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RESEARCH

Toxicological Effects of Mercury-Induced Biochemical Alterations in Curry Leaves (*Murraya koenigii*) Plants

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Abstract

Heavy metals, including mercury (Hg), accumulate in the environment via atmospheric deposition, aquatic transport, and terrestrial pathways, eventually settling in soil and sediments. Once these metals become bioavailable, they pose significant ecological and toxicological risks. Upon exposure, plants absorb them, leading to harmful agronomic, physiological, and biochemical effects. The present study aims to assess the toxicological effects of mercury on the biochemical alterations in *Murraya koenigii* (curry leaves) plants. *M. koenigii* plants were assigned to four groups: Group 1 (control) in uncontaminated soil, and Groups 2, 3, and 4 exposed to 50 mg, 100 mg, and 200 mg of Hg, respectively. All plants were kept under controlled environmental conditions to promote optimal growth. The results revealed that elevated mercury concentrations significantly impaired critical growth parameters, including seed germination, root and shoot length, fresh and dry weight, and vigour index, all of which reflect suppressed plant growth and productivity. Biochemical analysis further demonstrated substantial reductions in primary metabolites, such as carbohydrates and proteins, with the most pronounced decreases observed at higher mercury concentrations. These alterations suggest that Hg-induced oxidative stress causes cellular damage, disruption of nutrient assimilation, and disturbances in enzyme activity. Additionally, significant reductions in chlorophyll a, chlorophyll b, and total chlorophyll content were observed, further indicating impaired photosynthetic capacity. Overall, the findings underscore the detrimental effects of mercury on plant metabolic processes, highlighting its potential to cause long-term growth inhibition and metabolic dysfunction, with broader implications for plant productivity, nutrient cycling, and ecosystem health.

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Statement of Sustainability: This study emphasizes the need for sustainable management to address mercury contamination in plant ecosystems. The toxic effects of mercury on *Murraya koenigii* (curry leaves), including growth impairment and biochemical disruptions, highlight the importance of controlling heavy metal pollution. Sustainable agricultural practices, alongside stricter mercury emission regulations, are crucial to protect plant health, biodiversity, and ecosystem services. Implementing cleaner technologies, waste management, and environmental monitoring will reduce mercury accumulation, safeguard plant and human health, and promote long-term ecological sustainability.

1. Introduction

Heavy metals (HMs) contamination in agricultural soils is a global environmental concern. The detrimental effects of HMs on plant health and crop productivity pose significant challenges to agricultural sustainability and food security (Angon et al., 2024). The incorporation of HMs into ecosystems is facilitated by their bioavailability and soil mobility, as metallic cations form complexes with negatively charged particles such as clay minerals and organic matter. Upon desorption, these metals become bioavailable and are capable of bioaccumulating in biota (Kim et al., 2015). Plants, microorganisms, and invertebrates utilize various biochemical mechanisms, such as metal transporters and ion channels,

to uptake essential trace metals (e.g., Fe, Cu, Mg, Ni, Mn, Co) for cellular processes and metabolic functions. However, excessive concentrations of these metals can lead to toxic effects, disrupting homeostasis. Similarly, these uptake mechanisms also facilitate the entry of non-essential, highly toxic metals (e.g., As, Cd, Hg, Pb), which, even at trace concentrations, can cause oxidative stress and biomolecular damage (Gadd, 2010).

HMs and metalloids are considered soil pollutants due to their potential to adversely affect plant growth, physiology, and yield when present in elevated concentrations within the soil matrix (Rashid et al., 2023). These metals can enter agricultural soils through both natural processes and anthropogenic activities including agricultural runoff, improper waste disposal, and industrial practices such as coal combustion, mining, waste incineration, and cement production. HMs exhibit a high resistance to biotic and abiotic degradation, and if not taken up by plants or leached from the soil, they can persist in the soil environment for extended periods (Ghori et al., 2019). Through plant uptake, HMs can enter the food chain, posing risks to human and animal health. In soil, these metals often form stable inorganic complexes with various organic and inorganic soil constituents, including humic substances, clay minerals, and metal oxides which leads to changes in the soil's physicochemical properties such as particle size distribution, color, porosity, and pH (Zhang et al., 2023). These changes can further exacerbate the toxicity of HMs, impairing water retention, nutrient availability, and overall soil fertility. The vigour index is a key measure that integrates germination rate and seedling growth, offering a quantitative assessment of plant health and vitality. It is especially important in plant stress physiology, as it indicates the plant's ability to survive and grow under stressful conditions, such as those induced by HMs exposure.

