Research Article

Enhancement in Biomass and Yield of Soybean Var: JS-71-05 After Exclusion of Solar UV Components

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Abstract

A field experiment was conducted to assess the effects of excluding solar UV-B (280–315 nm) and UV-A (315–400 nm) radiation on the growth, physiology, and yield of soybean (Glycine max L. Merrill var. JS-7105). Plants were cultivated under open-field conditions using a specially designed UV-exclusion setup with selective filters that blocked either UV-B (<315 nm) or both UV-A and UV-B (<400 nm) components of the solar spectrum. Control plants were grown under filters that transmitted ambient solar UV radiation. Exclusion of UV-B and UV-A/B led to significant improvements in vegetative growth parameters, including plant height, internodal length, and leaf area. Biomass accumulation was enhanced, as reflected in increased fresh and dry weights. The maximum quantum efficiency of Photosystem II (Fv/Fm), measured in dark-adapted leaves, was also significantly improved under UV exclusion, indicating reduced photoinhibition. Levels of UV-absorbing substances (UAS) in the unifoliate leaves decreased by approximately 33% in UV-excluded plants compared to controls, suggesting lower UV-induced stress. Total soluble protein content increased, and SDS-PAGE analysis revealed a more intense 53 kDa protein band corresponding to the large subunit of Rubisco, indicating improved photosynthetic protein expression under UV exclusion. Yield parameters were markedly improved under UV exclusion. The number of seeds per plant increased by approximately 46% under -UV-B and 43% under -UV-A/B conditions. The 100-seed weight increased by 42% and 91% under -UV-B and -UV-A/B, respectively. Harvest index and pod number also showed significant enhancement. These findings demonstrate that ambient solar UV-B and UV-A negatively affect soybean growth and productivity by impairing photosystem II efficiency and Rubisco expression. Exclusion of these components enhances physiological performance and yield, suggesting that natural UV radiation is a limiting factor in soybean cultivation. However, the practicality and economic viability of implementing UV-exclusion strategies at a field scale require further investigation.

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1. INTRODUCTION

Light, while essential for photosynthesis, can be a significant damaging factor to the photosynthetic apparatus, particularly under exposure to ultraviolet (UV) radiation. Photosynthetic organisms, including higher plants, are inevitably exposed to both UV-A (315–400 nm) and UV-B (280–315 nm) components of sunlight. At the Earth's surface, the solar UV spectrum includes about 22% UV-B and 72% UV-A. These UV radiations are known to damage cellular components—lipids, proteins, and nucleic acids—and particularly impair key photosynthetic machinery such as Photosystem II (PSII), Rubisco, ATP synthase, chloroplasts, and the violaxanthin de-epoxidase enzyme (Jordan, 1996; Vass, 1997). Although the deleterious effects of UV-B have been extensively studied over the past two decades, the precise molecular mechanisms underlying the integrated plant responses remain unclear. Nevertheless, several studies (e.g., Tevini *et al.,* 1997; Ballare *et al.,* 2001) have consistently reported that UV-B exposure leads to reduced biomass, leaf area, yield, and photosynthetic efficiency. UV-B also triggers the accumulation of UV-absorbing compounds (Flint *et al.*, 2004), downregulates photosynthesis-related genes, and suppresses Rubisco transcript levels (Jordan *et al.,* 1992; Paula *et al.*, 2003). Consequently, a global crop yield reduction of 25–30% has been predicted due to enhanced UV-B radiation. However, many enhancement studies suffer from limitations such as unrealistically high UV levels and improper control of accompanying variables like photosynthetically active radiation (PAR) and UV-A intensity (Edwards, 1992; Adamse *et al.,* 1997). In contrast, relatively few studies have focused on UV exclusion under natural solar radiation conditions. Exclusion studies using UV-blocking filters have shown significant positive effects on plant growth and photosynthetic function in species like radish (Zavala & Botto, 2002), cucumber (Krizek & Mirecki, 2004), and soybean (Varalakshmi *et al.,* 2003; Guruprasad *et al.,* 2007). Exclusion of UV radiation enhances Rubisco activity and cellular concentration (Bischof *et al.*, 2002), CO_2 uptake, PS I efficiency (Krause, 2003), and root biomass and nodulation (Chouhan *et al.,* 2008). These findings underscore the inhibitory role of ambient UV radiation, particularly in tropical regions where UV levels are naturally higher than in temperate zones. To further elucidate the adaptive responses of tropical plants to solar UV, a controlled field experiment was conducted on soybean using UV cut-off filters. These filters selectively excluded UV-B and UV-A wavelengths while maintaining equal PAR and other microclimatic conditions across treatments. The study confirmed that the exclusion of UV radiation significantly improved biomass accumulation and yield, likely due to the alleviation of UV-induced stress on photosynthetic and metabolic processes.

