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REVIEW

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Geochemistry, Distribution and Toxicity of Barium in Terrestrial Ecosystem

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Abstract

Barium (Ba), a naturally occurring alkaline earth metal, has gained attention due to its environmental prevalence and potential toxicity. This review examines the sources of Ba in the environment, its distribution across ecosystems, and its toxicological impacts on plants and human health. Ba is widely distributed through natural processes such as the weathering of Ba-rich minerals like barite and witherite, volcanic eruptions, and biological uptake by certain plants and anthropogenic activities, including industrial discharges, oil and gas drilling, and improper waste disposal. Consequently, Ba accumulates in soils and water ecosystems, with concentrations influenced by geological and industrial factors. While Ba in its natural form generally exhibits low toxicity, it shows a dose-dependent impact on the physiology and growth of plants. Aquatic organisms are particularly vulnerable, as Ba disrupts physiological processes, threatening aquatic ecosystems. Regulatory agencies, including the Environmental Protection Agency (EPA) and the World Health Organization (WHO), have established guidelines for acceptable Ba levels in drinking water and soil to safeguard human health and the environment. This review emphasizes the critical need to understand Ba's sources, distribution patterns, and toxicological impacts to protect living organisms and environmental health.

Keywords: Barium; Environment; Toxicity; Ecosystem; Speciation; Geochemistry

Introduction

Environmental pollution has emerged as a pressing global concern, particularly due to the rapid urbanization and industrialization of recent decades. These developments have led to the widespread distribution of various pollutants, including toxic chemicals, pesticides, petroleum products, and heavy metals, which contaminate vital natural resources such as water, soil, and air. Heavy metals, including cadmium, lead, arsenic, mercury, and nickel, are of particular concern due to their high toxicity and environmental persistence. These metals adversely affect both plant life and human health. In plants, they can disrupt growth processes by retarding development, diminishing nutritional value, and damaging photosynthesis. As heavy metals accumulate in the soil, they create a toxic environment that can severely hamper plant growth, metabolism, seed germination, and seed yield. The impact of these metals extends beyond the plant kingdom; they pose significant health risks to humans, leading to various adverse health outcomes. In humans, acute exposure to high levels of Ba can result in cardiovascular, neurological, and gastrointestinal issues, while chronic exposure may lead to more subtle health effects. For plants, elevated Ba concentrations can hinder growth and affect nutrient absorption, ultimately impacting crop yield and quality. However, it seems to be essential for the proper growth of certain organisms. For instance, the desmid green alga *Closterium moniliferum* contains vesicles that store $BaSO_4$ in its crystalline form (Krejci et al., 2011). Understanding the characteristics and behaviour of Ba and its compounds is crucial, given their potential environmental and health implications. This review aims to summarize the effects of Ba on plant morphology, seed germination, and growth, while also highlighting the associated health risks for humans and the environment. This review is also helpful for synthesizing current knowledge on the distribution and geochemistry of Ba in the environment, focusing on its sources, environmental pathways, and the resulting impacts on plant and human health. By integrating geological, chemical, and biological perspectives, this study seeks to provide a comprehensive understanding of Ba's role in the terrestrial ecosystem.

