Anti-Aging Potential of Cosmos Caudatus Microgreens Extract Against Paraquat-Induced Oxidative Stress in Fruit Flies

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Abstract
Oxidative stress is a major contributor to aging and neurodegenerative diseases through excessive production of reactive oxygen species, leading to cellular damage and functional decline. Cosmos caudatus microgreens are rich in antioxidant compounds that may protect against oxidative stress-induced aging. This study investigated the anti-aging potential of Cosmos caudatus microgreens extract in a paraquat-induced oxidative stress model using Drosophila melanogaster. Male flies were assigned to four groups: control, paraquat at a concentration of 3.5 millimolar, 10 percent Cosmos caudatus microgreens extract, and 10 percent Cosmos caudatus microgreens extract combined with paraquat at a concentration of 3.5 millimolar. Antioxidant activity was evaluated using the 2,2-diphenyl-1-picrylhydrazyl assay, while anti-aging effects were assessed through survival rate, locomotor performance, malondialdehyde concentration, and lipofuscin accumulation. The extract showed very strong antioxidant activity with an inhibitory concentration of 2.887 micrograms per milliliter and contained high chlorophyll and carotenoid levels. Paraquat exposure reduced survival and climbing ability while increasing malondialdehyde concentration and lipofuscin accumulation. Treatment with 10 percent Cosmos caudatus microgreens extract improved survival and locomotor performance and reduced malondialdehyde concentration and lipofuscin accumulation. The extract alone maintained normal physiological function and exhibited lower oxidative stress markers than the control group. These findings demonstrate that Cosmos caudatus microgreens possess strong antioxidant and anti-aging properties by reducing oxidative damage and preserving physiological function, highlighting their potential as a natural therapeutic candidate for preventing oxidative stress-related aging.

Keywords: Cosmos Caudatus, Microgreens, Antioxidant Activity, Anti-Aging, Malondialdehyde, Drosophila Melanogaster, Lipofuscin

1. Introduction

The biological aging process involves the buildup of macromolecular damage in cells. This damage causes organ function to decline and reduces the ability of cells to repair themselves (Sanada et al., 2025). Every organism ages naturally. This process is unavoidable. One major theory explaining this process is the free radical theory. It suggests that the high levels of reactive oxygen species (ROS) lead to chronic oxidative stress (Anwar et al., 2026). Persistent oxidative stress progressively impairs cellular homeostasis, damages mitochondrial integrity, and accelerates the functional deterioration associated with biological aging. As oxidative damage accumulates, mitochondrial function becomes increasingly compromised, reducing cellular energy production and disrupting metabolic homeostasis. Consequently, experimental models that induce mitochondrial oxidative stress are widely employed to investigate aging mechanisms and evaluate the therapeutic potential of antioxidant compounds. Recent research on aging has looked into the effects of chronic paraquat exposure as a specific stressor for mitochondria. This exposure leads to continuous free radical production and acts as a model for neuromuscular aging. This condition is linked to the age-related decline in motor function (Fidan, 2026). Another study by Luo et al. (2026) found that paraquat causes excessive production of mitochondrial reactive oxygen species (mitochondrial ROS or mito-ROS). This disrupts how mitochondria function, encourages mitochondrial fragmentation, and ultimately results in cell death through apoptosis.

To reduce the harmful effects of both external and internal reactive oxygen species (ROS), the body needs to take in secondary antioxidants from outside sources (Manful et al., 2025). Microgreens, which are the growth stage of plants 7 to 21 days after germination, are now seen as top functional foods. They contain much higher levels of bioactive compounds, such as phenolics, flavonoids, chlorophylls, and carotenoids, compared to mature vegetables (Seth et al., 2025). One promising local plant for microgreen farming is cosmos.

Drosophila melanogaster is considered an ideal model organism for anti-aging and neurodegenerative studies due to the conservation of orthologous genes shared with humans in disease modeling, its short life cycle, and its high sensitivity to locomotor behavior assessment using the negative geotaxis assay, which can be measured precisely to analyze metabolism during the aging process (Pasam et al., 2025). Indicators of aging can also be determined through ex vivo assays, particularly those involving tissues, cells, and organs isolated from the model organism. These assessments include the determination of malondialdehyde (MDA) levels through lipid peroxidation assays, as MDA is a well-established biological marker of aging associated with oxidative stress. Another important evaluation involves measuring lipofuscin levels, a pigment resulting from the accumulation of lipochrome, which serves as a biomarker of aging in cells and tissues. Cosmos (Cosmos caudatus) microgreen extract is used to evaluate antioxidant activity through the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay and pigment content analysis, including chlorophyll a, chlorophyll b, and carotenoids. Based on the background described above, research on the effects of cosmos microgreen extract on Drosophila melanogaster as an anti-aging model organism.