2. MATERIALS AND METHODS SITE DESCRIPTION

A field experiment was conducted under natural sunlight at the Botanical Garden of the School of Life Sciences, Indore, India (22.40°N latitude). The study was carried out during the winter season (October to January 2009), a period when average daily solar UV radiation is approximately 50% higher than that typically received in temperate regions. Seeds of soybean (*Glycine max* L. Merrill var. JS-71-05) were obtained from the National Research Center for Soybean, Indore. Soybean seeds were sown directly into the soil within specially constructed iron-framed cages equipped with UV-cutoff filters (Garware Polyester Ltd., Mumbai, India). These filters selectively excluded UV-B (<315 nm) or both UV-A and UV-B (<400 nm) radiation. Two types of control treatments were used:

1. Filter Control – cages covered with UV-transmitting polyethylene film allowing full solar UV radiation.
2. Open Control – plants grown under open ambient sunlight without any filter.

The spectral transmittance properties of the filters were verified using a Shimadzu UV-1601 spectrophotometer.

Radiation Measurement: Solar irradiance across the treatment setups was recorded using a radiometer (IL1350, International Light Inc., USA). The average midday ambient solar irradiance during the experimental period was 382 µmol m^{-2} s^{-1}. The light intensity under the different treatments was reduced as follows:

- UV-B exclusion filter: 43% reduction (219 µmol m^{-2} s^{-1})
- UV-A/B exclusion filter: 44% reduction (214 µmol m^{-2} s^{-1})
- Polyethylene filter (filter control): 7% reduction (356 µmol m^{-2} s^{-1})

Growth Analysis: Plant height and leaf area were measured at 10-day intervals. Internodal length, fresh weight, and dry weight of leaves and whole plants were recorded every 20 days. For dry weight measurements, plant samples were oven-dried at 60°C for 72 hours until constant weight was achieved.

UV-Absorbing Substances (UAS): To assess UV-induced protective responses, UV-absorbing substances were extracted from 1 cm² leaf discs using 5 mL of methanolic-HCl solution (99:1, v/v), following the method of Mazza et al. (2000). The absorbance was measured spectrophotometrically and expressed on a mass basis (A mg^{-1}).

Chlorophyll a Fluorescence: Chlorophyll a fluorescence was analysed using a Plant Efficiency Analyzer (PEA, Hansa tech Instruments, UK). Leaves were dark-adapted for 20 minutes before measurement. Fluorescence transients from the initial (F_0) to maximum (F_m) fluorescence levels were recorded during a 1-second pulse of high-intensity actinic red light (~3500 µmol m^{-2} s^{-1}; peak at 655 nm). The Fv/Fm ratio, indicating PSII maximum quantum efficiency, was calculated.

Total Soluble Protein and SDS-PAGE Analysis: Total soluble protein content in leaves was quantified using the method of Lowry et al. (1951), with bovine serum albumin as the standard. Protein profiles were analyzed using SDS-polyacrylamide gel electrophoresis (SDS-PAGE) following Laemmli (1970). Proteins were resolved on 12% gels using electrophoresis units from Bangalore Genei Pvt. Ltd. (India). Molecular masses were determined by comparison with standard protein markers from the same supplier.

