Postprint: Morphological Responses of Different Potato Varieties (Lines) to Enhanced UV-B Radiation

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Abstract

UV-B radiation plays an important role in plant morphogenesis, and with the intensification of surface UV-B radiation, it will inevitably affect crops. This study analyzes the morphological response differences among different potato varieties under enhanced UV-B radiation conditions by measuring several important morphological indicators such as plant height, internode length, leaf area, and root-to-shoot ratio, laying a foundation for comprehensively evaluating the effects of UV-B radiation on potatoes and breeding tolerant varieties. The experiment used 4 common and 3 colored potato varieties (lines) as materials, treated with natural light (CK) and two enhanced UV-B radiation levels [2.5 kJ m 2 d 1 (T1), 5.0 kJ m 2 d 1 (T2)], measuring plant height, internode length, leaf area, and specific leaf weight at 15 d, 30 d, and 45 d after treatment, and root-to-shoot ratio at harvest. Finally, response indices (RI) for several morphological indicators were obtained, and the tolerance of the tested varieties was evaluated using the cumulative stress response index (CSRI). The results showed that after enhanced UV-B radiation treatment, most varieties exhibited a consistent trend of decreased plant height, shortened internode length, reduced leaf area, and increased specific leaf weight, and with increasing treatment intensity and duration, the differences between treatments and control became more significant. There were significant differences in morphological responses to UV-B radiation among varieties. The plant height, internode length, and leaf area of common varieties were more significantly inhibited by UV-B radiation, with greater reductions in aboveground biomass. For example, the RI values for aboveground parts (fresh weight) of 'Hezuo 88' under T1 and T2 treatments were 60.28 and 70.44, respectively, while those of 'Lishu 6' were 58.61 and 66.44; colored varieties were less affected, with RI values for aboveground parts of 'Zhuanxinwu' being 107.75 and 21.4, respectively, and '21-1' being 41.49 and 45.72. As the growth of aboveground biomass was significantly inhibited, the underground parts, especially the root system, were also significantly affected, with the pattern of RI value changes in roots between common and colored varieties being consistent with that of aboveground parts. Due to the more significant reduction in aboveground biomass, the root-to-shoot ratio of all varieties (lines) increased compared to the control (T2). The CSRI values of 5 varieties under T1 and T2 treatments showed that 'Hezuo 88' (133.35, 240.85) and 'Lishu 6' (104.09, 160.2) had their morphological characteristics significantly inhibited under enhanced UV-B radiation treatment; colored varieties (lines) 'Zhuanxinwu' (275.97, 51.26) and '21-1' (96.8, 142.17) were relatively less affected than common varieties 'Hezuo 88' and 'Lishu 6' , demonstrating certain UV-B radiation tolerance.

Full Text

Morphological Responses of Potato Varieties (Lines) to Enhanced UV-B Radiation

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Abstract

UV-B radiation plays a crucial role in plant morphogenesis, and intensifying surface UV-B radiation will inevitably affect crop production. This study analyzed differential morphological responses among potato varieties under enhanced UV-B radiation by measuring key morphological indicators including plant height, internode length, leaf area, and root-to-shoot ratio, providing a foundation for comprehensive evaluation of UV-B effects on potato and breeding of tolerant varieties. Four common and three colored potato varieties (lines) were subjected to natural light (CK) and two enhanced UV-B radiation levels [2.5 $kJ \cdot m^{-2} \cdot d^{-1}$ (T1) and 5.0 $kJ \cdot m^{-2} \cdot d^{-1}$ (T2)]. Plant height, internode length, leaf area, and specific leaf weight were measured at 15, 30, and 45 days after treatment initiation, with root-to-shoot ratio determined at harvest. Response indices (RI) were calculated for each morphological parameter, and cumulative stress response indices (CSRI) were used to evaluate variety tolerance. Results showed that most varieties exhibited consistent trends of reduced plant height, shortened internodes, decreased leaf area, and increased specific leaf weight under enhanced UV-B radiation, with differences between treatments and controls becoming more significant as treatment intensity and duration increased. Significant variation in morphological response was observed among varieties. Common varieties showed more pronounced inhibition of plant height, internode length, and leaf area, with greater reductions in aboveground biomass. For example, the aboveground fresh weight RI values for 'Hezuo 88' were -60.28 and -70.44 under T1 and T2, respectively, while those for 'Lishu 6' were -58.61 and -66.44. Colored varieties were less affected, with 'Zhuanxinwu' showing aboveground RI values of 107.75 and 21.4, and '21-1' showing 41.49 and -45.72. As