2. Methodology

2.1 Experimental Design

This study used a Completely Randomized Design (CRD) because we assumed all experimental units were in similar conditions. This approach ensured that each treatment had an equal chance of being assigned to any unit. The design included four treatment groups: one normal control group, one negative control group, and two treatment groups that received microgreens cosmos extract. Each group had five replications to improve the reliability of the results. The R0 group acted as the normal control, using standard culture media without any treatment. This group represented the baseline or normal condition of the samples. The R1 group served as the negative control, exposed to 3.5 mM paraquat to induce oxidative stress. This group provided a comparison for the treatment groups. The R2 group received 10% microgreens cosmos extract without paraquat to see how the extract worked under normal conditions. The R3 group combined the treatments of 3.5 mM paraquat and 10% microgreens cosmos extract to evaluate the potential protective or antioxidant effects of the extract against paraquat-induced oxidative stress.

2.2 Cultivation and Preparation of Microgreen Extract

Cosmos caudatus seeds were sown in a uniform soil medium with enough moisture to encourage proper germination. The seeds were kept in the dark for 2 days until they germinated. Once germination occurred, the seedlings were moved to a well-lit area to help the microgreens grow. The plants were grown until day 10, at which point they reached a height of about 2 to 5 cm and were harvested for the extraction process. The extraction was done mechanically using a blender, adding distilled water at a 1:1 (w/v) ratio to the microgreen biomass. The resulting mixture was filtered through several steps, with the final filtration done using 10 μm filter paper to get a clearer extract free from large particles. The finished extract was then used for further analyses or experimental applications based on the study's objectives.

2.3 Survival Rate

The survival rate was measured by counting the number of living flies each day during the 4-day treatment period. Each treatment included five replicates, with 20 flies in each bottle. We calculated the survival rate based on how many flies were still alive at the end of the experiment (Gruss et al., 2023).

2.4 Locomotor Assay (Negative Geotaxis Test)

We measured the locomotor activity in fruit flies using the negative geotaxis test. First, we briefly anesthetized the flies on ice and then placed them in a vertical glass tube. Once the flies recovered from the cold, we gently tapped the tube to move all the flies to the bottom. We then observed their climbing behavior. To evaluate the effect of paraquat on movement, we looked at how many flies climbed more than 5 cm within 6 seconds. We presented the results as percentages (Moulin et al., 2023).

2.5 Determination of Malondialdehyde Levels

Lipid peroxidation was measured by blending 15 adult Drosophila melanogaster in 0.6 mL of a solution containing 50 mM sodium phosphate buffer (pH 6.0) and 10% trichloroacetic acid (TCA). The mixture was then spun in a centrifuge at 10,000 rpm for 10 minutes. The supernatant was divided into two parts. The first part (0.3 mL) was mixed with 0.1 mL of 0.1 M EDTA and 0.6 mL of a solution with 1% thiobarbituric acid (TBA) in 0.05 M NaOH. This mixture was incubated at 100°C for 15 minutes. The second part, used as the control, included 0.3 mL of the supernatant mixed with 0.7 mL of distilled water. It was also incubated under the same conditions. The concentration of malondialdehyde (MDA), which shows lipid peroxidation, was measured by checking the absorbance of the thiobarbituric acid-reactive products at 535 nm using a UV-Vis spectrophoto-meter (Carmona et al., 2016).

2.6 Lipofuscin Assay

We mixed Drosophila melanogaster samples in a chloroform:methanol solution at a 2:1 ratio. Then, we centrifuged the mixture at 3,000 rpm for 10 minutes. We measured the fluorescence intensity of the supernatant using a spectrophotometer. The excitation wavelength was set to 360 nm and the emission wavelength to 430 nm. We used quinine sulfate as the calibration standard, with standard solutions prepared in 0.1 N H_2SO_4. We determined lipofuscin levels using the quinine sulfate calibration curve, reporting them as micrograms per milligram (Falfushynka et al., 2014).