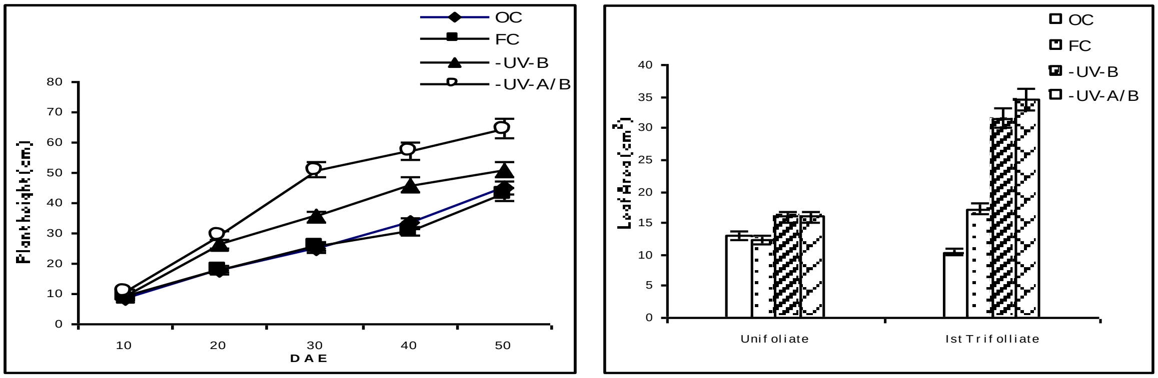
Yield Assessment: Yield parameters were evaluated just before the onset of pod shattering. Ten plants from each treatment were analyzed (in duplicate) for the following metrics:

- Number of pods per plant
- Number of seeds per plant
- Seed weight per plant
- 100-seed weight
- Harvest index

3. RESULTS

Plant height and Leaf area

Plant height was measured at an interval of 10 days from the day of emergence of seedlings. Exclusion of UV-B radiation enhanced the plant height, but to a lesser extent. However, the enhancement was higher in the plants grown under UV-A/B exclusion. The maximum enhancement was recorded on the 40th day after emergence (DAE) of seedlings. The enhancement was 50% after exclusion of UV-B and 87% after exclusion of UV-A/B over filter control. The leaf area of unifoliate and Ist trifoliate leaves was measured. The elimination of UV-B and UV-A/B both caused a significant increase in leaf area as compared to the respective controls. More promotion was found in the Ist trifoliate leaf; exclusion of both UV-A/B radiations from the solar spectrum caused 100% promotion, while the promotion after exclusion of UV-B alone was to a lesser extent than UV-A/B exclusion, i.e., 83% in the Ist trifoliate leaf over the control. (Fig.1).



A B

Fig 1: Effect of solar UV-B and UV-A/B exclusion on plant height (A), leaf area (B) on soybean var: JS-71-05. The vertical line indicates ±SE (n=10) assayed in duplicate. DAE is (day after emergence)

Fresh and dry weight of the leaf and plant

Measurement of fresh and dry weight of the leaves of plants grown under UV-B and UV-A/B exclusion filters showed an increase compared to plants that received complete ambient solar radiation. On 20th DAE fresh weight increased by 41% in leaves grown under UV-B exclusion filter, while 50% enhancement was found in the leaves grown under UV-A/B exclusion filter. An increase of 80% after UV-B exclusion was found in the fresh weight of leaves, which was further enhanced to 121% after excluding UV-A/B on the 40th DAE as compared to a filter control plant. Dry weight of leaves was enhanced by 15% on 20th DAE and 82% on 40th DAE in plants grown under UV-B exclusion filters. Exclusion of UV-A/B caused 40% promotion on 20th DAE and 99% on 40th DAE as compared to the filter control plant. Fresh weight of the plant increased by 34% on 20th DAE and 60% on 40th DAE of the plant grown under UV-B exclusion filter, while the increase of 39% on 20th DAE and 111% on 40th DAE of the plant grown under UV-A/B exclusion filter was found as compared to filter control plants. Dry weight of the plant was enhanced by 44% on 20th DAE of the plant and 46% on 40th DAE under UV-B exclusion. This increase was further promoted by 65% on 20th DAE and 70% on 40th DAE after excluding UV-A/B, as compared to the filter control plant. (Table 1).

Table 1. Leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight of soybean var: JS-71-05 after exclusion of solar UV-B and UV-A/B. The values are mean ± SE (n=10). (Values in parentheses show percent increase).