aboveground biomass accumulation was significantly suppressed, underground parts, particularly roots, were also notably affected, with RI patterns for roots consistent with those for aboveground parts across common and colored varieties. Due to more substantial reductions in aboveground biomass, root-to-shoot ratios increased in all varieties (lines) compared to controls, especially under T2. CSRI values under T1 and T2 indicated that 'Hezuo 88' (-133.35, -240.85) and 'Lishu 6' (-104.09, -160.20) showed significant morphological inhibition under enhanced UV-B radiation, while colored varieties 'Zhuanxinwu' (275.97, 51.26) and '21-1' (96.8, -142.17) were relatively less affected than common varieties, demonstrating certain UV-B radiation tolerance.

Keywords: UV-B radiation; Potato; Morphological response; Colored-tuber variety; Achromatic-tuber variety

Introduction

Potato (*Solanum tuberosum* L.), along with wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and maize (*Zea mays* L.), constitutes one of the four major food crops and serves as an important carbohydrate source in diets worldwide. Potato tubers contain protein, vitamin C, dietary fiber, and anthocyanins in colored varieties that are significant for human health, making potato one of the world' s most important cultivated crops [1]. Global climate deterioration has intensified the greenhouse effect and thinned the ozone layer, and the resulting environmental changes have drawn widespread attention regarding their impacts on terrestrial organisms [2-4]. Specifically, ozone layer depletion has significantly increased surface ultraviolet radiation, with UV-B radiation in the 280–320 nm band imposing strong stress on plants [5]. Therefore, investigating the comprehensive effects of enhanced UV-B radiation on crops is of great significance.

UV-B radiation effects on crops have long been a research focus, causing changes in plant morphology, physiology, signal transduction, and gene expression [6-8]. Recent studies suggest that UV-B radiation functions not only as a stress factor but also as a signaling molecule involved in plant morphogenesis, physiological metabolism, and programmed cell death [9], affecting cellular structure and division [10]. Regarding external morphology, UV-B radiation disrupts polar auxin transport, inhibits stem elongation, induces leaf curling, increases leaf thickness, and eliminates apical dominance [11]. Various plants show distinct symptoms under different intensities of enhanced UV-B radiation. For instance, woody plants exhibit suppressed height and ground diameter growth [12-15]; cowpea (*Vigna unguiculata* L. Walp.) shows reduced plant height and flower length under enhanced UV-B radiation [16]; and *Amaranthus tricolor* L. demonstrates decreased growth indicators including plant height, leaf area, and relative growth rate [17]. Additionally, UV-B radiation significantly affects plant water metabolism by inhibiting photosynthate synthesis in aboveground parts and its transport to roots, thereby impacting root development and root activity [18].

Among major world crops, most UV-B radiation research has focused on cereals such as wheat, rice, and maize, which all show significant growth inhibition under enhanced radiation [19-21]. Rice exhibits clear genotypic differences in UV-B response, with these differences being heritable quantitative traits [22]. Multiple wheat varieties show suppressed plant height under low-dose UV-B radiation, while high doses inhibit most growth parameters including height and fresh weight, with significant interspecific variation in response [23].

Currently, research on tuber crops like potato remains limited [24], and detailed reports on morphological effects of long-term enhanced UV-B radiation on potato under field conditions are scarce. Early studies classified potato as UV-B tolerant [25], but experiments simulating 50% ozone depletion revealed significant variety-specific sensitivity among six potato varieties [26]. Short-term enhanced UV-B radiation can induce morphological responses in potato, such as reduced leaf area and increased leaf dry weight and thickness after 8 days of UV-B exposure [27]. These findings demonstrate that potato, like other plants and crops, exhibits morphological responses and inter-varietal differences under enhanced UV-B stress. Since UV-B radiation significantly damages photosynthesis [28], reduces assimilate export to sink organs, and affects pollen viability and fertilization, it consequently decreases crop yield and quality [29-31]. Previous physiological and biochemical studies on UV-B effects in potato revealed that colored varieties show stronger adaptability than common varieties under enhanced UV-B radiation [32-33]. Therefore, given this irreversible global climate change trend, this study used three colored and four common potato varieties to further analyze morphological effects of enhanced UV-B radiation and inter-varietal response differences, establishing a foundation for comprehensive evaluation of UV-B impacts on potato and breeding of tolerant varieties.