Mercury (Hg) is a pervasive environmental contaminant due to its significant detrimental effects on both human and ecosystem health (Singh et al., 2023). Hg that accumulates in terrestrial ecosystems can gradually be mobilized into surface water and other environmental media, a process that may persist for centuries (Pirrone et al., 2010). Plants are frequently utilized as bioindicators for monitoring Hg contamination in the environment, given their capacity to absorb and accumulate metals from the soil (Lodenius, 2013). The interaction of Hg with plant physiological processes is particularly significant, especially in relation to its widespread use in seed disinfectants, herbicides, and fertilizers which may exacerbate Hg exposure (Cavallini et al., 1999). However, exogenous Hg enters the soil, and it undergoes various interactions, including exchange reactions, surface adsorption, complexation, precipitation, and chelation. These processes reduce their biological effectiveness, resulting in what is known as the aging effect (Zhang et al., 2016). Due to its high toxicity and potential for bioaccumulation in trophic levels, Hg remains hazardous even at trace concentrations (Sharma et al., 2015). Hg exposure is known to interfere with the plant's antioxidant defense system by altering the levels of nonenzymatic antioxidants such as glutathione (GSH) and nonprotein thiols, as well as enzymatic antioxidants such as superoxide dismutase (SOD), ascorbate peroxidase (APX), and glutathione reductase (GR), thereby disrupting cellular redox homeostasis (Israr et al., 2006).

The curry tree (*Murraya koenigii*) is a tropical to subtropical species within the Rutaceae family, native to the Asian region. Despite sometimes being referred to as "sweet neem," *M. koenigii* belongs to a distinct botanical family from neem (*Azadirachta indica*), which is classified in the Meliaceae family. The tree's leaves, commonly known as curry leaves, are widely utilized in the culinary traditions of the Indian subcontinent, particularly in the preparation of curries, where they contribute distinctive volatile compounds and bioactive constituents that impart a unique fragrance and flavor. Due to its rich aromatic profile, *M. koenigii* is considered a key ingredient in South Asian cuisine (Ghimire and Magar, 2018). Remarkably, the leaves retain their organoleptic properties, including flavor and aroma, even after desiccation, making them a preferred spice and condiment in tropical and subtropical regions (Verma, 2018). Hg in soils exists in three main forms: elemental Hg, inorganic compounds, and organic Hg complexes (Hg^{2+}). The most harmful form is methylmercury, a neurotoxin absorbed by the gastrointestinal tract. While primary exposure occurs through contaminated fish and shellfish, humans can also be exposed by consuming crops like spinach, radish, lettuce, rice, cabbage, and corn grown in Hg-contaminated soils (Shao et al., 2012).

Various parts of *M. koenigii* have been traditionally utilized to treat a wide range of ailments. The fresh leaves are an integral component of both Indian cuisine and traditional Indian medicine. In cooking, they are predominantly used in southern and west coast Indian dishes, where they are typically fried with mustard seeds, vegetable oil, and chopped onions as part of the initial preparation stage. Additionally, *M. koenigii* leaves serve as a key herb in Ayurvedic and Siddha medicine. Research has demonstrated that these leaves exhibit a variety of pharmacological activities which include antidiabetic, anticancer (Igara et al., 2016), antioxidant (Tachibana et al., 2001), anti-inflammatory, analgesic

(Gupta et al., 2010), hypoglycemic (Tembhurne and Sakarkar, 2009), cardioprotective (Elina et al., 2012), antiobesity, antihyperlipidemic (Birari et al., 2010) and antipyretic (Rageeb et al., 2012) properties. The essential oil of *M. koenigii* has also been shown to exhibit antimicrobial, hypolipidemic, antioxidant, and antihypertensive effects (Kumar et al., 2012). Additionally, curry leaves boiled in coconut oil are reduced to a residue, which is then used as a potent hair tonic, promoting hair growth, maintaining natural hair color, and preventing premature graying (Jain et al., 2012).

Hg toxicity in *M. koenigii* underlines the harmful impact of HM pollution on plant health and ecosystem integrity. Investigating the effects of Hg on *M. koenigii* not only reveals its vulnerability to environmental contaminants but also provides valuable insights into its potential as a bioindicator of Hg pollution and its capacity for use in phytoremediation. Thus, this study aims to evaluate the toxicological effects of Hg and the induced biochemical alterations in *M. koenigii* plants.

2. Materials and Methods

The experimental protocol formulated to fulfill the study objectives was executed in accordance with the established standard operating procedures. *M. koenigii* seeds were acquired from a local agronomical supplier in Puducherry, and mercuric chloride was used as an exogenous Hg source to induce metal-mediated phytotoxicity, thereby facilitating the investigation of Hg stress responses in the plants.

