chlorophyll fluorescence. Chlorophyll fluorescence test indicate the all treatments and cultivars grown at highland are stressed mainly by UV-B due to high seasonal ozone depletion at highland. Similar study were reported by Madronich et al. (1998) who stated that, exposure to UV-B level differ in different latitude and altitude mainly variation in Ozone depletion. The highest Chlorophyll fluorescence or (Fv/Fm) 0.68 was detected at UV-B + End of day time light quality exclusion at highland and Hawassa-83 cultivar interaction. Which indicate photosynthetic efficiency reduction by (32%) at this treatment. it could be mainly due to high cloud cover at highland and this UV-B + End of day time light quality exclusion plastics reduces light quality and intensity which result stress and Hawassa-83 cultivar was the most sensitive cultivar to this low light intensity and quality relative to Kulfo. This difference may be due to its bulky nature, large leaf size, leaf area, bulky stem and leaf that require high light quality and intensity to increase the photosynthetic efficiency.

A **B**

Fig. 2. Kulfo cultivar response to UV-B and end of day time light quality at highland and lowland, data was at middle of October. A: Highland; B: Lowland.

Table 4. Interaction effect of altitude, cultivar, UV-B, end of day time light quality and its exclusion on photosynthetic efficiency

Treatment			FV/FM	gs (mol-m^{2}s^1)	Pn (mol-m^{2}s^1)	E (mol-m^{2}s^1)
Lowland	-UV-B	Kuflo	0.84	0.20	23.58	4.85
		H83	0.81	0.13	17.36	5.49
	+UV-B	Kulfo	0.81	0.18	21.05	6.91
		H83	0.82	0.06	19.30	6.0
	-UV-B + Eod	Kulfo	0.82	0.23	24.81	4.30
		H83	0.80	0.06	19.76	4.78
Highland	-UV-B	Kuflo	0.75	0.037	8.08	2.76
		H83	0.80	0.053	3.27	2.16
	+UV-B	Kulfo	0.71	0.057	3.48	2.85
		H83	0.73	0.047	4.92	3.35
	-UV-B + Eod	Kulfo	0.69	0.06	3.23	1.05
		H83	0.68	0.06	4.11	1.17
P^{-Value}						
Exu × Cul			0.71	0.22	0.03	0.70
Exu × Alt			0.02	0.27	0.35	0.57
Cul × Alt			0.10	0.58	0.01	0.91
Ex× Cu × Al			0.29	0.14	0.64	0.22

Key abbreviations: Fv/Fm- Chlorophyll florescence or quantum efficiency, gs-stomatalconductance, Pn- photosynthesis rate, E-transpiration rate, -UV-B=UV-B exclusion, +UV-B =control or open and –UV-B +EOD= UV-B and end of day time light quality exclusion,Exu × Cul- exclusion by cultivar interaction, Exu × Altitiude- exclusion by altitude interaction, Cul × Alt-cultivar by Altitude interaction, Ex × Cu × Al-exclusion by cultivar by altitude interaction.

CONCLUSION

From the study I can conclude that, Photosynthetic efficiency ofKulfo cultivar was less affected by UV-B and End of day time light quality when we compare with Hawassa83 cultivar. This may be because of its color that may be indicators of high anthocyanin content. Altitude differences are highly affecting the overall photosynthetic efficiency parameters, at highland due high UV-B radiation photosynthetic efficiency was reducedand chlorophyll fluorescence tests also indicate (0.72), high stress at highland. These indicate UV-B was inducing high stress at highland area and affecting sweet potato productivity. UV-B and End of day time light quality affect photosynthetic efficiency at lowland. Since, UV-B + End of day time light quality exclusion increase stomatal conductance. According to chlorophyll fluorescence test (FV/FM) under UV-B exclusion there is no stress but at +UV-B and UV-B + End of day time light quality exclusion at highland stress was detected this indicate UV-B exclusion alleviate the UV-B effect on photosynthetic efficiency of sweet potato cultivars but UV-B + End of day time light quality exclusion at highland cause high stress and affect photosynthetic efficiency and productivity of sweet potato.

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Conflict of interest
There is no conflict of interest between authors this research.

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