Sources and Geochemistry of Barium

Ba derived from the Greek word "barys," meaning heavy, is a soft, silvery alkaline earth metal with an atomic number of 56 and an atomic mass of 137.34 uma. It is the fifth element in Group 2 of the periodic table, situated in the S-block. In the environment, various Ba compounds are prevalent, including Barium sulphate ($BaSO_4$), Barium carbonate ($BaCO_3$), Barium bicarbonate ($BaHCO_3$), Barium nitrate ($BaNO_3$), Barium chloride ($BaCl_2$), Barium hydroxide $Ba(OH)_2$, Barium fluoride (BaF_2), and Barium acetate $Ba(CH_3COO)_2$ (McGrath et al., 1989). Ba is not known to play a biological role in humans (Zoroddu et al., 2019). Ba is commonly found in the environment at relatively high concentrations, primarily due to anthropogenic activities such as ore mining, refining, and the manufacturing of Ba salts (Choudhury and Cary, 2001). Industrially, Ba is utilized in various forms, including its role in the production of alloys (such as Ba-Ni), soap, rubber, linoleum, and valves, as well as serving as a filler in paper manufacturing. Ba compounds have diverse applications across several industries, including cement, speciality arc welding, glass, electronics, cosmetics, insecticides, pharmaceuticals, and paints (Choudhury and Cary, 2001). The total annual global production of Ba compounds is estimated to be around 6 million tons. As a metallic element, Ba is strongly electropositive and exhibits higher reactivity than magnesium, calcium, or strontium. It is never found in nature as a free element because of its high chemical reactivity. In all its compounds, Ba consistently has an oxidation state of +2. Ba exhibits chemical behaviour similar to that of calcium and magnesium (Choudhury and Cary, 2001). It shares geochemical properties with radium, particularly in terms of ionic radius and its tendency to pair with sulphate ions. This similarity often results in the co-occurrence of radium and Ba in groundwater systems (Moffett et al., 2007). At standard temperature and pressure, Ba adopts a body-centred cubic crystal structure. It is a soft, silvery-white metal with medium-specific weight and good electrical conductivity. Barium (Ba), calcium (Ca), and magnesium (Mg) are alkaline earth metals located in Group 2 of the periodic table. They share several similarities due to their group classification, yet they also exhibit distinct properties. A summary of significant physico-chemical properties of Ba, Ca, and Mg are given in Table 1.

Table 1. Physico-chemical properties of Ba, Ca, and Mg

S. No.	Properties	Ba	Ca	Mg
1.	Group, Period, Block	2, 6, S- block	2, 4, S- block	2, 3, S-block
2.	Atomic number	56	20	12
3.	Relative atomic mass	137.327 g mol^{-1}	40.078 g mol^{-1}	24.305 g mol^{-1}
4.	Melting Point	727^0C, 1341^0F, 1000K	842^0C, 1548^0F, 1115K	650^0C, 1202^0F, 923K
5.	Boiling Point	1845^0C, 3353^0F, 2118K	1484^0C, 2703^0F, 1757K	1107^0C, 1994^0F, 1363K
6.	Density (g.cm)	3.62	1.54	1.74
7.	Vander Waals Radius	0.222 nm	0.197nm	0.160nm
8.	Oxidation states	+1, +2	+2	+2
9.	State at 20^0C	Solid	Solid	Solid
10.	Electron negativity	0.89	1.00	1.2
11.	Key isotopes	^{138}Ba	^{40}Ca	^{24}Mg
12.	Enthalpy of Hydration	1296 KJ/MOL	1579 KJ/MOL	1926 KJ/MOL
13.	Ionization potential	502.8 KJ/MOL	589.83 KJ/MOL	737.50 KJ/MOL
14.	Ionic radius (Pauling)	0.135 nm	0.099 nm	0.065 nm

Understanding these properties and behaviours of Ba is significant for evaluating its environmental significance and potential interactions with other elements (Ca and Mg) in natural systems. The geochemistry and sources of Ba are essential for assessing its environmental impact on living organisms and ecosystem productivity.

Geographical distribution of Barium

The geographical distribution and production of barite ($BaSO_4$) are essential for assessing its availability and implications for industry and the environment. Barite deposits are found in all regions of the world. The most important sources in Europe are in Germany, France, Italy, the UK, Belgium, and Spain, with minor amounts coming from Portugal and Greece. In the Americas, significant deposits are found in the United States, Canada, Mexico, Brazil, and Argentina. The largest producer of barite is China (appr.3.8×10^6 t/a). Other major barite producers are in the middle of Turkey, with further amounts coming from Indonesia, North Korea, and Thailand, and lesser amounts from Pakistan, Malaysia, Japan, and Australia. In the global scenario, India is endowed with the third position in terms of reserves and second in the production of barytes. Mangampet in Andhra Pradesh is the world's largest single barytes deposit with 68.4 million tonnes of recoverable reserves (IBM, 2015). Significant deposits of barytes are found in several districts of Rajasthan, especially Udaipur and Alwar. In Udaipur, barytes are located near the village of Relpatliya, where approximately 1 million tonnes of resources have been estimated, containing 80-95% barium sulphate. In Alwar, barytes occur in various areas, including Sainpuri, Zahir ka Kera, Ramsinghpura, Bhankhera, Karoli, Jamroli, Umrain, and Girara. The estimated resources in this region amount to 75,000 tonnes, with a $BaSO_4$ concentration of 95%. Additionally, in the Rajsamand district, barytes are found in the Delwara-Kesuli-Nathdwara belt, with about 41,000 tonnes of resources assessed, containing 60-95% $BaSO_4$. In Bundi, the Umar area hosts an estimated 1,650 tonnes of barytes, with a $BaSO_4$ content of 78.6%. Lastly, in the Bhilwara district, resources of approximately 1,600 tonnes have been calculated, containing 80-90% $BaSO_4$. The geographical distribution and production of barite are essential for assessing its availability and implications for industry and environmental sustainability.