Parameters	*20 DAE*				*40 DAE*			
	OC	*FC*	*–UV-B*	*–UV-A/B*	*OC*	*FC*	*–UV-B*	*–UV-A/B*
Leaf Fresh Weight (g)	0.427 ± 0.07	0.483 ± 0.10	0.682 ± 0.13 (+41.2%)	0.728 ± 0.14 (+50.7%)	2.026 ± 0.56	2.183 ± 0.54	3.932 ± 0.88 (+80.1%)	4.820 ± 1.04 (+121.2%)
Leaf Dry Weight (g)	0.099 ± 0.02	0.114 ± 0.02	0.131 ± 0.22 (+14.91%)	0.160 ± 0.03 (+40.35%)	0.819 ± 0.17	0.786 ± 0.16	1.430 ± 0.31 (+81.93%)	1.566 ± 0.31 (+99.23%)
Plant Fresh Weight (g)	1.049 ± 0.22	1.240 ± 0.27	1.663 ± 0.36 (+34.11%)	1.720 ± 0.36 (+39.19%)	3.396 ± 0.98	4.154 ± 0.98	6.651 ± 1.50 (+60.11%)	8.764 ± 2.11 (+110.97%)
Plant Dry Weight (g)	0.160 ± 0.02	0.163 ± 0.03	0.235 ± 0.04 (+44.17%)	0.269 ± 0.05 (+65.03%)	1.275 ± 0.25	1.460 ± 0.25	2.141 ± 0.44 (+46.64%)	2.491 ± 0.50 (+70.61%)

UV-absorbing substances (UAS)

UV-absorbing substances absorb UV radiation but transmit the visible photosynthetically active radiation (PAR) to the chloroplasts containing mesophyll cells within the leaf interior. After exclusion of UV-B, the UAS content decreased by 31%, and after exclusion of UV-A/B, it further decreased by 33% in the unifoliate leaf. Whereas in the Ist trifoliate leaf, only a 4% decrease was observed after UV-B exclusion and a 5% decrease after UV-A/B exclusion as compared to the filter control. (Fig.2).

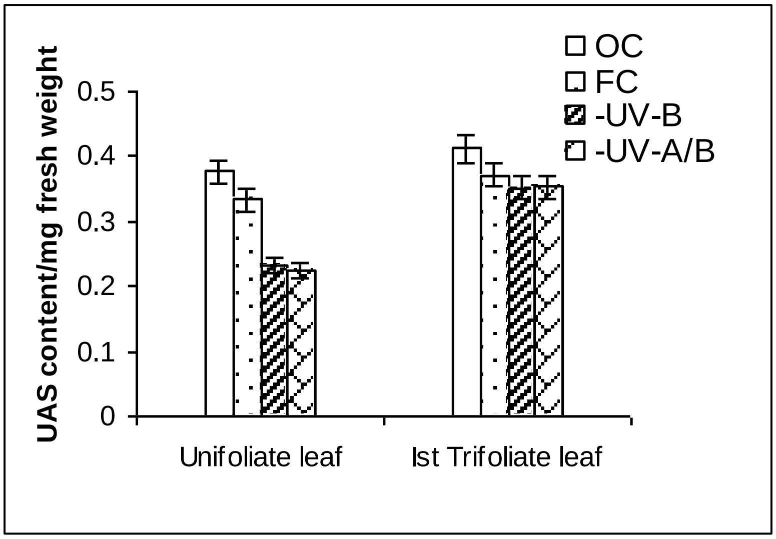
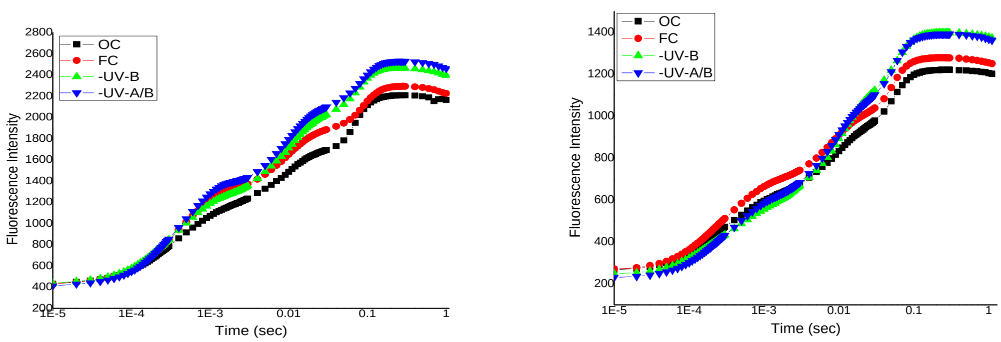