2.7 Determination of Pigment Content and Antioxidant Activity

Chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid contents were measured using an acetone-based spectro-photometric method outlined by Devi and Gayathri (2014). We assessed antioxidant activity using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. The results were shown as the half-maximal inhibitory concentration (IC_{50}), which indicates the amount of extract needed to scavenge 50% of DPPH radicals.

3. Results And Discussion

3.1 Results

3.1.1 Antioxidant Activity of Cosmos caudatus Microgreens Extract

We assessed the antioxidant activity of Cosmos caudatus microgreens extract through spectrophotometric analysis of photosynthetic pigments and the DPPH free radical scavenging assay. The data provide insights into the composition of photosynthetic pigments and the antioxidant potential of the microgreens extract.

Table 1. Antioxidant activity of Cosmos caudatus microgreens extract measured by the DPPH assay compared to ascorbic acid, which served as the positive control

Sample	**Concentration (µg/mL) (x)**	**% Inhibition (y)**	**Equation (y = bx + a)**	**IC_{50} (µg/mL)**
Ascorbic Acid	2	43.52	y= 5.288x+41.646 R^2= 0.652	1.58 *very strong
	4	68.94		
	6	73.41		
	8	80.94		
	10	94.23		
Cosmos *Microgreens* Extract	1	35.45	y= 3.0826x + 41.1009 R^2 = 0.8616	2.887 *very strong
	2	48.10		
	5	67.51		
	10	72.22		
	15	83.95		

The ability of a sample to block free radicals is shown as its percentage of inhibition. In this method, the IC_{50} value serves as the main measure to determine the amount of an antioxidant compound needed to inhibit 50% of the oxidation process. A lower IC_{50} value means stronger antioxidant activity. The results of this study showed that cosmos (Cosmos caudatus) microgreen extract displayed very strong antioxidant activity, with an IC_{50} value of 2.887 µg/mL. This suggests that cosmos microgreens have much greater antioxidant capacity than mature cosmos plants. Previous studies found that the ethanol extract of mature Cosmos caudatus leaves exhibited antioxidant activity with an IC_{50} value of 72.15 µg/mL. According to Zainuddin (2017), the antioxidant activity of microgreens comes from their ability to donate hydrogen atoms. This is shown by the color change of the DPPH solution from purple to pale yellow during the reaction. An IC_{50} value below 50 µg/mL is usually a sign of extremely high antioxidant activity.

Table 2. The concentrations of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids were measured and reported as mg/g of sample

Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total Chlorophyll (mg/g)	Carotenoids (mg/g)
3.325	0.659	3.984	1.467

The study found that cosmos microgreens had a total chlorophyll content of 3.984 mg/g, which included 3.325 mg/g of chlorophyll a and 0.659 mg/g of chlorophyll b. The total carotenoid content in the cosmos microgreens was 1.467 mg/g. These values came from calculations using established analytical formulas. A study by Latiff et al. (2021) showed that the bioactive content of Cosmos caudatus leaves, including these pigments, boosts their antioxidant activity. While the study did not specifically analyze chlorophyll, it is still significant as the main pigment in green leaves.

3.1.2 Survival Rate

The survival data collected during the four-day observation period showed clear differences in survival rates among the treatment groups. Tracking the survival of Drosophila melanogaster after paraquat exposure for four days was an effective way to assess the viability of male flies. If the observation period lasted more than seven days, it could lead to deaths not related to the treatment. Exposure to 3.5 mM paraquat caused significant oxidative stress, which greatly reduced the survival of Drosophila melanogaster.

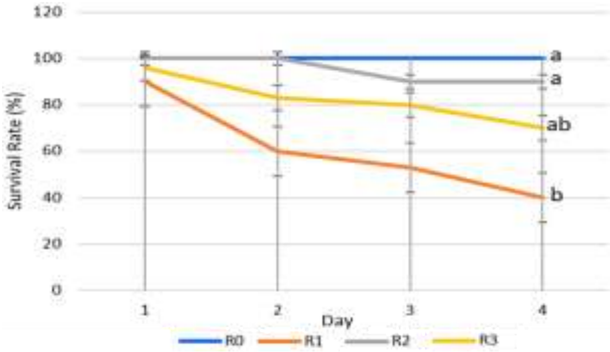

Figure 1. Survival Rate of Drosophila melanogaster. R0: Control. R1: 3.5 mM paraquat. R2: 10% microgreens extract. R3: 10% microgreens extract plus 3.5 mM paraquat

The R1 group, which only received paraquat, had the highest mortality rate, leading to a survival rate of only 60.75%. This was because of the buildup of harmful reactive oxygen species (ROS) that damaged mitochondrial membranes. In contrast, the R3 group, which got 10% cosmos microgreens extract, had a higher survival rate of 82.25%. These results show that the bioactive compounds in the microgreens effectively donate electrons to neutralize superoxide. anions caused by paraquat, reducing oxidative stress and improving survival.