Dispersion of Ba in soil ecosystems and atmosphere

Ba has an average crustal abundance of approximately 425 ppm, making it the 14th most abundant element in the Earth's crust (Nan et al., 2018). This abundance is relatively high compared to manganese, which is just over twice as abundant as Ba. Soil concentrations of Ba vary widely, typically ranging from 13 to 2050 mg kg^{-1} in subsoils and from 30 to 1870 mg kg^{-1} in top soils (Harada et al., 2019). However, not all Ba present in the soil is readily available for uptake by living organisms. Ba exists in various forms, including soluble, insoluble, inorganic, and organic compounds. The majority of Ba in the environment is found in low-solubility forms, primarily as sulphate or carbonate. Common Ba minerals, such as barite ($BaSO_4$) and witherite ($BaCO_3$), are less soluble, and field-grown plants typically contain around 15 mg kg^{-1} of Ba (Pais and Jones, 1998).

The U.S. Environmental Protection Agency (USEPA) has established a maximum concentration limit (MCL) for Ba in drinking water at 2.0 mg L^{-1}. Ba is ubiquitous in soils, with concentrations ranging from 15 to 3500 mg kg^{-1} (ATSDR, 2007). The chemical characteristics of Ba are crucial for its bioavailability, as Ba readily reacts with carbonate or sulphate ions to form insoluble salts like barite and witherite (Kabata-Pendias, 2011). Subsequently, not all Ba compounds in soil are bioavailable, influencing their uptake by plants and their ecological significance. Ba is naturally present in small amounts within most plant species, although concentrations can vary significantly between different species. Coscione and Berton (2009) reported that Ba concentrations in plants range from 4 to 50 mg kg^{-1}. Kabata-Pendias (2011) documented Ba concentrations in various food and feed plants between 2 and 13 mg kg^{-1}. Raghu (2001) observed elevated Ba concentrations in plants growing in proximity to barite mining areas, highlighting the influence of environmental factors on Ba uptake. While high concentrations of Ba in the soil around 500 mg kg^{-1} can adversely affect plant growth, certain species, such as *Indigofera cordifolia*, exhibit adaptability to elevated Ba levels and can thrive even under such conditions. Understanding the variation in Ba concentrations across different plant species is essential for assessing its ecological impact and potential applications in phytoremediation efforts. The distribution of Ba contributes to our consideration of geochemical processes in soils, such as nutrient cycling and mineral interactions. Overall, the distribution of Ba in soil and the environment is vital for assessing ecological health, guiding agricultural practices, ensuring water safety, and exploring sustainable remediation strategies, which are essential for soil fertility and ecosystem sustainability.

Effect of Ba on animal and human health

The effects of Ba on both animals and plants have been relatively underexplored in scientific research. While some studies have highlighted potential toxicity and bioaccumulation issues, a comprehensive understanding of Ba's impact on various species and ecosystems is still lacking. Investigating how different concentrations of Ba influence physiological processes, growth, and reproductive success in both flora and fauna is essential. Most human exposure to Ba occurs through inhalation or ingestion (Gould et al., 1973; McNeill and Isoardi, 2019; Siddiqui, 2017). Reported concentrations of Ba in human tissues and blood vary, with levels of 3-70 ppm in bone, 0.04-1.2 ppm in the liver, 0.09 ppm in muscle, and 0.06 mg dm^3 in blood. Ba exposure can lead to multiple adverse health effects in animals, including damage to the cardiovascular, renal, respiratory, haematological, nervous, and endocrine systems. In particular, the ingestion of Ba in soluble forms is highly toxic to both animals and humans. Studies indicate that even small quantities of water-soluble Ba can result in serious health issues, including muscular paralysis, gastrointestinal disturbances, stomach irritation, changes in nerve reflexes, swelling of the brain and liver, heart damage, high blood pressure, and in severe cases, death (USEPA, 2009). This highlights the critical need for ongoing research to fully understand the implications of Ba exposure on health. According to the U.S. Environmental Protection Agency (USEPA), exposure to Ba at levels exceeding the maximum concentration limit (MCL) for even short durations can lead to gastrointestinal disturbances, muscular weakness, and elevated blood pressure. More severe toxic effects associated with Ba exposure include pulmonary edema, intestinal and gastric hemorrhages, cardiac and renal failure, and respiratory paralysis (Krishna et al., 2020; McNeill and Isoardi, 2019; Poddalgoda et al., 2017). Highly soluble Ba compounds, such as barium chloride ($BaCl_2$), are particularly toxic and can cause a range of symptoms, including cardiac arrhythmias, vomiting, diarrhea, liver and kidney failure, anxiety, tremors, dyspnea, and, in severe cases, ventricular fibrillation, paralysis, and brain swelling (Bohn et al., 2011; Krauskopf, 1982; McNeill and Isoardi, 2019). Soluble Ba compounds are especially concerning because the Ba^{+2} ion can initially stimulate muscles before leading to paralysis.

