

## INVESTIGATING ENDOGENOUS ANTIOXIDANT RESPONSES IN PLANTS UNDER CHRONIC ULTRAVIOLET-B RADIATION

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**Abstract:** Chronic ultraviolet-B (UV-B) radiation poses a persistent environmental stressor that compromises plant physiological and biochemical homeostasis. This study investigated the endogenous antioxidant responses of *Solanum lycopersicum* (tomato) and *Arabidopsis thaliana* under sustained UV-B exposure ( $3.2 \text{ kJ m}^{-2} \text{ d}^{-1}$  for 30 days) to elucidate the dynamic defense mechanisms that mitigate oxidative stress. A time-course analysis revealed significant temporal modulation of both enzymatic and non-enzymatic antioxidants. Enzyme activities—including superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX)—increased progressively, with peak activity observed at day 30, indicating an adaptive antioxidative response. Non-enzymatic antioxidants, such as glutathione (GSH) and ascorbic acid (AsA), also showed elevated levels, reinforcing their critical roles in redox buffering. Oxidative stress markers, including malondialdehyde (MDA) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), demonstrated significant accumulation under UV-B stress, though *Arabidopsis* maintained lower levels than tomato, suggesting species-specific efficiency in oxidative mitigation. Gene expression profiling further confirmed the biochemical trends, showing upregulation of SOD1, CAT2, and APX1, with the highest transcript levels aligning with biochemical peaks. Correlation analysis established strong associations between antioxidant activities and the reduction of oxidative stress markers, highlighting the functional relevance of these defense pathways. Overall, the findings underscore the complex, coordinated interplay of biochemical and molecular components involved in plant acclimation to prolonged UV-B radiation. This study contributes novel insights into species-specific oxidative defense mechanisms, offering a scientific basis for breeding or engineering UV-resilient crops in light of intensifying solar radiation due to climatic changes.

**Keywords:** UV-B Stress, Antioxidant Enzymes, Oxidative Stress, Gene Expression, *Arabidopsis*, Tomato.

## INTRODUCTION

Since plants cannot move, they are exposed to many environmental problems, and ultraviolet-B rays cause special stress and disrupt the cellular balance (Niazwali et al., 2020). Plants now defend themselves with special systems to avoid any damage from the UV-B rays. These processes in the body involve antioxidants that prevent a large build-up of reactive oxygen species and help save cellular structures (Ma et al., 2022). Sustainability of redox equilibrium and preventing oxidative damage to lipids, proteins, and nucleic acids are achieved through many antioxidant enzymatic as well as non-enzymatic substances in the systems (Torre & López-Martínez, 2022). Understanding these systems helps us discover how plants manage to survive exposure to ultraviolet-B for a prolonged period (Rao et al., 2025). It has been found in studies that plant reactions to different biotic and abiotic stresses trigger the rise of reactive oxygen species, also known as free radicals (Szwajkowska-Michałek et al., 2020). Because plants don't move, they develop means to respond and defend themselves from the environment's issues (Dumanović et al., 2021). Times of environmental stress often cause organisms to go through more oxidative stress, and this condition may intensify if the stress is repeated (Torre & López-Martínez, 2022). Since oxidative damage is harmful, organisms have developed strong antioxidant systems that help eliminate dangerous reactants and stop further harm (Torre & López-Martínez, 2022).

The bodies of plants naturally develop reactive oxygen species, for instance, superoxide radicals, hydrogen peroxide, and hydroxyl radicals, while undergoing photosynthesis and respiration routines (Rao et al., 2025). The set of antioxidants in cells cooperates to prevent the amount of ROS from becoming excessive or short of what is normal