2.1. Seed Sterilization

Uniform-sized *M. koenigii* seeds were meticulously selected for the experiment. To prevent fungal contamination, the seeds underwent surface sterilization with a 0.1% mercuric chloride solution for 2-3 minutes. After sterilization, the seeds were promptly retrieved and thoroughly washed multiple times with sterile, distilled water to remove any residual chemical contaminants and ensure purity.

2.2. Polyethylene Bag Experiment

Polyethylene bag culture experiments were conducted to assess the physiological and biochemical effects of Hg-induced toxicity on *M. koenigii* plants. The growth medium within the polyethylene bags comprised soil artificially contaminated with Hg at concentrations of 50, 100, and 200 mg. Surface sterilized seeds were sown in each bag by creating 2 cm deep depressions using a sterile wooden implement. Each seed was subsequently covered with a thin layer of soil to optimize microenvironmental conditions for germination. Soil moisture content was meticulously monitored and adjusted to maintain the soil's field capacity, utilizing distilled tap water to ensure adequate hydration, thus promoting optimal seedling growth and mitigating water stress. The soil used in the polyethylene bag culture experiment had a pH range of 6.0-7.0, providing ideal conditions for seed germination and plant growth. It had a loamy texture with approximately 2-4% organic matter, supporting microbial activity and ensuring nutrient availability.

2.3. Experimental Design

Following the preliminary phase, *M. koenigii* plants were assigned to four distinct experimental treatment groups. Group 1, serving as the control, was cultivated in soil devoid of any Hg contamination. In contrast, plants in Groups 2, 3, and 4 were exposed to sublethal concentrations of Hg at 50 mg, 100 mg, and 200 mg, respectively, for the duration of the experiment. An equilibration period of 48 hours was observed to allow for the stabilization of mercury levels in the soil before the plants were exposed to the treatments. The plants were grown under controlled environmental conditions, including regulated relative humidity, ambient temperature, and a natural photoperiod, to replicate standard growth parameters that promote optimal physiological and metabolic processes for plant development.

2.4. Germination Parameters

The germination percentage (%) was calculated by dividing the number of seeds that germinated on each day by the total number of seeds sown, multiplying by 100, and then summing the daily percentages to obtain the overall germination rate.

$$\text{Germination rate} = \text{No. of Seeds germination} / \text{Total number of seeds}$$

$$\text{Germination \%} = \text{Germination rate} \times 100$$

2.4.1. Root Length and Shoot Length

The root and shoot length from the ground level to the tip of the root and shoot is measured using a standard centimeter scale.

2.4.2. Fresh Weight and Dry Weight

The fresh weight and dry weight of the whole plant are determined using an electronic balance.

2.4.3. Vigour Index

For the Vigour index, the value was recorded on a germination basis. Using the mean value of root length and shoot length, the Vigour index was calculated by the formula of Baki and Anderson (1973).

$$\text{Vigour Index} = (\text{Mean Shoot length} + \text{Mean root length}) \times \text{Germination \%}$$

2.5. Biochemical Estimations

2.5.1. Estimation of Carbohydrate

The carbohydrate content was quantitatively determined using the method described by Hedge and Hofreiter (1962). A precise volume of 0.2 to 1.0 ml of the working standard solutions was pipetted into separate test tubes, while 0.5 ml of the sample extract was placed in another test tube. The volume in each test tube was then adjusted to 1 ml with distilled water. Next, 4 ml of Anthrone reagent was added to each test tube, which was then shaken to ensure thorough mixing. The test tubes were heated in a boiling water bath for 20 minutes, after which the solutions were allowed to cool. The absorbance of the resulting green-colored complex was then measured at 640 nm.

2.5.2. Estimation of Proteins

The protein content was determined using the Lowry (1951) method. Accurate volumes of 0.2 to 1.0 ml of the working standard protein solutions were pipetted into a series of test tubes, while 0.2 ml of the sample extract was added to a separate test tube. Each test tube was then filled with distilled water to a final volume of 1.0 ml, with 0.5 ml of distilled water used as the blank. The contents of the tubes were thoroughly mixed and allowed to stand for 10 minutes. Following this, 0.5 ml of Folin-Ciocalteu reagent was added to each test tube, and the mixtures were shaken well. The test tubes were then incubated in the dark at room temperature for 30 minutes, during which a blue color developed. The absorbance of the resulting solution was measured spectrophotometrically at 660 nm.