Fig 2: Effect of solar UV-B and UV-A/B exclusion on UV-absorbing substances (UAS).
Each bar represents the mean of five samples assayed in duplicates, and the vertical line indicates ±SE (n=10).

Chlorophyll a fluorescence of Photosystem II

After elimination of UV-B and UV-A/B, unifoliate leaf showed an increase of 6 to 8 % in Fm (maximum fluorescence) value, 9 to 11% in Fv (variable fluorescence) value, and only 2 to 3% in Fv/Fm (variable to maximum fluorescence) ratio, while a decrease of 1 to 6% observed in Fo (initial fluorescence) value. In Ist rifoliate leaf UV-B and UV-A/B exclusion showed an increase of 9% in Fm value,13 to 15 % in Fv value, the Fv/Fm ratio increased by 3 to 5%, whereas Fo value decreased by 7 to 16% compared to plants grown inside a polythene filter. Fv/Fo (Variable to initial fluorescence ratio) shows an increase of 14% in unifoliate leaf anf 22% in Ist trifoliate leaf in UV-B excluded condition, while 18% increase in Fv/Fo ratio has been observed in unifoliate leaf and 37% in Ist Trifoliate leaf after elimination of UV-A/B both, as compared to filter control plants. The performance index (PI) shows the vitality and stability of the plant. PI of control plants was very much less than the plants grown in UV-excluded conditions. Unifoliate leaf of plant grown in UV-B excluded condition showed 42% increase in PI, which was further enhanced to 56% by eliminating UV-A/B, whereas in Ist trifoliate leaf UV-B and UV-A/B exclusion from solar radiation produced a large increase of 127% in the PI as compare to filter control plants receiving ambient solar radiation. (Fig.3 & Table 2).



A. **B**.

Fig 3: Effect of UV-B and UV-A/B exclusion on fluorescence emission transient of PS II in unifoliate (A) and Ist trifoliate leaf (B).

Table 2: Fluorescence parameters in unifoliate and I[st] trifoliate leaves after exclusion of UV-B and UV-A/B in soybean plant var-JS-71-05

Parameter	Unifoliate Leaf				1st Trifoliate Leaf			
	OC	FC	–UV-B	–UV-A/B	OC	FC	–UV-B	–UV-A/B
Fo	467	458	444 *(–1.9%)*	425 *(–6.19%)*	255	256	237 *(–7.43%)*	215 *(–16.02%)*
Fm	2191	2263	2458 *(+8.61%)*	2413 *(+6.62%)*	1221	1279	1398 *(+9.30%)*	1392 *(+8.83%)*
Fv	1724	1810	2014 *(+11.27%)*	1988 *(+9.83%)*	966	1023	1161 *(+13.48%)*	1177 *(+15.05%)*
Fv/Fm	0.788	0.800	0.819 *(+2.37%)*	0.824 *(+3.00%)*	0.791	0.800	0.830 *(+3.75%)*	0.846 *(+5.75%)*
Fv/Fo	3.698	3.951	4.536 *(+14.80%)*	4.677 *(+18.37%)*	3.788	3.996	4.898 *(+22.57%)*	5.474 *(+36.98%)*
PI	1.234	1.918	2.725 *(+42.07%)*	2.993 *(+56.04%)*	1.989	1.770	4.027 *(+127.51%)*	4.023 *(+127.28%)*

Total soluble protein and its profile

Total soluble protein was enhanced in unifoliate and I[st] trifoliate leaf after UV-B and UV-A/B exclusion. Removal of UV-B from solar radiation increases the quantity of total soluble protein by 35% in unifoliate and 49% in I[st] trifoliate leaf. Elimination of UV-A/B caused a 59% increase in unifoliate and a 101% increase in the I[st] trifoliate leaf. For the profile of total soluble protein, 12% SDS-PAGE was used. Partially purified Rubisco (sigma) has been used as a ladder; a higher intensity band of 53 KDa was observed (larger subunit of Rubisco) after UV exclusion in unifoliate and I[st] trifoliate leaves. (Table 3 & Fig. 4).