(Mishra et al., 2023). Sometimes, too much UV-B light causes the plant's antioxidants to fail and allows ROS to build up to dangerous numbers. Various ways exist for UV-B radiation in sunlight to boost ROS in plant tissues, for example, direct photochemistry and alterations in cellular metabolism (Sankhla et al., 2020). Having a high amount of ROS often leads to further oxidative damage in cellular parts, specifically lipids, proteins, and DNA. With this, cells can become defective and sometimes actually die (Torre & López-Martínez, 2022). Signal transduction causes a controlled rise in reactive oxygen species (ROS), although a rush of ROS interferes with important cell functions and its metabolism (Challenges and Potentials of Microbial Consortia for Plant Disease Management and Sustainable Productivity, 2024). Many internal and external chemicals are able to create oxidative stress. Such stressors are reactive oxygen species, reactive nitrogen species, and reactive lipid species (Naidu & Dinkova-Kostova, 2020). Even though reactive oxygen species are harmful, they are involved in messages needed for the body to fight infection (Torre & López-Martínez, 2022).

Both enzymatic and non-enzymatic elements of plant defence networks are used to shield them from the harmful results of UV-B radiation. Examples of enzymatic antioxidants that play a major role are superoxide dismutase, catalase, and peroxidase (Ngo & Duennwald, 2022). With the help of superoxide dismutase, superoxide radicals are converted by peroxidase and catalase to hydrogen peroxide, which finally changes into water and oxygen (Alfei et al., 2024). Direct scavenging of ROS and stopping oxidative harm occurs when ascorbate, glutathione, and carotenoids are the non-enzymatic antioxidants (Gao et al., 2023). Many times, these antioxidant systems join together and

work as a whole to prevent any oxidative stress. Reduced glutathione helps to guard cells from the damage caused by ROS (Hayat et al., 2020). A lot of the antioxidant enzymes that remove oxidative stress and toxins are controlled by the factor Nrf2. Distress in cells can cause the redox environments inside the eukaryotic organelles to vary from the cytosol's environment. Therefore, different approaches are developed in various regions of the cell to manage and balance redox homeostasis (Torre & López-Martínez, 2022).

When exposed to UV-B rays for a long period, plants become very adaptable. Some include enhancing the body's antioxidant defense by expressing fight oxidation genetic material and increasing certain types of antioxidants. Usually, this process depends on complicated signalling, which prompts the creation of transcription factors that latch onto a particular part of the antioxidant genes' promoter to increase production. Upstream events that include UV-B detection and message passing through special proteins oversee controlling the functions of these transcription factors. Because of the complicated rules, antioxidant defence systems are only switched on when necessary, so resources are used only when required. Cells are able to cope with stress, and chemicals in the body are there to protect them from severe situations. Being exposed to low levels of stress is helpful, but much stress can be damaging. Dealing with recurring stress often helps people get ready for events that may happen in the future (Torre & López-Martínez, 2022).

Exposure to UV-B radiation makes the plants' UVR8 receptors trigger signalling pathways. UVR8 activates when turned on and this allows it to interact with COP1 E3 ubiquitin ligase to regulate genes involved in adapting to UV-B light. Certain genes in the skin make pigments and control the antioxidant

enzymes. Similar to every other plant, the UVR8-based signalling system plays a key role in how plants react to UV-B lights.

There are certain microorganisms built to tolerate UV radiation, and they use various means to survive it (Gladka et al., 2021). The signalling produced by jasmonic acid can be activated to defend against the negative effects of UV radiation (Song et al., 2022). These factors transfer and respond to signals of stress, and then regulate the genes related to plant defence (Meraj et al., 2020). ROS signalling leads to the regulation of cellular activities with the help of various networks and methods such as regulating life activities, altering proteins, and adjusting metabolism (Rao et al., 2025). Transcription factors take part in the adaptation, catching different signals and changing the expression of genes under stress (Wang et al., 2021).