2.6. Photosynthetic Pigments Analysis

For the estimation of chlorophyll a, chlorophyll b, and total chlorophyll content, 1 g of fresh leaves was homogenized in 20 ml of 80% acetone, and the resulting mixture was centrifuged at 5000 rpm for 5 minutes. The supernatant was carefully transferred to a 100 ml volumetric flask, and the extraction procedure was repeated until the residue became colorless, ensuring complete extraction of the chlorophyll pigments. The collected supernatants were combined and the final volume was adjusted to 100 ml with 80% acetone to maintain a consistent solvent concentration. Chlorophyll content was quantified spectrophotometrically according to the method described by Arnon (1949), with absorbance measurements taken at 645 nm and 663 nm to determine the concentrations of chlorophyll a and chlorophyll b, respectively.

2.7. Statistical Analysis

The results are expressed as means ± standard deviation, based on six plants per group. Data was analyzed using a one-way analysis of variance (ANOVA), and significant differences between treatment groups were determined using Duncan's multiple-range test (DMRT). Results were considered statistically significant when $p<0.05$. All statistical analyses were performed using the SPSS software package, version 15.0 (SPSS, Tokyo, Japan).

3. Results and Discussion

3.1. Effects on Germination Percentage, Root length, and Shoot length

The presence of HMs in the environment can adversely affect plant ecosystems by impacting their growth, metabolism, physiology, productivity, and even accelerating senescence (Hafeez et al., 2023). Phytotoxicity assessments are essential for understanding how plants respond to environmental stressors, particularly those caused by contaminants like HMs (Bae et al., 2014). Figure 1 illustrates the effect of Hg-induced stress on seed germination

percentage, while Figure 2 depicts the effect of Hg exposure on root length and shoot length in various experimental groups of *M. koenigii* plants. These physiological changes were monitored 30 days after sowing. It is well-documented that the accumulation of HMs in plants disrupts vital physiological processes and genetic pathways, leading to impaired germination, growth, and overall productivity (Manara, 2012). Seed germination, a critical stage in the plant life cycle, plays a vital role in plant establishment, population dynamics, and agricultural productivity (Al-Khateeb et al., 2010). In our study, Hg exposure exerted a significant phytotoxic effect on seed germination, likely due to the abiotic stress induced by high concentrations of HMs. Specifically, the decrease in germination rates of *M. koenigii* can be attributed to the accelerated breakdown of stored food reserves within the seed, a process worsened by Hg toxicity. Additionally, the reduction in germination may be linked to changes in the selective permeability of the cell membrane, disrupting ion and nutrient transport, as well as a loss of seed viability due to reduced energy production in the embryo, likely caused by Hg-induced dysfunctions (Moosavi et al., 2012). Furthermore, the seeds of *M. koenigii* were significantly affected by the HMs, losing their viability and growth potential as the concentration of HMs in the medium increased (Siddiqui et al., 2014), which is consistent with our findings.

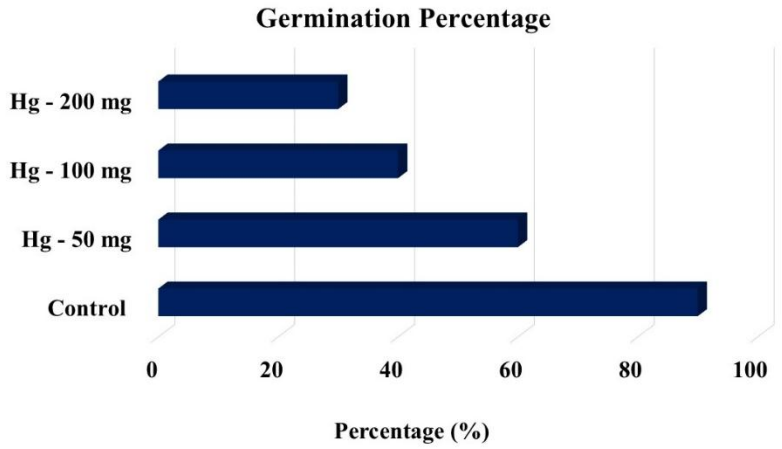

Figure 1. Effect of mercury on germination percentage in different experimental groups of *M. koenigii* plants.