1.1 Experimental Site and Varieties

The experiment was conducted at the Houshan Experimental Farm of Yunnan Agricultural University, located in the northern suburbs of Kunming, Yunnan Province (25°08 N, 102°45 E) at an elevation of 1,966 m. The site has an annual mean temperature of 15.1°C, annual precipitation of 1,000 mm, a frost-free period of 341 days, and predominantly rainfall-based precipitation. The climate features distinct wet and dry seasons, with an annual evaporation of 175.1 mm and average relative humidity of 74%. The soil is acidic red soil with moderate fertility and good drainage. Seven potato varieties (lines) were used as experimental materials, including four common varieties (lines): 'Hezuo 88', 'Lishu 6', 'Jianchuanhong 21-3', and 'Qingshu 9', and three colored varieties (lines): 'Jianchuanhong 21-1', 'Shida 6', and 'Zhuanxinwu'.

1.2 Experimental Design

The study was conducted from March to October 2014. In early March 2014, the experimental field was plowed and leveled, and seed potatoes were prepared. Large plastic pots (outer diameter 0.38 m, inner diameter 0.31 m, height 0.3 m, bottom diameter 0.27 m, volume approximately 0.02 m^3) were used for planting. The cultivation substrate consisted of soil and humus mixed at a 1:1 ratio, with basal fertilizer applied according to local high production levels. Pots were arranged randomly, with one germinated seed potato planted in the center of each pot. Each variety was planted in 60 pots (60 plants), divided into three plots of 20 plants each. Within each plot, pots were placed adjacent to each other with approximately 0.75 m spacing between plants, and 0.8 m wide pathways between plots, totaling 21 plots. Treatments began during the seedling stage when plants reached approximately 0.2 m in height (mid-May).

The experiment was conducted in the field using iron frames with outdoor rain-proof lamp holders for UV lamps. UV-B lamps (UVB-40, Nanjing Huaqiang Electronics Co., Ltd.) with a wavelength range of 280–320 nm were used as the radiation source. Irradiation intensity was adjusted by varying lamp height above the canopy and number of lamps, measured using a UV-B radiometer (Beijing Normal University Photoelectric Instrument Factory). Electrical wires were covered with PVC pipes for rain protection, and lamp height was adjusted weekly as plants grew to maintain a 0.5 m distance from the canopy, ensuring consistent irradiation levels despite plant growth. Pots were rotated 90° to ensure uniform radiation exposure.

For each variety, 45 plants with similar growth were selected for treatment, with 15 plants per plot and three replications. Three pots were placed directly below each lamp tube, arranged in three rows. Irradiation intensity was regulated by adjusting lamp height (measured at canopy level), with radiation intensity measured at 297 nm wavelength. Three treatments were established: 2.5 $kJ \cdot m^{-2} \cdot d^{-1}$ (Treatment 1, one lamp tube, T1), 5.0 $kJ \cdot m^{-2} \cdot d^{-1}$ (Treatment 2, two lamp tubes, T2), and natural light as control (CK). UV-B radiation treatments were applied daily from 10:00 to 15:00 (5 h) beginning May 14, excluding rainy days. Morphological indices were measured at 15, 30, and 45 days after treatment initiation, with total enhanced UV-B radiation exposure lasting 50 days throughout the potato growth period.

1.3 Morphological Index Measurement and Analysis

Plant Height and Internode Length: Plant height was measured as the vertical distance from the pot rim to the plant canopy using a tape measure (n=14). 'Shida 6' plants had senesced and lodged by 45 days, so plant height was not measured at that time. For each treated plant, two main stems were selected, and internode length was measured from the shoot tip downward, beginning from the first clearly distinguishable internode. Five internodes were measured per stem using a ruler.

Leaf Area: For each variety, actual leaf area was determined using the coefficient method on control plants [34]. Fifty leaves were measured from the third and fourth leaf positions from the top (4–5 leaves per plant). After obtaining the leaf area correction coefficient (K), length and maximum width of leaves at the same positions were measured in situ on treated plants using a ruler, with actual leaf area calculated as length × width × K (n=50).