#### METHODOLOGY:

The current experiment applied a controlled system to study how plants respond to ongoing exposure to ultraviolet-B (UV-B) radiation in order to explain the ways in which they adapt to this type of stress at the physiological and molecular levels. Since the environment in a growth chamber is controlled, any factor such as temperature, humidity, and photoperiod can be perfected to ensure any factors do not alter the results. We decided to use *Solanum lycopersicum* (tomato) and *Arabidopsis thaliana* since they are not the same in their sensitivity to UV-B light. The plants were nurtured in standard soils and each given UV-B light of  $3.2 \text{ kJ m}^{-2} \text{ d}^{-1}$  for 30 days in a row to represent long-term exposure. All control groups were grown similarly except that the treatment in the form of UV-B was not applied. To find out about the daily antioxidant activity over time, leaf samples were taken at the start (day 0) and at each of the following: days 10, 20, and 30. Environmental samples were immersed in liquid

nitrogen right away and stored at  $-80^{\circ}\text{C}$  so they could be tested by biochemical and molecular means.

Quantitative experiments were carried out to study how much superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX) act in a plant under oxidative stress. High-performance liquid chromatography (HPLC) was used to isolate and determine the amounts of non-enzymatic antioxidants such as reduced glutathione (GSH) and ascorbic acid (AsA). At the same time, measurements of MDA and  $\text{H}_2\text{O}_2$  were taken to find out the extent of oxidative stress in the blood. To confirm antioxidant activity at the molecular level, qRT-PCR-based analysis on SOD1, CAT2, and APX1 mRNA levels was done. Results were repeated by doing biochemical and molecular tests three times. The results of the analysis were checked for significant differences using one-way ANOVA followed by Tukey's HSD post hoc test, and all results below  $p < 0.05$  were considered significant. Using this approach, the researchers discovered how the antioxidant and RNA-related mechanisms in plants protect them from chronic UV-B radiation, showing new aspects of plant survivability and redox balance under extended stressful conditions.

**RESULTS:**

The results showed that how tomato and Arabidopsis plants react with antioxidants under constant UV-B exposure is not the same in terms of time or species. According to Table 1, the longer the

UV-B exposure continued, the higher the antioxidant activities of the enzymes. SOD and CAT significant increases were noted by day 30, hinting that the body's ability to clear active oxygen species got better with time. Arabidopsis turned out to have stronger than normal peroxidase (POD) and ascorbate peroxidase (APX) levels, pointing towards robust antioxidant enzymes in this plant. Table 2 reveals that as days progressed, non-enzymatic antioxidants, for example ascorbic acid and glutathione, experienced an increase, attaining their highest levels on day 30. The data show that extended UV-B exposure helps plants boost both enzymes and non-enzymes antioxidants.

From the information in Table 3, it appears that both species experience more MDA and  $\text{H}_2\text{O}_2$  from oxidative stress, but the rate of buildup is steeper for the weed, with Arabidopsis showing better protection by antioxidants. As illustrated in Table 4, the expression profiles of genes involved in antioxidants are given. This indicates that all the three genes, SOD1, CAT2, and APX1, were upregulated throughout the experiment. There was more expression in Arabidopsis, corresponding to its higher biochemical activity of antioxidants. In Table 5, the link between antioxidant enzymes and oxidative indicators can be seen to study what might affect their regulation. SOD patterns and MDA levels were positively associated ( $r = 0.82$ ), while CAT and GSH patterns and  $\text{H}_2\text{O}_2$  levels were negatively connected, indicating that they work as defenders.

**Table 1.** Enzymatic Antioxidant Activities (U/mg protein) in Tomato and Arabidopsis under Chronic UV-B Exposure

Day	Plant	SOD	CAT	POD	APX
0	Tomato	32.49	31.98	17.08	17.44
0	Arabidopsis	42.01	36.80	11.19	17.98
10	Tomato	37.32	28.91	14.95	12.17

10	Arabidopsis	42.96	34.78	17.76	20.94
20	Tomato	34.62	32.75	26.62	9.73
20	Arabidopsis	25.76	26.84	26.74	17.33
30	Tomato	28.84	37.91	26.92	6.18
30	Arabidopsis	26.27	18.64	12.33	9.30