3.1.3 Locomotor Behavior (Negative Geotaxis)

The locomotor assay served as a way to measure neuroprotective activity. It helped evaluate how much the central nervous system and muscles decline with accelerated aging. We assessed the locomotor performance of Drosophila melanogaster in four treatment groups after four days of treatment.

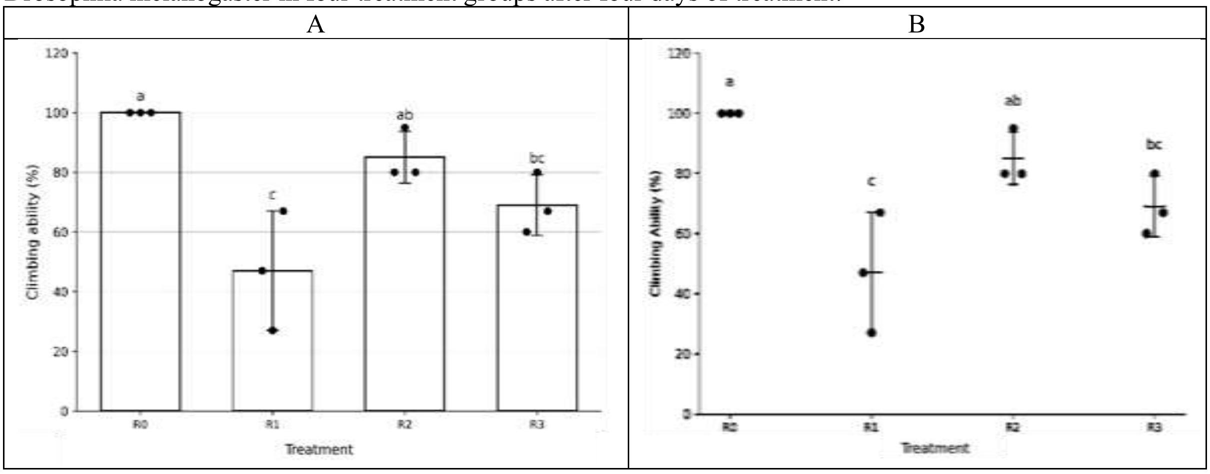

Figure 2. Locomotor activity of Drosophila melanogaster. (a) Bar graph and (b) dot plot. R0: Control. R1: 3.5 mM paraquat. R2: 10% microgreens extract. R3: 10% microgreens extract with 3.5 mM paraquat

The decline in locomotor performance observed in R1 suggests that motor neurons might be damaged, leading to issues similar to those seen in neurodegenerative disorders. The improvement in locomotor function in R3 supports the idea that carotenoids in cosmos microgreen extract may have neuroprotective effects.

3.1.4 Malondialdehyde (MDA) Levels

Malondialdehyde (MDA) is a harmful dialdehyde formed as a key end product of lipid peroxidation in cell membranes. Measuring MDA levels provides a useful biomarker for determining the amount of membrane damage caused by oxidative stress.

Table 3. The levels of malondialdehyde (MDA) as an indicator of lipid peroxidation in Drosophila melanogaster subjected to different experimental treatments

Treartment	MDA Level (nMol/mL)
R0 : Control	11.76 ± 0.07
R1 : Paraquat 3.5 mM	13.45 ± 0.04
R2 : Microgreens Cosmos Extract 10%	10.53 ± 0.06
R3 : Microgreens Cosmos Extract 10% + Paraquat 3.5 mM	12.17 ± 0.06

The control group (R0) showed a baseline MDA level of 11.76 ± 0.07 nMol/mL. When exposed to paraquat at a concentration of 3.5 mM (R1), MDA levels increased significantly to 13.45 ± 0.04 nMol/mL. This change indicates higher oxidative stress and more lipid peroxidation. Treatment with 10% Cosmos caudatus microgreens extract alone (R2) lowered MDA levels to 10.53 ± 0.06 nMol/mL. This suggests a potential antioxidant effect of the microgreens. In contrast, the combined treatment of 10% microgreens extract and 3.5 mM paraquat (R3) showed an intermediate MDA level of 12.17 ± 0.06 nMol/mL. This indicates that while the microgreens extract may provide some protection against oxidative damage.