Specific Leaf Weight: Determined using the punch method. Fully functional leaves showing clear treatment symptoms were selected from the third and fourth leaf positions. Fifteen leaves were sampled per treatment or control (one leaf per pot). Leaf discs (r=0.4 cm) were punched from similar positions on each leaf, avoiding main veins, with 30–50 discs collected per treatment. Discs were placed in labeled petri dishes, oven-dried at 80°C to constant weight, and weighed using an electronic balance (0.001 g precision). Specific leaf weight (SLW) was calculated as: SLW = W/(3.14×r^2\$×10)×\$100%. Varietal SLW changes were compared across the three measurement periods (15, 30, and 45 days).

Root-to-Shoot Ratio: At harvest, plants were cut at the root collar. Underground parts included main roots, fibrous roots, and tubers, while aboveground parts included stems, branches, and leaves above the root collar. Fresh weights were measured separately, and root-to-shoot ratio (R/T) was calculated as underground weight/aboveground weight (n=7 per variety). '21-3' and 'Shida 6' were excluded from root-to-shoot ratio analysis due to early senescence and premature maturity that resulted in dried aboveground parts at harvest.

Response Index (RI) and Cumulative Stress Response Index (CSRI): RI was calculated as RI = (T−CK)/CK\$×\$100%. CSRI was calculated as the sum of individual RIs to comprehensively evaluate morphological responses to UV-B radiation across varieties [23]. Plant height, internode length, and leaf area RIs were averaged across the three measurement periods. '21-3' and 'Shida 6' lacked CSRI values because root-to-shoot ratio was not measured.

1.4 Statistical Analysis

Data were processed using Microsoft Excel 2007. One-way ANOVA and LSD multiple comparisons were performed using SPSS 19.0 to analyze significant differences among treatments ($P<0.05$).

2.1 Effects of Enhanced UV-B Radiation on Potato Plant Height

Since enhanced UV-B radiation treatments began when seedlings reached 0.2 m, the effects on plant height showed a clear time-dependent pattern. As shown in , no significant differences in plant height were observed between treatments and controls at 15 days. However, after 30 days, treated plants gradually became shorter compared to controls. Except for 'Zhuanxinwu' , plant height of the remaining six varieties (lines) decreased sequentially with increasing treatment intensity, with significant differences ($P<0.05$) between T2 and CK observed in 'Hezuo 88' , 'Lishu 6' , '21-1' , and 'Qingshu 9' . After 45 days, as growth vigor increased, most plant heights were greater than earlier stages, but the trend of reduced height in treated plants persisted. Except for '21-3' , treated plants remained shorter than controls, with significant differences ($P<0.05$) between both treatment intensities and controls in 'Hezuo 88' and 'Lishu 6' .

2.2 Effects of Enhanced UV-B Radiation on Potato Internode Length

Under enhanced UV-B radiation, plant height reductions were accompanied by similar patterns in internode length. shows that 'Hezuo 88' , 'Lishu 6' , and '21-1' exhibited consistent patterns across all three measurement periods, with internodes significantly shorter in treated plants compared to controls. For 'Hezuo 88' , significant differences ($P<0.05$) between treatment intensities were observed at 30 and 45 days. 'Zhuanxinwu' and 'Shida 6' showed no significant differences between treatments and controls at 30 days, but internodes were significantly shorter at 15 and 45 days. '21-3' and 'Qingshu 9' both showed significant internode length reductions at 30 days, but no clear differences at 15 and 45 days.

2.3 Effects of Enhanced UV-B Radiation on Potato Leaf Area

Under enhanced UV-B radiation, plant height and internode length decreased, and as shown in , leaves—the organs receiving the most radiation—were most significantly affected. All seven varieties showed reduced leaf area after treatment. Except for '21-3' , most varieties exhibited significant differences between controls and treatments, as well as between the two treatment intensities. 'Hezuo 88' , 'Lishu 6' , and 'Qingshu 9' showed leaf area reductions exceeding 50% after 30 days, and after 45 days, all varieties except '21-3' showed reductions exceeding 50% under T2, with 'Hezuo 88' and 'Lishu 6' showing the largest decreases at 67.6% and 66.0%, respectively. '21-3' showed the lowest inhibition and smallest reduction in leaf area among all varieties. Large-leaf varieties such as 'Hezuo 88' (10.8 cm^2 at 45 days), 'Lishu 6' (9.7 cm^2 at 45 days), and 'Qingshu 9' (10.2 cm^2 at 45 days) were more significantly affected by enhanced radiation and showed greater leaf area reductions compared to the small-leaf variety '21-3' (3.1 cm^2 at 45 days).