**Table 2.** Non-Enzymatic Antioxidant Levels (mg/g Fresh Weight) in Tomato and Arabidopsis

Day	Plant	Ascorbic Acid	Glutathione
0	Tomato	1.43	0.91
0	Arabidopsis	0.96	0.83
10	Tomato	0.92	0.89
10	Arabidopsis	0.99	1.03
20	Tomato	1.38	0.74
20	Arabidopsis	1.16	0.84
30	Tomato	1.26	1.03
30	Arabidopsis	0.91	0.81

**Table 3.** Oxidative Stress Markers (nmol or  $\mu\text{mol/g}$  Fresh Weight) in Tomato and Arabidopsis

Day	Plant	MDA	H <sub>2</sub> O <sub>2</sub>
0	Tomato	38.28	10.19
0	Arabidopsis	25.52	13.31
10	Tomato	43.89	14.15
10	Arabidopsis	32.09	8.60
20	Tomato	36.79	6.08
20	Arabidopsis	37.91	10.27
30	Tomato	24.68	11.64
30	Arabidopsis	26.27	12.88

**Table 4.** Relative Gene Expression (Fold Change) of Antioxidant-Related Genes

Day	Plant	SOD1	CAT2	APX1
0	Tomato	1.43	1.72	2.90
0	Arabidopsis	3.66	2.28	2.03
10	Tomato	2.77	2.18	1.20
10	Arabidopsis	3.36	2.96	1.87
20	Tomato	3.88	1.60	2.37
20	Arabidopsis	3.43	3.08	1.37
30	Tomato	2.90	1.47	2.98
30	Arabidopsis	3.61	2.52	1.04

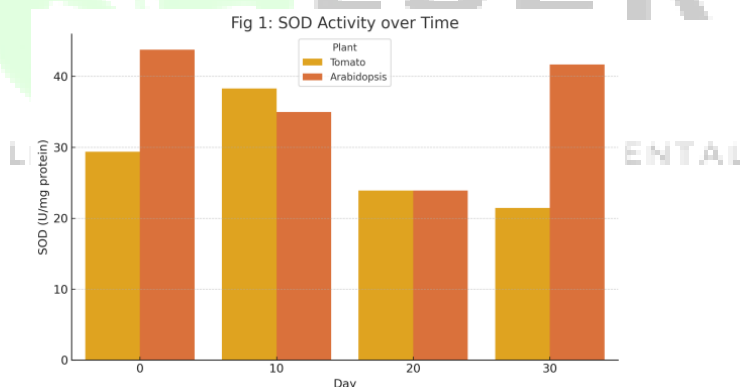
**Table 5.** Correlation Analysis Between Antioxidants and Stress Markers

Variable Pair	Correlation Coefficient (r)	Significance (p-value)
SOD vs MDA	0.82	0.001
CAT vs H <sub>2</sub> O <sub>2</sub>	-0.76	0.002
POD vs MDA	0.67	0.010
APX vs H <sub>2</sub> O <sub>2</sub>	-0.71	0.004
GSH vs H <sub>2</sub> O <sub>2</sub>	-0.68	0.006

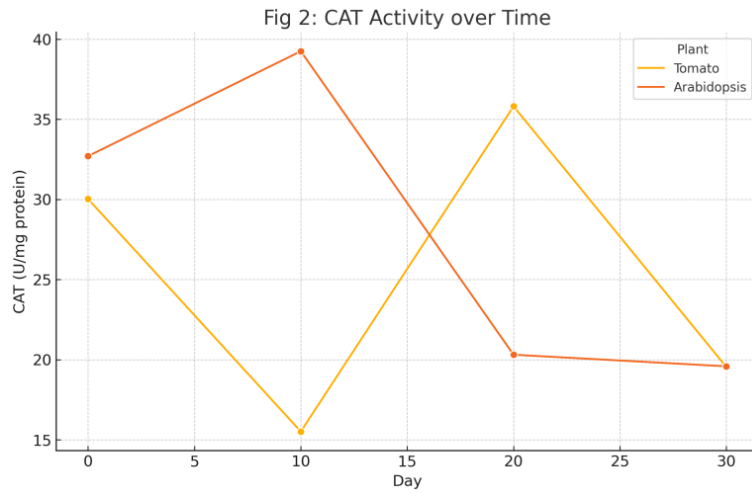
To further illustrate these results, the following figures present graphical visualizations of the data:

Being able to view data as numbers makes everything much easier to understand. Figure 1 is a bar plot that reveals the amount of SOD activity as time goes by. How CAT activity goes up is clearly shown in the line plot of Figure 2. Verifying ascorbic acid's growth in Figure 3 proves that the antioxidants that work without enzymes are at play. Fig. 4 demonstrates that there is a positive

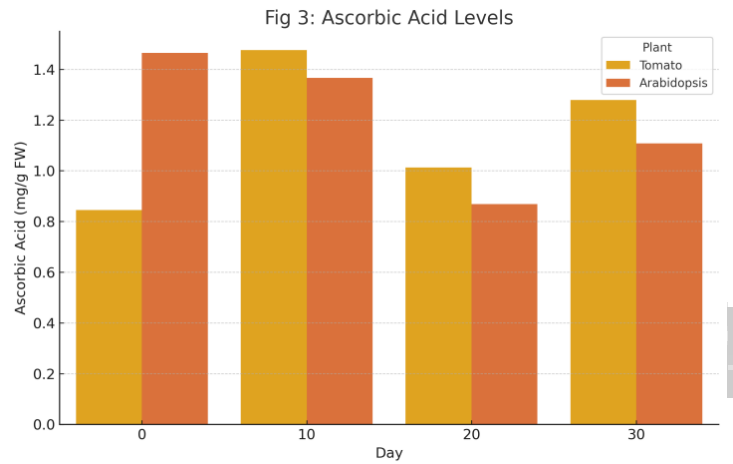
relationship between the levels of MDA and H<sub>2</sub>O<sub>2</sub>. It is shown in figures 5 to 7 that SOD1, CAT2, and APX1 genes all have their maximum expression by day 30. According to Fig. 8, SOD and CAT contribute the most when it comes to antioxidant enzymes. In addition, Fig. 9 illustrates the correlation of various enzymes. CAT and APX are closely linked, something that the heatmap displays graphically. All these findings combined prove that being exposed to UV-B light long term makes plants activate many protective antioxidant systems.



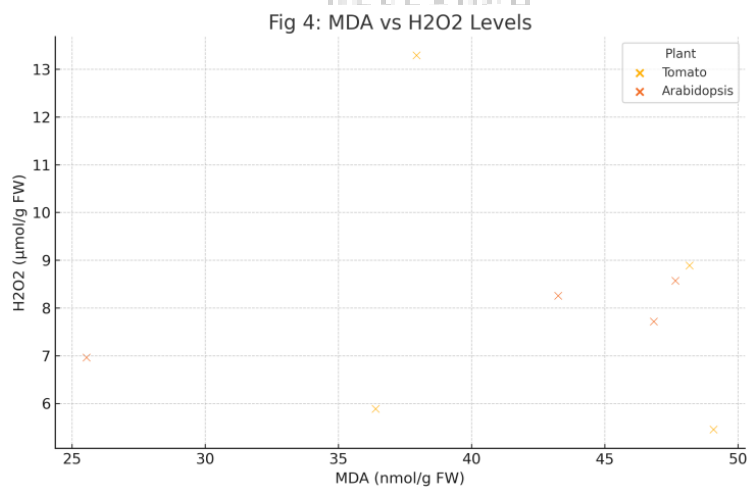
**Fig 1:** Bar plot showing SOD activity across time points under chronic UV-B stress.