Table 3: Total soluble protein in the leaf of soybean var: JS-71-05 after exclusion of solar UV-B and UV-A/B.
The values are mean±SE (n=9), assayed in triplicate. (Values in the parentheses show percent increase)

Treatment	Unifoliate Leaf (μg/mg fresh weight)	1st Trifoliate Leaf (μg/mg fresh weight)
OC	22.31 ± 0.38	27.71 ± 0.35
FC	23.84 ± 0.32	37.99 ± 0.30
-UV-B	32.32 ± 0.19 (**+35.66%**)	46.91 ± 0.37 (**+49.33%**)
-UV-A/B	35.57 ± 0.24 (**+59.45%**)	55.78 ± 0.47 (**+101.27%**)

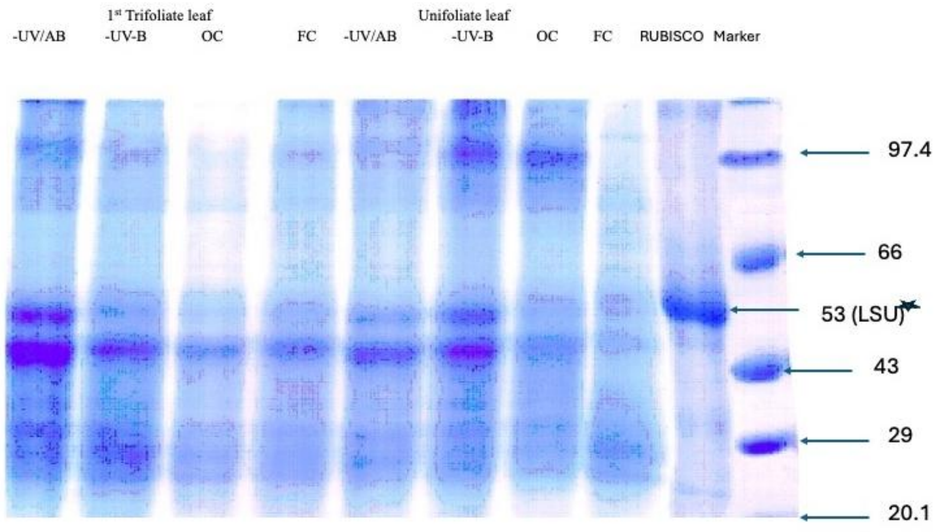


Fig 4: SDS-PAGE analysis of total soluble protein from leaves of soybean var: JS-71-05 after exclusion of solar UV components.

Yield Data: No. of pods/plant significantly increased by 27% after UV-B exclusion and 22% after UV-A/B exclusion. Enhancement of 46% has been observed in several seeds/plant in plants grown under UV-B cut – off filters, whereas UV-A/B cut-off leads to 43% enhancement. Seed weight/plant after UV-A/B exclusion condition increased by 159%, and UV-B exclusion increased by only 46% as compared to control plants. 100 seed weight showed an increase of 42% in UV-B cut-off condition and 91% in UV-A/B cut-off condition. The potential yield in terms of the harvesting index of the soybean crop Var. JS-71-05 was increased due to and larger number of seeds and biomass under UV-excluded conditions. An increase of 67% in the harvesting index of UV-B-excluded plants and 187% after UV-A/B exclusion has been observed. (Table 4).