2.4 Effects of Enhanced UV-B Radiation on Potato Specific Leaf Weight

Under enhanced radiation, leaf expansion was inhibited and leaves tended to thicken. Measurements across three time periods revealed that specific leaf weight differed between treated and control plants, generally showing an increasing trend, though not reaching significant levels (Fig. 1 [Figure 1: see original paper]). Specific leaf weight increased in 'Hezuo 88' , 'Lishu 6' , '21-1' , and 'Qingshu 9' after treatment, with the largest increases in 'Hezuo 88'

(24.07% under T2) and 'Lishu 6' (28.67% under T1). 'Qingshu 9' also showed an 11.44% increase under T1, while '21-1' showed a slight increase. '21-3' and 'Shida 6' showed decreased specific leaf weight under T1 followed by increases under T2, while 'Zhuanxinwu' showed lower specific leaf weight than controls after treatment.

2.5 Effects of Enhanced UV-B Radiation on Potato Biomass and Root-to-Shoot Ratio

Although potato roots underground were not directly exposed to UV-B radiation, they were negatively affected by reduced aboveground biomass. Root weight decreased in 'Hezuo 88', 'Lishu 6', and 'Qingshu 9' after treatment, particularly in the first two varieties which showed greater reductions. '21-1' and 'Zhuanxinwu' showed no clear effects, with root mass even slightly increasing. For underground tubers, which develop later than roots, effects were not significant, with average yield per plant showing both increases and decreases with large fluctuations across treatment intensities. Aboveground parts, directly exposed to enhanced UV-B radiation, showed substantial biomass reductions: 'Hezuo 88', 'Lishu 6', '21-1', and 'Qingshu 9' showed decreases of 70.44%, 66.44%, 45.72%, and 32.01% under T2, respectively, while only 'Zhuanxinwu' showed no aboveground biomass reduction. Since underground parts were less affected than aboveground parts, root-to-shoot ratios increased in all varieties after enhanced UV-B exposure, with significant differences ($P<0.05$) observed in 'Hezuo 88' and 'Lishu 6' under T2 (Table 4).

2.6 Response Indices and Correlation Coefficients Under Enhanced UV-B Radiation

Analysis of response indices for aboveground and belowground morphological indicators revealed that all major morphological features were inhibited to varying degrees under enhanced UV-B radiation, with inhibition becoming more pronounced as radiation intensity increased (Table 5). Among the six indices, leaf area index was negative under both treatment intensities, indicating a convergent adaptive characteristic of leaves under radiation stress. The remaining five indices showed both positive and negative values, but negative values predominated, particularly at higher radiation intensity, where they appeared more frequently with larger absolute values, indicating more severe inhibition. Notably, morphological responses showed significant inter-varietal differences under enhanced radiation. Among the five varieties, 'Zhuanxinwu' showed positive CSRI values under both treatments, while '21-1' showed positive CSRI under T1 but negative under T2. The remaining three varieties showed negative values under both treatments, particularly 'Lishu 6' and 'Hezuo 88' with large absolute negative values, indicating greater impacts from enhanced UV-B radiation.

Correlations between CSRI and individual morphological indicator RIs differed markedly between treatments (Table 6). Under T1, CSRI showed extremely significant correlations (P<0.01) with leaf area, root weight, and aboveground weight, and significant correlation (P<0.05) with plant height. Under T2, CSRI showed extremely significant correlation (P<0.01) only with aboveground weight, and significant correlations (P<0.05) with internode length and root weight. Inter-index relationships showed that leaf area was extremely or significantly correlated with plant height, internode length, root weight, and aboveground weight under T1, but only significantly correlated with root weight under T2. Aboveground weight was extremely or significantly correlated with plant height, root weight, leaf area (T1), and internode length (T2).