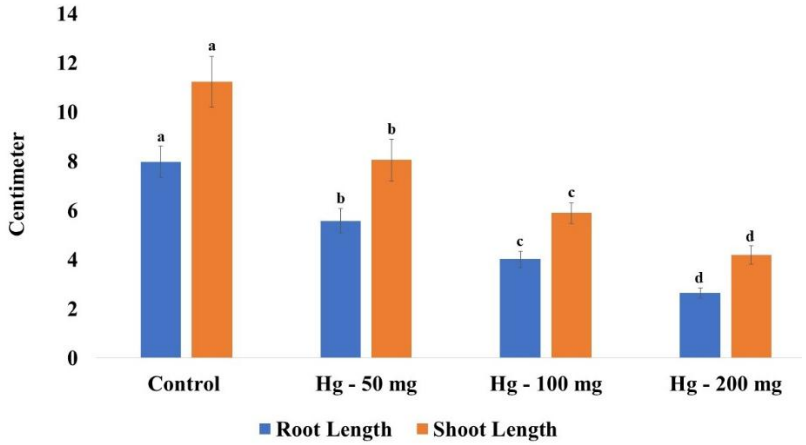

Figure 2. Effect of mercury on root length and Shoot length in different experimental groups of *M. koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at $p<0.05$. Duncan's multiple range test (DMRT).

Root length is a crucial physiological indicator of a plant's ability to absorb water and nutrients, as it reflects the efficiency of the root system in acquiring essential resources (Liu et al., 2022). Huybrechts et al. (2020) reported that exposure to high concentrations of HMs inhibits plant growth by disrupting processes such as cell division, elongation, and differentiation. In this study, Hg toxicity manifested pronounced adverse effects on both root and shoot length in *M. koenigii*. The reduction in root length observed in Hg-exposed plants is likely due to impaired mitotic activity in the root's meristematic zone, which hinders cell division and elongation. The harmful effects of HMs on plant growth are dose-dependent and closely linked to the accumulation of these toxic substances from the surrounding environment.

The observed alterations in root growth parameters likely result from the direct exposure of the radical to Hg, causing localized metal toxicity, followed by preferential accumulation of Hg in the emerging roots and subsequent slow translocation to the aerial parts of the plants (Godzik, 1993). High Hg concentrations in the rhizosphere have been shown to disrupt shoot development, leading to stunted plant height and impaired root growth, which ultimately reduces the plant's ability to absorb water and nutrients (Bahira et al., 2018). Moreover, while Hg toxicity negatively impacts key seed characteristics, the extent of damage to germination, root length, and shoot length is concentration-dependent, highlighting the critical role of Hg levels in influencing plant developmental processes.

3.2. Effects on Fresh Weight, Dry Weight, and Vigour Index

Figure 3 illustrates the effect of Hg on fresh weight and dry weight parameters, while Figure 4 depicts the impact of Hg exposure on the vigour index across different experimental groups of *M. koenigii* plants. These measurements were recorded 30 days post-sowing. The vigour index, which integrates growth parameters, provides a comprehensive assessment of plant vitality and serves as an effective metric for assessing the impact of HMs stress on overall plant development. Hg toxicity significantly impaired the fresh weight, dry weight, and vigour index in *M. koenigii* compared to control plants, highlighting a detrimental effect on the relative growth rate, seedling growth, and tolerance index due to elevated Hg concentrations. Significantly, the phytotoxic effect of Hg was more pronounced in plants exposed to higher Hg concentrations, resulting in a substantial reduction in biomass. This decline in biomass is likely a direct consequence of Hg-induced inhibition of chlorophyll biosynthesis and disruption of photosynthetic efficiency (Hasan et al., 2009). These results align with the findings of Vijay et al. (2025), who observed a significant reduction in fresh weight, dry weight, and vigour index in radish plants exposed to higher Hg concentrations, relative to untreated control plants.

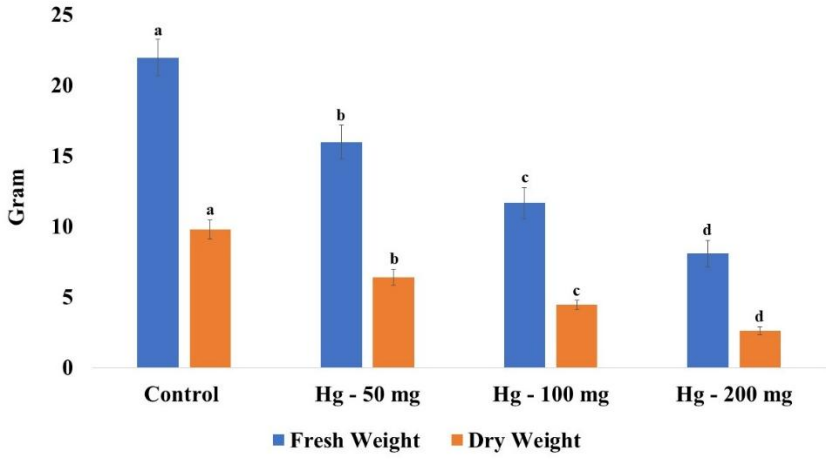

Figure 3. Effect of mercury on fresh weight and dry weight in different experimental groups of *M. koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at $p<0.05$. Duncan's multiple range test (DMRT).