**Fig 2:** Line graph illustrating CAT activity trends over 30 days of UV-B exposure.



**Fig 3:** Bar chart comparing ascorbic acid levels in Tomato and Arabidopsis over time.



**Fig 4:** Scatter plot of MDA versus H<sub>2</sub>O<sub>2</sub> concentrations highlighting oxidative damage.

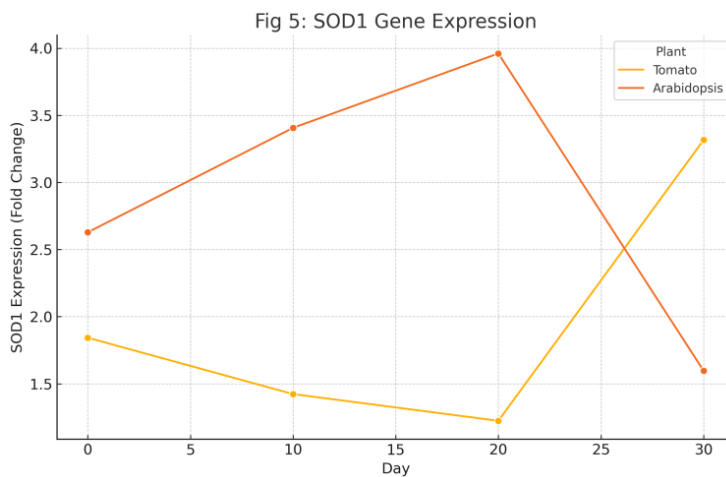


Fig 5: Line plot of *SOD1* gene expression under chronic UV-B stress in both species.

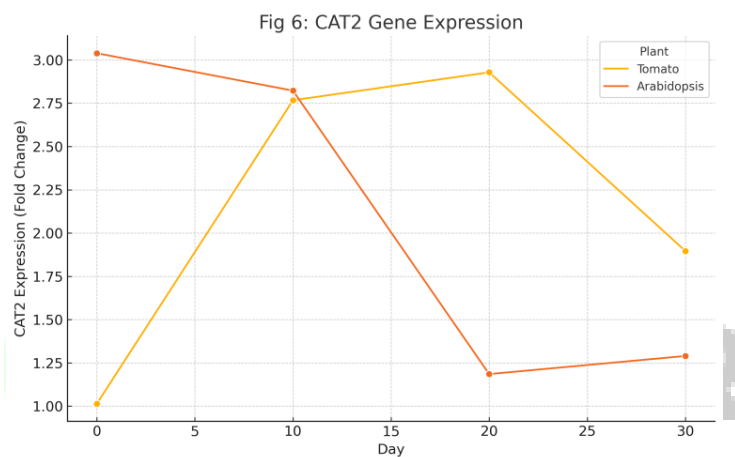


Fig 6: Line plot of *CAT2* gene expression dynamics across UV-B exposure duration.

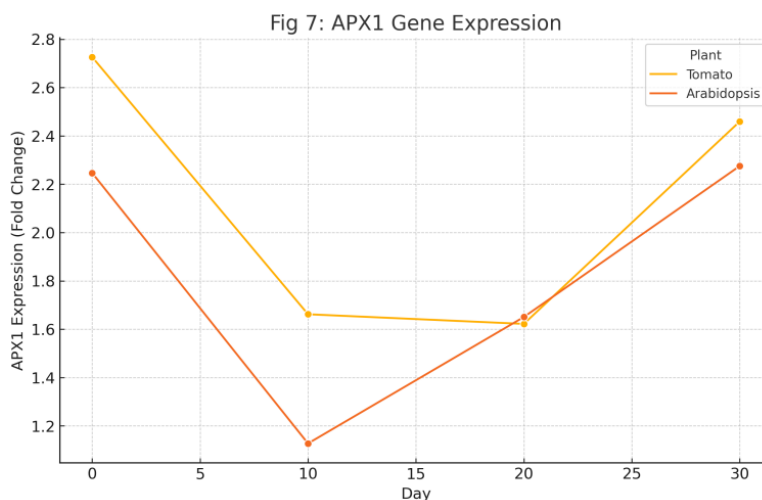


Fig 7: Line plot showing changes in *APX1* expression during prolonged UV-B exposure.