3.1.5 Lipofuscin Levels

Lipofuscin is an insoluble yellowish-brown intracellular pigment that accumulates as aggregates of oxidized proteins and lipids within lysosomes. It is widely regarded as a universal biomarker of chronic cellular aging and oxidative stress.

Table 4. The lipofuscin levels in Drosophila melanogaster as an accumulation of oxidatively damaged proteins and lipids within lysosomes

Treatment	Lipofuscin Level (µg/mg)
R0 : Control	2.759 ± 0.02
R1 : Paraquat 3.5 mM	4.912 ± 0.03
R2 : Microgreens Cosmos Extract 10%	2.139 ± 0.02
R3 : Microgreens Cosmos Extract 10% + Paraquat 3.5 mM	3.773 ± 0.02

The paraquat-treated group (R1) had the highest lipofuscin concentration at 4.912 ± 0.03 µg/mg. This was significantly higher than the control group (R0), which had a concentration of 2.759 ± 0.02 µg/mg. On the other hand, flies treated with 10% microgreens cosmos extract alone (R2) had the lowest lipofuscin level at 2.139 ± 0.02 µg/mg, even lower than the control. The combined treatment of microgreens cosmos extract and paraquat (R3) showed an intermediate lipofuscin level of 3.773 ± 0.02 µg/mg. This indicated a reduction compared to paraquat treatment alone, but the level was still higher than the control.

3.2 Discussion

This study shows that Cosmos caudatus microgreens extract has strong anti-aging effects against oxidative stress caused by paraquat in Drosophila melanogaster. We saw this through improved survival rates, better locomotor activity, and lower levels of oxidative stress markers like malondialdehyde (MDA) and lipofuscin. The extract's potent antioxidant activity (IC_{50} = 2.887 µg/mL) confirms that Cosmos caudatus microgreens effectively scavenge free radicals. This value is categorized as very strong antioxidants (Table 1), indicating a high presence of beneficial compounds like chlorophylls, and carotenoids. Microgreens typically have higher concentrations of these compounds compared to mature plants, which boosts their biological activity.

Antioxidants likely play a key role by donating hydrogen atoms and stabilizing reactive oxygen species (ROS). This supports recent findings that plant-based polyphenols can affect oxidative stress pathways and improve cellular resilience (Zhang et al., 2023; Li et al., 2024). Additionally, chlorophyll and carotenoids work together to defend against oxidative damage by deactivating singlet oxygen and stabilizing lipid membranes. Carotenoids especially prevent lipid peroxidation by interacting with peroxyl radicals (Saini et al., 2023).

Paraquat is commonly used to create oxidative stress due to excessive mitochondrial ROS production, which leads to cell dysfunction and death. In this study, paraquat exposure significantly lowered the survival rate (60.75%) and locomotor performance, confirming its toxic effects. The improvement in the treatment group (R3) suggests that Cosmos caudatus microgreens extract helps reduce paraquat-induced damage. The increased survival rate (82.25%) points to antioxidant compounds neutralizing superoxide radicals and diminishing mitochondrial dysfunction (Figure 1). This aligns with previous studies showing that dietary antioxidants can lessen paraquat toxicity by boosting natural defense systems like superoxide dismutase (SOD) and catalase (CAT) (Wang et al., 2024). Moreover, antioxidant have been found to protect mitochondrial integrity by managing oxidative phosphorylation and preventing cell death (Chen et al., 2023).

A decline in locomotor ability is a common sign of aging and neurodegeneration. The reduced climbing ability of paraquat-treated flies indicates neuronal damage and poor neuromuscular coordination. In contrast, the improved locomotor activity in flies treated with the extract suggests neuroprotective effects (Figure 2). This might be due to chlorophyll and carotenoids crossing the blood-brain barrier and reducing oxidative damage in neurons. These compounds can modulate signaling pathways like Nrf2/Keap1 and decrease neuroinflammation, thus preserving neuronal health (García-Sánchez et al., 2024). Therefore, the results support the idea that Cosmos caudatus microgreens could serve as a helpful neuroprotective agent, especially in neurodegenerative conditions linked to oxidative stress.