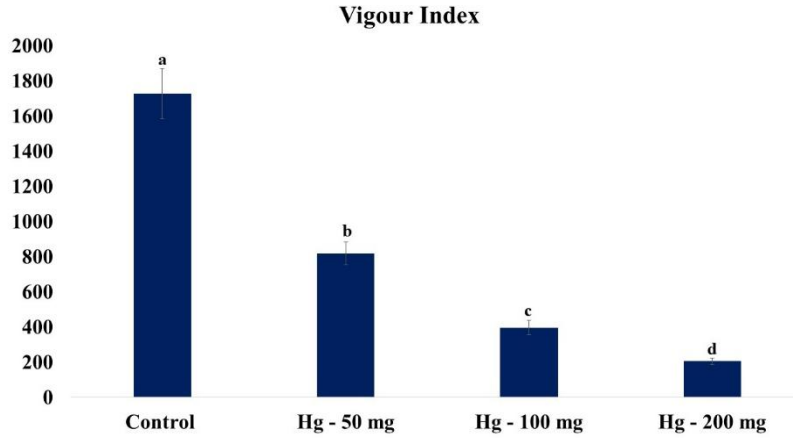

Figure 4. Effect of mercury on vigour index in different experimental groups of *M. koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at $p<0.05$. Duncan's multiple range test (DMRT).

3.3. Effects on Carbohydrates and Protein Contents

Figure 5 illustrates the impact of Hg on the carbohydrate concentrations in various experimental groups of *M. koenigii* plants, with data collected on the 30th day post-sowing. A majority of studies suggest that acclimatization or adaptation to elevated metal concentrations often leads to enhanced tolerance through the modulation of biochemical or physiological processes (Soldo and Behra, 2000). HM-induced stress can also impair nutrient acquisition and translocation by disrupting photosynthetic efficiency and carbohydrate metabolism (Cheng et al., 2024). Carbohydrate concentration in plants is a critical indicator of metabolic activity and energy reserves, making it an invaluable metric for assessing the physiological consequences of HMs stress. Exposure to toxic HMs can disrupt the metabolism of carbohydrates, resulting in an altered accumulation of starch and other sugars. Thus, carbohydrate contents serve as a crucial parameter in evaluating the physiological consequences of HMs toxicity and the plant's adaptive responses. Our findings demonstrate that Hg toxicity significantly diminishes carbohydrate contents in comparison to control plants, leading to disturbances in carbohydrate homeostasis. This observation is consistent with previous studies that reported decreased carbohydrate levels under HMs exposure, as seen in Capsicum annuum (Vijay et al., 2024). The generation of reactive oxygen species (ROS) and the subsequent disruption of the electron transport chain (ETC) due to HMs are known to hinder carbohydrate biosynthesis (Sandalio et al., 2001). A substantial reduction in carbohydrate levels can be indicative of impaired photosynthetic performance, reduced growth, and overall deterioration in plant health.

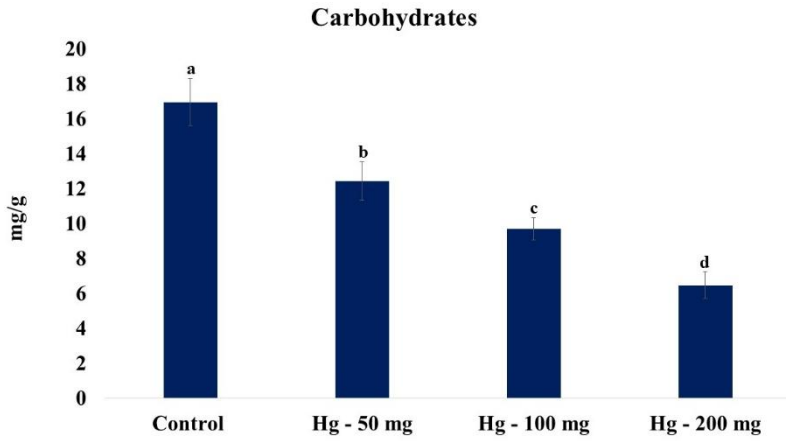

Figure 5. Effect of mercury on Carbohydrate levels in different experimental groups of *Murraya koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at $p<0.05$. Duncan's multiple range test (DMRT).