The World Health Organization (WHO, 2004) has indicated that even low doses of Ba in the environment may have adverse effects on blood pressure. Furthermore, high environmental concentrations of Ba are hypothesized to be associated with multiple sclerosis (MS) and other neurodegenerative diseases (Purdey, 2004). A key factor influencing the development of health effects is the solubility of the Ba compound. Soluble Ba compounds pose a greater health risk than insoluble forms due to their higher potential for absorption (ATSDR, 2007). In animal studies, the bioavailability of barite can increase in the upper gastrointestinal (GI) tract when hydrochloric acid (HCl) in the stomach dissolves and dissociates $BaSO_4$ (McCauley and Washington, 1983; Stoewsand et al., 1988). Understanding these dynamics is essential for assessing the risks associated with Ba exposure.

Impact of Ba on plants

Ba can significantly affect plant health and growth, with both beneficial and detrimental effects depending on its concentration and form. Ba can influence plant growth, metabolism, and yield in various ways. While it is not an essential nutrient for most plants, exposure to Ba can lead to both positive and negative effects. High concentrations of Ba in the soil may disrupt nutrient uptake and hamper root-shoot development. Additionally, excessive Ba can be toxic, causing physiological stress and reduced photosynthesis and respiration. On the other hand, at low levels, it might play a role in certain metabolic processes. Overall, the presence of Ba in the environment can significantly affect plant vitality and agricultural productivity. Ba is a nonessential element that can be harmful to both plants and animals (Lamb et al., 2013). While most plants contain small amounts of Ba, its concentration varies significantly across different species. Elevated levels of Ba, particularly those exceeding 500 mg kg^{-1}, are often found in plants located near mining areas, especially barite mining sites (Raghu, 2001). These high concentrations can inhibit normal plant growth. Suwa et al. (2008) demonstrated that Ba induces phytotoxicity in soybean plants (*Glycine max*) at concentrations of 100, 1000, and 5000 µM. Markedly, the 5000 µM treatment led to significant disruptions in stomatal activity and decreased carbon fixation and translocation processes. Lu et al. (2019) reported extremely high Ba concentrations in paddy soils near mining and Ba salt production facilities, ranging from 518 mg kg^{-1} to 65,760 mg kg^{-1}.

Increased Ba concentrations in nutrient solutions have been shown to reduce leaf area and overall plant yield (Monteiro et al., 2011). Symptoms of phytotoxicity, such as leaf damage, have been observed in Tanzanian guinea grass at Ba levels of 225 mg kg^{-1} (Monteiro et al., 2011). These findings underscore the detrimental effects of Ba on plant health and productivity, particularly in the higher application of Ba. Sleimi et al. (2021) explored the effects of Ba on seed germination and vegetative development in *Cucumis sativus* L. The study found that Ba concentrations of 500 and 2000 µM stimulated seed germination when compared to control levels (0, 200, 500, 1,000, and 2,000 µM). Monteiro et al. (2011) observed the long-term effects of Ba on plant development were assessed by treating the plants with increasing doses of Ba over 45 days and it was identified as a toxic element for most plants. The critical toxic concentrations of Ba in the substrate can vary significantly based on its availability. Generally, Ba is recognized as a toxic element and has been studied as a pollutant in various regions worldwide (Schroeder et al., 1972). For instance, a reduction in shoot growth and yield depression has been reported at 481 µM of free Ba in trifoliate leaves of bush beans, with symptoms of phytotoxicity observed at 700 and 460 mg kg^{-1} (Llugany et al., 2000).