MDA is a known marker of lipid peroxidation and oxidative harm. The significant rise in MDA levels in the paraquat group (13.45 nMol/mL) shows increased damage to membranes. Treatment with microgreens extract brought MDA levels down to 10.53 nMol/mL, suggesting it reduces lipid peroxidation (Table 3). This drop can be attributed to the antioxidant compounds capturing free radicals before they damage lipids in membranes. Similar results have appeared in studies of plant-based antioxidants, where extracts rich in flavonoids notably reduced MDA formation (Rahman et al., 2023). However, the partial reduction seen in the combined treatment group (R3) indicates that while the extract offers some protection, it may not fully counteract the high oxidative stress caused by paraquat. This points to a limitation based on dose or stress intensity.

Lipofuscin buildup is a sign of aging, representing the accumulation of oxidized proteins and lipids. The significantly higher levels of lipofuscin in paraquat-treated flies (4.912 µg/mg) point to accelerated aging. The marked reduction in lipofuscin levels in the extract-treated groups suggests that Cosmos caudatus microgreens effectively prevent the accumulation of oxidative damage (Table 4). This effect may relate to improved lysosomal function and less protein oxidation. Recent studies indicate that antioxidants can delay lipofuscin formation by boosting autophagy and lowering oxidative stress (Kwon et al., 2024). Thus, the findings emphasize the potential of microgreens as dietary aids against aging.

4. Conclusion

Microgreens extract of Cosmos caudatus has been scientifically demonstrated to exhibit remarkable efficacy as a functional anti-aging agent. Its secondary metabolites possess potent antioxidant activity (IC_{50} = 2.887 µg/mL), and the extract is enriched with chlorophyll and carotenoids, providing comprehensive cellular protection. In a paraquat-induced oxidative stress model using Drosophila melanogaster, administration of 10% microgreens extract successfully maintained survival rates (82.25%), preserved neuromuscular locomotor function (69.00%), suppressed lipid peroxidation products (malondialdehyde, MDA), and inhibited the accumulation of the functional aging pigment lipofuscin, without compromising the biological integrity of organs.