Table 4: Yield data of soybean var: JS-71-05 after exclusion of solar UV-B and UV-A/B. The values are mean ± SE (n= 10), assayed in duplicates. (Values in parentheses show percent increase)

Parameters	OC (Open Control)	FC (Filter Control)	–UV-B	–UV-A/B
No. of pods/plant	6.1 ± 1.0	8.4 ± 0.90 *(+27.38)*	10.7 ± 1.40 *(+75.41)*	10.3 ± 1.10 *(+68.85)*
No. of seeds/plant	12.4 ± 2.3	15.0 ± 1.60 *(+20.97)*	21.9 ± 3.1 *(+76.61)*	21.5 ± 2.1 *(+73.39)*
Seed weight/plant (g)	0.533 ± 0.09	0.717 ± 0.10 *(+34.46)*	1.534 ± 0.16 *(+187.87)*	2.678 ± 0.25 *(+402.63)*
Harvest Index (%)	10.345 ± 1.69	13.519 ± 1.32 *(+30.71)*	22.683 ± 1.6 *(+119.3)*	38.884 ± 4.01 *(+275.86)*
100 Seed weight (g)	5.519	5.315 *(–3.69)*	7.596 *(+37.63)*	10.186 *(+84.53)*

4. DISCUSSION AND CONCLUSION

The present study demonstrates that the exclusion of UV-B and UV-A components of solar radiation induces significant physiological and biochemical changes in soybean (*Glycine max* L. Merrill var. JS-71-05). Plants grown under UV-excluded conditions exhibited a visible and quantifiable improvement in morphological traits, including increased plant height, internodal length, and leaf area. These enhancements were more pronounced in plants from which both UV-A and UV-B were excluded, indicating a cumulative inhibitory effect of solar UV radiation on soybean growth. Among the key physiological changes observed was the significant increase in total soluble protein content and Rubisco accumulation. Rubisco (Ribulose-1,5-bisphosphate carboxylase/oxygenase) is a central enzyme in the Calvin-Benson cycle and plays a critical role in photosynthetic CO_2 fixation. Its enhanced synthesis under UV exclusion conditions correlates with improved photosynthetic capacity and biomass accumulation. The dual function of Rubisco as both a photosynthetic enzyme and a major leaf protein reserve further underscores its importance in determining plant productivity. Previous studies have also reported a positive correlation between Rubisco levels and yield in several crop species (Frey & Moss, 1976; Murthy & Singh, 1979; Martinez-Barajas *et al.*, 1992), supporting our findings. Chlorophyll *a* fluorescence measurement indicated a modest increase (3–5%) in the Fv/Fm ratio, reflecting an improvement in the maximum quantum efficiency of Photosystem II (PSII). However, the performance index (PI), a more sensitive indicator of overall photosynthetic performance, showed a much more substantial increase under UV exclusion. These results suggest that the primary inhibitory effects of UV radiation on photosynthesis are not due to direct photodamage to PSII, but rather are likely related to the activity of light-independent enzymes such as Rubisco. Furthermore, the synthesis of UV-absorbing substances (UAS), a plant protective response to UV exposure, was significantly reduced in UV-excluded plants. This supports earlier reports that UAS accumulation is an adaptive mechanism to mitigate UV-induced damage (Laposi *et al.*, 2002; Mazza *et al.*, 2000). The observed reduction in UAS under exclusion conditions confirms the attenuation of UV stress.

From an ecological and agronomic perspective, the enhancement of growth, biomass, and yield under UV exclusion implies a potential suppression of carbon assimilation by ambient UV radiation. Given that atmospheric CO_2 concentrations have risen from preindustrial levels of 280 ppm to over 375 ppm, increasing the carbon fixation capacity of plants is critical for both food security and climate change mitigation. Our findings show that soybean plants under UV exclusion have a greater potential for carbon sequestration due to higher biomass accumulation and Rubisco content. In conclusion, the results indicate that ambient UV-B and UV-A radiation suppress soybean growth and productivity by affecting key physiological and biochemical processes. Exclusion of these UV components leads to improved CO_2 assimilation, greater protein content, and higher yield. These findings open new avenues for research in the field of UV radiation biology, particularly about crop productivity under changing atmospheric conditions. While the current study highlights the biological benefits of UV exclusion, further research is needed to evaluate the economic feasibility and scalability of UV-filtering technologies in large-scale agricultural settings.

Abbreviations: OC (open control), FC (filter control), -UV-B (-ultraviolet B), -UV-A/B (-ultraviolet A/B)

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