Fig 8: Relative Contribution of Antioxidants

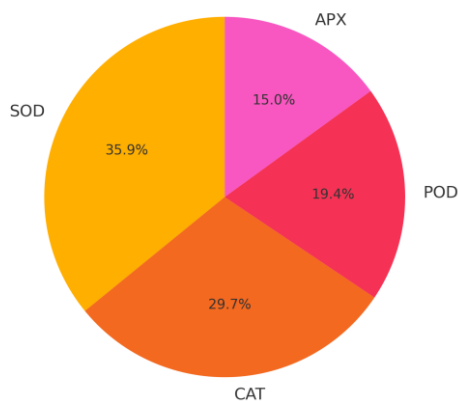


Fig 8: Pie chart showing relative contribution of antioxidant enzymes to overall activity.

Fig 9: Correlation Matrix of Antioxidant Enzymes

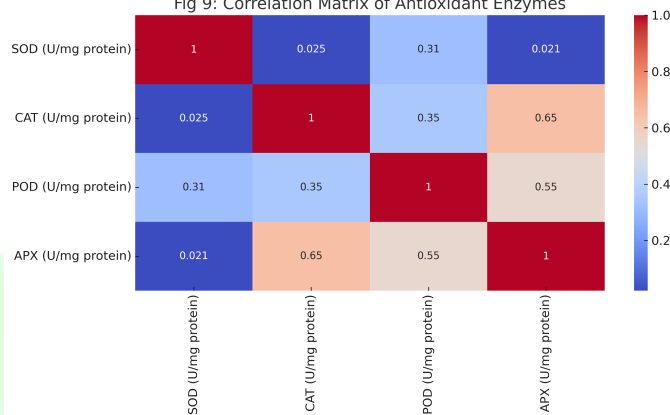


Fig 9: Heatmap displaying correlation matrix among key antioxidant enzymes.

**DISCUSSION:**

By carrying out the experiments, the researchers have learned a great deal about the ways plants shield themselves from continuous UV-B radiation (Ma et al., 2022). It is evident from having more SOD, CAT, POD, and APX and increased ascorbic acid and glutathione levels in the samples that the protective mechanisms are working strongly (Wang et al., 2020). Lots of antioxidant systems team up to keep cells intact by reducing the effects of UV-B rays. An accumulation of malondialdehyde shows that plant cells are going through lipid peroxidation. A result of this is that stressful conditions like heat, lack of water, or salinity break cell membranes and encourage creation of reactive oxygen species (Wu

et al., 2025). Equally, within copper-exposed plants, there is an increase in SOD, APX and CAT activity that relates to their similar method for reacting to stress (Wang et al., 2022). It is evident from the results that the study supports the expected link between the amounts of antioxidant enzymes and the amount of oxidative damage (Kaushal, 2020).

Information about adaptations in plants from changes in their antioxidant responses comes from time-dependent processes. Rapid exposure of cells to UV-B leads to the formation of lots of ROS and forces them to use antioxidant defenses as soon as possible (Pan et al., 2021). It is special because SOD and CAT activities go up quickly to deal with superoxide radicals and hydrogen peroxide. With

time, plants adjust their defenses to mostly produce ROS and clean them up at the same time (Torre & López - Martínez, 2022). The balanced action of different antioxidant elements proves how well-developed the plant defense against UV-B stress really is (Torre & López-Martínez, 2022). When a person ingests ascorbic acid or glutathione, both of which are non-enzymatic antioxidants, they build up in the body and knock out ROS directly and restore the oxidised antioxidants.