These findings highlight the dual nature of Ba, where certain concentrations can stimulate germination, while elevated levels can be detrimental to overall plant health and development (Table 2). Choudhary and Kumar (2023) reported Ba promoted seed germination and seedling growth at lower concentrations (10 µg g^{-1}) in wheat and mung bean. Bouslimi et al. (2021) report increasing Ba concentrations (100, 200, 300 µM) promoted the growth of *Brassica juncea* but suppressed the production of fresh biomass in *Cakile maritime.* It also observed the antioxidant defense system of *Brassica juncea* and *Cakile maritima* was triggered by Ba and observed as increased activity of catalase (CAT) and ascorbate peroxidase (APX) and total phenols, and secondary metabolites content in the plant leaves (Bouslimi et al., 2021). Ba toxicity has been a significant concern in agricultural practices, affecting plant growth and yield. Minton and Wilson (1973) observed that isolated mitochondria from plants grown in high Ba environments exhibited rapid respiration rates; however, the coupling parameters were markedly reduced, indicating impaired energy efficiency. Chaudhry et al. (1977) further explored the impact of Ba on specific crops, finding that high levels of Ba application (500 µg g^{-1} and 2000 µg g^{-1}) led to substantial yield reductions of 38% in barley (*Hordeum vulgare*) and up to 63% in bush beans (*Phaseolus vulgaris*). Remarkably, lower Ba concentrations did not significantly affect barley yields.

Research indicates that plants growing in Ba-rich soils, such as those found near barite outcrops or mine spoils, often accumulate high concentrations of Ba. The impact of various Ba compounds on plant physiology and growth across different plant species are given in Table 2. Llugany et al. (2000) revealed that Ba levels in aboveground organs can equal or exceed those in roots, with some species displaying considerable variability in Ba accumulation. The physiological effects of excessive Ba include generating reactive oxygen species (ROS), which arise when Ba concentrations exceed a certain threshold. Raghu (2001) observed that some plant species have adapted to tolerate elevated levels of trace metal elements (TME), including Ba, allowing them to survive in contaminated environments. However, the presence of ROS leads to oxidative damage to lipids, proteins, nucleic acids, and cellular antioxidants. In response to oxidative stress, plants activate their natural antioxidant defense mechanisms. This includes the production of both enzymatic and non-enzymatic antioxidants (Ali et al., 2008). Explains the impact of Ba toxicity on plants, highlighting various morphological, physiological, and biochemical changes resulting from Ba accumulation within the plant system (Fig. 1). Elevated levels of Ba can lead to stunted growth, reduced leaf size, and chlorosis, affecting overall plant morphology. Physiologically, Ba toxicity disrupts essential processes such as photosynthesis and nutrient uptake, leading to diminished energy production and impaired metabolic functions. Biochemically, the accumulation of Ba can induce oxidative stress, increasing reactive oxygen species (ROS) levels and triggering antioxidant responses. These changes compromise plant health and productivity, underscoring the significance of monitoring Ba levels in agricultural practices.

Table 2. Impact of various Ba compounds on plant physiology and growth in different plant species

S. No.	Test Plant	Barium Doses	Effect on Plants	References
1.	*Brassica juncea, Cakile maritime*	100- 500 µM	Biomass, antioxidant enzyme activity and total phenols and flavonoid increased	Bouslimi et al. (2021)
2.	*Cucumis sativus*	500 and 2,000 µM	Seed germination enhanced and biomass declined	Sleimi et al. (2021)
3.	*Oryza sativa*	0.10 to 3.5 mg kg^{-1}	Elevated uptake of Ba in plant tissues	Lu et al. (2019)
4.	*Trifolium pratense*	56-15800 mg kg^{-1}	Increased uptake of Ba in plant roots	Kujawska and Pawlowska (2019)
5.	*Cyamopsis tetragonoloba*	10 mM	Growth parameters reduced	Marisamy et al. (2015)
6.	*Panicum maximum*	1.24 mmol L^{-1}	The leaf area and yield of the plants declined.	Monteiro et al. (2011)
7.	*Glycine max*	5000 µM	Reduced stomatal activity, hindering carbon fixation processes and disrupted metabolic translocation.	Suwa et al. (2008)
8.	*Phaseolus vulgaris*	500 and 5000 µM	Decline in shoot growth	Llugany et al. (2000)
9.	*Triticum aestivum* L.	60-100 mM	Seedling length and dry weight reduced	Javed and Shagufta (1989)
10.	*Phaseolus aureus, Cephalandra indica, Lactuca sativa*	80 and 100 mM	Inhibited hypocotyl elongation	Debnath and Mukherji (1982)
11.	*Phaseolus vulgaris* and *Hordeum vulgare*	2000 µg g^{-1}	The yields of both species declined.	Chaudhry et al. (1977)
12.	*Phaseolus aureus*	40 mM	Decreased Shoot growth	Minton and Wilson (1973)