Figure 6 depicts the influence of Hg exposure on protein concentrations in various experimental groups of *M. koenigii* plants. HMs generate ROS, leading to oxidative stress and elevated intracellular ROS levels, which in turn cause extensive damage to biomolecules, including proteins, nucleic acids, lipids, and enzymes. The impairment of these macromolecules results in several physiological disturbances, including cellular dysfunction, DNA damage, and inhibition of enzymatic activity, all of which can ultimately culminate in plant mortality (Wu et al., 2016). Proteins, in particular, are primary targets of HMs toxicity, as these metals may either form complexes with the functional side chains of proteins or displace essential metal ions from metalloproteins, thereby disrupting normal physiological processes (Tamas et al., 2014). Monitoring protein contents serves as a vital tool in assessing the degree of stress and the plant's capacity to sustain fundamental metabolic functions under toxic conditions. Our findings indicate that elevated Hg concentrations induce a significant reduction in protein contents compared to untreated control plants. As the concentration of HMs increases, a more pronounced decrease in protein levels is observed, which correlates with the suppression of photosynthetic activity. This reduction in protein content has been associated with enhanced activity of protease enzymes, accelerating the degradation of proteins (Lokhande et al., 2020), or the disruption of nitrogen metabolism, which is crucial for protein synthesis. Additionally, HM-induced stress impairs protein functionality, gene expression, and metabolic processes (Fraire-Velázquez and Emmanuel, 2013). A decline in protein levels is indicative of cellular injury, compromised metabolic processes, and diminished growth potential, positioning protein content as a key biomarker for evaluating the adverse effects of HMs toxicity. Redox modifications of glycolysis and TCA cycle enzymes are key damaging responses in plants under oxidative stress. Additionally, Lehman et al., 2012, showed that oxidative stress leads to a reduction in glycolysis, TCA cycle metabolism, and amino acid metabolism in plants.

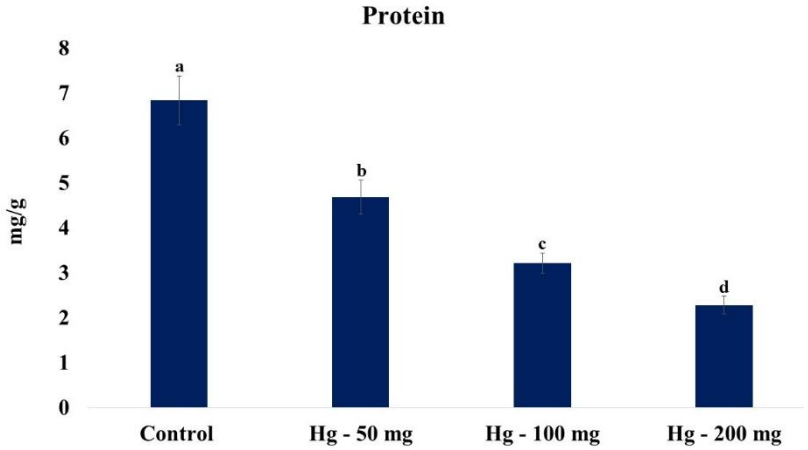

Figure 6. Effect of mercury on Protein contents in different experimental groups of *M. koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at p<0.05. Duncan's multiple range test (DMRT).

3.4. Effects on Chlorophyll a, Chlorophyll b, and Total chlorophyll

Chlorophyll biosynthesis is a critical and indispensable process in plant cells, representing a key biomolecule essential for plant metabolism, photosynthesis, and overall physiological development, even under abiotic stress conditions (Bekim et al., 2024). Chlorophyll quantification has been widely utilized as a reliable diagnostic tool for assessing HMs toxicity and oxidative damage in plants (Chen et al., 2019). Green tissues in terrestrial plants serve as the primary sites for the synthesis of organic compounds required for growth and development, thus, maintaining a balanced chlorophyll metabolism is essential throughout the plant's life cycle, making its regulatory parameters highly relevant. The impact of HMs contamination on chlorophyll metabolism is modulated by various soil physicochemical factors, including soil texture, pH, and organic matter content. These physicochemical characteristics can significantly alter the severity of HM-induced chlorophyll degradation, affecting plant health and function (Aponte et al., 2015). Environmental factors play a crucial role in regulating the biosynthetic machinery of secondary metabolites in plants by influencing their stress response mechanisms (Anjitha et al., 2021). Exposure to metals has been shown to enhance the biosynthesis of secondary metabolites in various plant species (Hurmat and Bansal, 2020). Moreover, Phytohormones, such as abscisic acid, auxins, cytokinins, ethylene, and others, interact with plant defense systems to regulate growth and a wide range of metabolic aspects of plant responses to heavy metals (Nguyen et al., 2020).