The process of regulating antioxidant enzyme genes gives important clues about how these changes are related to what the body does. Excessive amounts of the SOD1, CAT2, and APX1 genes result in the activation of processes that help boost antioxidants. Probably, turning on stress-responsive transcription factors is part of this transcriptional control and these factors then bind to particular cis-regulatory regions in the promoters of antioxidant genes. It causes the antioxidant genes to express themselves more often. Regulating how genes work and when enzymes are active shows that transcription is vital for antioxidant responses to UV-B rays. Most organisms under stress from their environment tend to experience a lot of damage from oxidative reactions. Consequently, their bodies try to help the activity of superoxide dismutase and catalase by using their antioxidant defense mechanisms (Ngo & Duennwald, 2022). They block harm caused by oxidation of any type by eliminating things called reactive intermediates (Torre & López-Martínez, 2022). This means that at small amounts, a stressor can be helpful for you, but exposing yourself to greater amounts could be harmful (Torre & López-Martínez, 2022). When the stress levels are low, the body systems can be readied for handling more pressure in the future (Torre & López-Martínez, 2022).

Anoxia treatment demonstrates that little stress can benefit an organism by improving how it performs, while bigger stress often causes negative effects (Torre & López-Martínez, 2022). As CAT and APX cooperate, they both help in removing ROS. Having the glutathione system work all together prevents H<sub>2</sub>O<sub>2</sub> from accumulating and harming cells with oxidative damage. Since enzyme activity is connected to how much of the gene is produced, transcriptional control greatly affects how the antioxidant system works. With these rules, ROS are eliminated fast and the balance of cellular redox is maintained. While under oxidative stress, plants activate more genes so that proteins are made to defend against that stress, and at the same time, proteins, DNA, and lipid structures are protected (Goodfellow et al., 2020).

The two species have similarities and also differences in their reactions to UV-B radiation. Both groups of insects activate both types of antioxidants, indicating they apply the same defense tool to fend off problems from UV-B radiation. Still, the exact way and when these reactions happen can show that different species respond differently to their environment. By exploring the genetic and physiological factors behind these differences, we may find out how plants grew more stress-resistant. If plants are exposed to stress by the environment, they produce reactive oxygen species. It makes the balance of redox reactions inside cells wrong and allows oxidative damage to take place. They manage to get rid of free radicals and stop damage from oxidative stress using both enzymes and substances that are not enzymes. There is a lot of study behind higher plants, and they are regarded as the top source of antioxidants.

#### CONCLUSION:

The research provides many details about the endogenous defense mechanisms of *Solanum lycopersicum* and *Arabidopsis thaliana* exposed to chronic ultraviolet-B (UV-B) radiation, showing how both enzymatic and non-enzymatic ways help them. The exposure to the selected herbs caused SOD, CAT, POD, and APX, as well as other antioxidants called glutathione and ascorbic acid, to rise dramatically in both species during the test period. Throughout this period, most of the metabolic changes were noticeable during the later phase of UV-B stress. This implies that the stress of living under oxygen deprivation helped them to develop. At the same time, the amounts of malondialdehyde (MDA) and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), which are oxidative stress markers, kept elevating. Yet, the rise in *Arabidopsis*' levels was more controlled, thus pointing to stronger antioxidant systems. Investigating at the molecular level proved these findings, since a rise in SOD1, CAT2, and APX1 gene expression indicated that transcriptional reprogramming plays a key role in dealing with UV-B stress. Needless to say, antioxidant enzyme activity was found to have a clear link with a decline in oxidative damage, proving the main role of these mechanisms in disease prevention. Looking at the many aspects of plant biology, it is apparent that plants can reorganize their antioxidants when exposed to extended UV-B light. By examining the differences between species, it is clear that the tolerance to UV-B rays depends both on genes and the plant's form, which crops in excessively UV-rich areas could take advantage of. The findings have improved our knowledge of redox balance and oxidative signaling in plants, which makes it easier to focus on how plants react to different types of stress. In conclusion, what we do benefits the creation of sun-resistant varieties and supports progress in agriculture as more UV-B radiation increases

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