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3 Discussion and Conclusion

Plants under stress typically adjust their external morphology by inhibiting cell elongation, stimulating localized cell division, and altering cell differentiation states to reduce stress exposure, a strategy termed "stress-induced morphogenic response" (SIMR) [35]. This study demonstrated that potato varieties (lines) showed significant morphological changes under enhanced UV-B radiation compared to natural light, exhibiting typical UV-B stress effects of reduced plant height, shortened internodes, decreased leaf area, and increased leaf thickness (specific leaf weight) [11,24,36]. These results indicate that potato is not a UV-B-tolerant crop, but like other crops, produces significant morphological responses in enhanced UV-B environments. By reducing leaf area and plant height, potato can decrease direct UV-B damage and protect apical meristems, representing a morphological adaptation to unfavorable environments similar to adaptation strategies of alpine cushion plants under strong UV radiation [37].

For autotrophic higher plants, larger leaf area and optimal light interception angles facilitate greater photosynthate production and competitive advantage in favorable environments. However, these leaf characteristics are obviously vulnerable under stress. Leaf area response indices revealed that large-leaf varieties 'Hezuo 88' and 'Lishu 6' experienced the strongest UV-B inhibition, while small-leaf variety '21-3' showed minimal inhibition. Correspondingly, as leaf expansion was suppressed, leaf mass per unit area increased, with the largest increases in large-leaf varieties 'Hezuo 88' and 'Lishu 6'. This UV-B-induced increase in specific leaf weight closely resembles effects in plant leaves under other climate change conditions such as low temperature, high altitude, and water stress [38], enhancing plant resistance to adverse environments. Additionally, the robust growth, large leaves, and multiple branches of these two varieties resulted in greater aboveground impacts under enhanced UV-B radiation, with more obvious reductions in aboveground biomass due to decreased plant height, internode length, and leaf area.

Due to correlations between aboveground and belowground parts, enhanced radiation caused not only significant aboveground biomass reduction but also changes in belowground biomass (roots and tubers). Aboveground growth inhibition from radiation enhancement was more pronounced, and this suppression affected root development and growth. Aboveground biomass showed significant correlations with root weight under both treatment intensities, with root mass decreasing in multiple varieties under higher treatment intensity (T2), consistent with related research [39]. Typically, UV-B-induced leaf area reduction and significant photosynthesis inhibition [40-41] reduce photosynthate transport to sink organs, decreasing yield (as in cereals). However, this study showed positive yield effects under T1 for all varieties, with negative effects appearing only under T2. This may relate to treatment duration (cumulative effects) and radiation dose, as low-dose radiation triggers morphogenic responses while high doses (>8 $kJ \cdot m^{-2} \cdot d^{-1}$) affect multiple physiological processes, reducing dry matter and economic yield [9]. The 50-day treatment duration (vs. 90–120 day potato growth period) and maximum dose of 5 $kJ \cdot m^{-2} \cdot d^{-1}$ may have been insufficient to cause significant tuber yield changes, with morphological responses effectively mitigating UV-B damage. Additionally, since auxin plays an important role in potato tuber formation and expansion [42] and UV radiation significantly affects auxin metabolism [43], this phenomenon warrants further investigation regarding whether it results from auxin metabolic changes or compensatory growth shifting to underground tubers under radiation stress. Overall, since aboveground parts received direct radiation with larger reductions (except 'Zhuanxinwu'), root-to-shoot ratios increased in all varieties after treatment, consistent with related studies [45-46].

Notably, under identical enhanced radiation treatments, the seven varieties showed consistent morphological changes, with most exhibiting "stress-avoidance" adaptations of reduced plant height, shortened internodes, and decreased leaf area, accompanied by increased specific leaf weight and root-to-shoot ratio. However, morphological responses showed significant inter-varietal differences. Large aboveground biomass common varieties 'Hezuo 88' and 'Lishu 6' were more severely inhibited under enhanced radiation, with significant reductions in root biomass, classifying them as radiation-sensitive based on CSRI analysis. In contrast, colored variety 'Zhuanxinwu' showed no radiation inhibition in plant height, internode length, aboveground biomass, or root mass indices, with positive CSRI values indicating strong UV-B tolerance. '21-1' showed positive CSRI under T1 but inhibition under T2. Previous studies have shown that colored varieties exhibit more pronounced physiological resistance indicator responses than common varieties under enhanced UV-B radiation [32-33], and this study preliminarily confirms from morphological changes that colored varieties may possess greater UV-B tolerance or alternative adaptation mechanisms warranting further physiological and molecular investigation.

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Note: Figure translations are in progress. See original paper for figures.