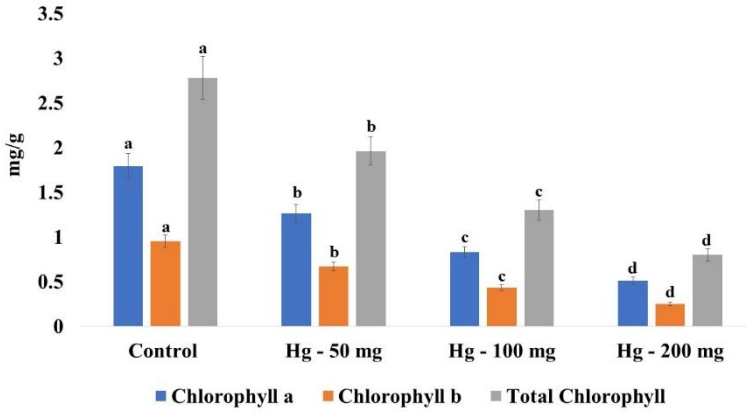

Figure 7. Effect of mercury on Chlorophyll a, b and total chlorophyll contents in different experimental groups of *Murraya koenigii* plants. Values are expressed as mean±SD. Groups not sharing a common superscript letter differ significantly at p<0.05. Duncan's multiple range test (DMRT).

Figure 7 illustrates the effect of Hg exposure on plant pigments, specifically chlorophyll a, chlorophyll b, and total chlorophyll content, across various experimental groups of *M. koenigii* plants. The results of our study demonstrate a significant reduction in chlorophyll concentrations at elevated Hg levels. The observed decrease in chlorophyll content may be attributed to the inhibition of chlorophyll biosynthesis and the enhanced degradation of chlorophyll molecules.

Additionally, the reduction in chlorophyll content and its degradation in curry leaves can be linked to the excessive generation of ROS and lipid peroxidation, both of which are induced by Hg toxicity at higher concentrations. Moreover, ROS are generated as one of the byproducts of the photosynthetic ETC and can induce oxidative damage, resulting in the degradation of chlorophyll contents (Triantaphylides and Havaux, 2009).

4. Conclusion

The experimental data demonstrate that Hg-induced stress had a deleterious effect on the growth and biochemical parameters of *Murraya koenigii* plants. Specifically, critical growth metrics, including germination rate, root length, shoot length, fresh weight, dry weight, and vigour index, were significantly reduced in Hg-exposed plants as compared to the control group. Furthermore, Hg exposure resulted in a substantial reduction in the concentrations of essential macromolecules, such as carbohydrates and proteins, underscoring the adverse impact of Hg toxicity on both metabolic and physiological functions. In addition, chlorophyll a, chlorophyll b, and total chlorophyll levels were significantly reduced under elevated Hg concentrations, further indicating disruption in photosynthetic capacity and overall plant health. The observed reductions in growth metrics and biochemical parameters, such as essential macromolecules and chlorophyll contents, suggest that Hg toxicity impairs both the metabolic and photosynthetic processes crucial for plant development. Hg contamination in *M. koenigii* plants not only compromises their growth and biochemical functions but also threatens ecosystems that depend on this species, particularly in areas where it plays a vital role in the local flora. The resulting growth impairment and reduced photosynthetic ability may decrease plant productivity, potentially affecting biodiversity and food security in regions where *M. koenigii* is cultivated. Furthermore, Hg accumulation in these plants can harm herbivores and, through biomagnification, disrupt entire food chains, emphasizing the wider ecological risks of Hg pollution. These findings emphasize the need for further research into the mechanisms underlying Hg toxicity in plants and the potential ecological implications of Hg contamination on plant health and productivity. Future research could focus on the use of Hg-tolerant plant species, in phytoremediation efforts, utilizing mechanisms such as Hg uptake, sequestration, and detoxification. Incorporating these strategies could offer practical solutions to reduce Hg contamination in the environment and improve plant health and productivity in affected areas.

Author Contributions: Conceptualization: Mani Vijay, Gnanamoorthy Vijayasanthi, Kassim MohammedKhaleef; Data curation: Mani Vijay, Gnanamoorthy Vijayasanthi, Kassim MohammedKhaleef; Funding acquisition: Mani Vijay, Gnanamoorthy Vijayasanthi, Kassim MohammedKhaleef; Investigation: Mani Vijay; Methodology: Mani Vijay; Resources Mani Vijay; Software: Mani Vijay; Supervision: Mani Vijay; Validation: Mani Vijay; Visualization: Mani Vijay; Writing – original draft: Mani Vijay, Gnanamoorthy Vijayasanthi, Kassim MohammedKhaleef; Writing – review & editing: Mani Vijay, Gnanamoorthy Vijayasanthi, Kassim MohammedKhaleef. All authors have read and agreed to the published version of the manuscript.

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Supplementary Information Availability: Not applicable.

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