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6. References

1. Anwar, S., Alharbi, H. O. A., Babiker, A. Y., & Rahmani, A. H. (2026). Oxidative stress in health and disease: Mechanisms and therapeutic perspectives. *International Journal of Molecular Sciences*, *27*(6), Artikel 2681. https://www.mdpi.com/1422-0067/27/6/2681
2. Carmona, E. R., Inostroza-Blancheteau, C., Rubio, L., & Marcos, R. (2016). Genotoxic and oxidative stress potential of nanosized and bulk zinc oxide particles in *Drosophila melanogaster*. *Drug and Chemical Toxicology*, 32(12).
3. Chen, L., Zhang, Y., & Wang, Q. (2023). Flavonoids as mitochondrial protectors in oxidative stress-related diseases. *Free Radical Biology and Medicine*, 196, 45-58. https://doi.org/10.1016/j.freeradbiomed.2023.01.012
4. Fidan, M. (2026). Differential effects of paraquat-induced oxidative stress on functional aging and lifespan in male and female *Drosophila melanogaster*. *PLOS ONE*, *21*(3), Artikel e0336096. https://pmc.ncbi.nlm.nih.gov/articles/PMC12991275
5. García-Sánchez, A., Huerta-Cepas, J., & Pérez, M. (2024). Polyphenols and neuroprotection: Modulation of oxidative stress and inflammation pathways. *Nutrients*, 16(3), 512. https://doi.org/10.3390/nu16030512
6. Gruss, I., Twardowski, J., Samsel-Czekała, M., Wiglusz, R. J., Beznosiuk, J., & Wandzel, C. (2023). The isothermal Boltzmann–Gibbs entropy reduction affects survival of the fruit fly *Drosophila melanogaster*. *Scientific Reports,* 13, 14166. https://doi.org/10.1038/s41598-023-41482-x
7. Kwon, H. J., Lee, S. Y., & Kim, J. W. (2024). Role of oxidative stress in lipofuscin accumulation and aging. *Ageing Research Reviews*, 89, 101987. https://doi.org/10.1016/j.arr.2024.101987
8. Latiff, N. A., Ong, P. Y., Abd Rashid, S. N. A., Abdullah, L. C., Amin, N. A. M., & Fauzi, N. A. M. (2021). Enhancing recovery of bioactive compounds from *Cosmos caudatus* leaves via ultrasonic extraction. *Scientific Reports, 11*, 17297. https://doi.org/10.1038/s41598-021-96623-x
9. Li, X., Zhao, Y., & Sun, H. (2024). Dietary polyphenols and their role in oxidative stress modulation. *International Journal of Molecular Sciences*, 25(7), 3892. https://doi.org/10.3390/ijms25073892
10. Luo, Y., Lu, Y., Tang, Y., Zhao, X., Wang, J., Liu, Y., Jiang, S., Zhu, Y., Qi, J., Xing, L., Yan, C., Liu, X., Huang, C., Wang, H., Xu, H., & Wang, L. (2026). Synergistic neurotoxicity of environmental Cadmium and Paraquat in Parkinsonism: Unveiling the Mito-ROS/OPA1/Caspase-3/GSDME-driven apoptosis axis. *International Journal of Biological Sciences*, *22*(6), 2885-2905.
11. Manful, C. F., Fordjour, E., Subramaniam, D., Sey, A. A., Abbey, L., & Thomas, R. (2025). Antioxidants and Reactive Oxygen Species: Shaping Human Health and Disease Outcomes. *International Journal of Molecular Sciences*, *26*(15), Artikel 7520. https://doi.org/10.3390/ijms26157520
12. Moulin, T. C., Stojanovic, T., Rajesh, R. P., Pareek, T., Donzelli, L., Williams, M. J., & Schiöth, H. B. (2023). Effects of Transient Administration of the NMDA Receptor Antagonist MK-801 in *Drosophila melanogaster* Activity, Sleep, and Negative Geotaxis. *Biomedicines*, *11*(1), 192. https://doi.org/10.3390/biomedicines11010192
13. Pasam, E. S., Madamanchi, K., & Melkani, G. C. (2025). Dissecting metabolic regulation of behaviors and physiology during aging in *Drosophila*. *Biogerontology*, *26*(5).
14. Rahman, M. M., Islam, M. S., & Uddin, G. (2023). Natural antioxidants reduce lipid peroxidation and improve cellular health. *Journal of Food Biochemistry*, 47(5), e14289. https://doi.org/10.1111/jfbc.14289
15. Saini, R. K., Keum, Y. S., & Rengasamy, K. R. R. (2023). Carotenoids as natural antioxidants: Chemistry and biological functions. *Food Chemistry*, 404, 134610. https://doi.org/10.1016/j.foodchem.2022.134610
16. Sanada, F., Hayashi, S., & Morishita, R. (2025). Targeting the hallmarks of aging: mechanisms and therapeutic opportunities. *Frontiers in Cardiovascular Medicine*, *12*, Article 1631578. doi.org
17. Seth, T., Mishra, GP., Chattopadhyay, A., Deb Roy, P., Devi, M., Sahu, A., Sarangi, S. K., Mhatre, C. S., Lyngdoh, Y. A., Chandra, V., & authors, et al. (2025). Microgreens: Functional Food for Nutrition and Dietary Diversification. *Plants*, *14*(4), Artikel 526. https://doi.org/10.3390/plants14040526
18. Wang, J., Liu, Y., & Chen, X. (2024). Antioxidant defense systems in paraquat-induced oxidative stress. *Toxicology Letters*, 387, 45–56. https://doi.org/10.1016/j.toxlet.2024.02.003
19. Zainuddin, I.M. 2017. RNAi Inhibition of Feruloyl CoA 6'-hydroxylase Reduces Scopoletin Biosynthesis and Post-Harvest Physiologycal Deterioration in Cassava (Manihot esculentas Crantz) Storage Roots. Plant Mol Biology 94(1): 185-195.
20. Zhang, H., Liu, R., & Tsao, R. (2023). Phenolic compounds and their antioxidant mechanisms. *Food Research International*, 162, 112040. https://doi.org/10.1016/j.foodres.2022.112040

21. Falfushynska, H.I., Gnatyshyna, L.L., Osadchuk, O.Y., Farkas, A., Vehovszky, A., Carpenter, D.O., Gyori, J. and Stoliar, O.B. 2014. Diversity Of The Molecular Responses to Separate Wastewater Effluents in Freshwater Mussels. *Comp Biochem Physiol C Toxicol Pharmacol*. 164(1): 51-58.
22. Devi, R., dan Gayathri, R. 2014. Green Synthesis of Zinc Oxide Nanoparticles by Using Hibiscus rosa-sinensis. *International Journal of Current Engineering and Technology* 44(44): 2444–2446.