Plants employ various strategies to mitigate the adverse effects of heavy metal toxicity, which often results in the overproduction of reactive oxygen species (ROS). This excessive ROS generation can lead to the peroxidation of essential cellular components. To counteract this oxidative stress, plants have developed an efficient antioxidant defense system composed of both enzymatic and non-enzymatic antioxidants. The enzymatic antioxidants include superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and glutathione-S-transferase (GST).

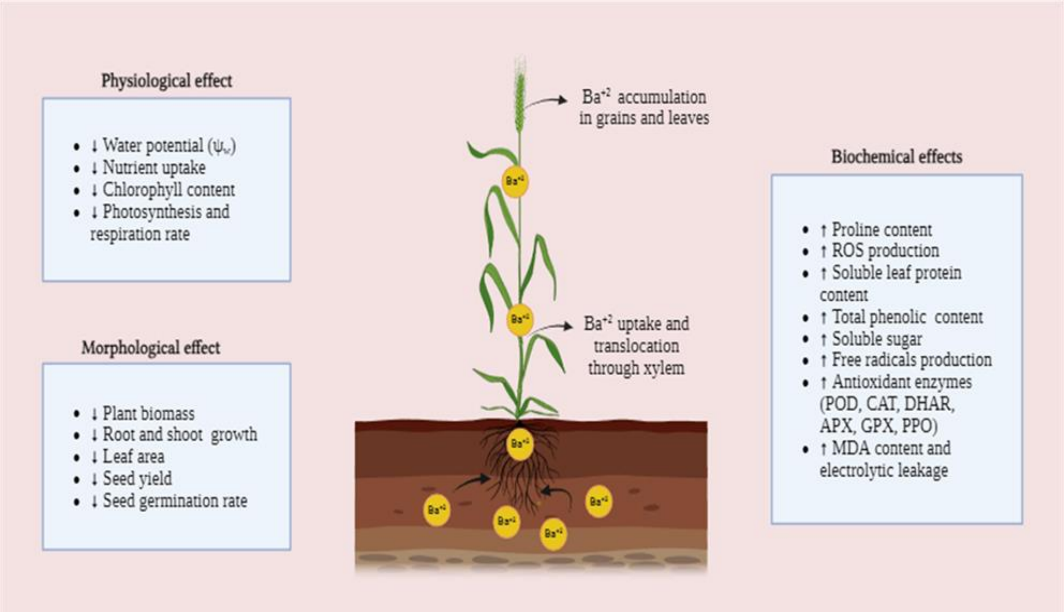

Figure 1. Impact of Ba on morphological, physiological, and biochemical processes of plants.

These enzymes play a crucial role in converting superoxide radicals into hydrogen peroxide, which is subsequently broken down into water and oxygen. Additionally, low molecular weight non-enzymatic antioxidants, such as proline, ascorbic acid, and glutathione, can directly detoxify ROS. When present as free ionic metals, such as Ba^{+2} and Cd^{+2}, these heavy metals can impair plant function from the subcellular level to the ecosystem level (Ernst et al., 1992). The interaction of free ionic metals with cellular components can trigger various metabolic responses almost instantaneously, often resulting in the direct or indirect generation of ROS (Babu et al., 2001). Due to their highly reactive nature, ROS are cytotoxic to all living organisms (Arruda and Azevedo, 2009), making it critical for plants to minimize their production. The primary mechanisms for ROS scavenging in plants involve key enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GR) (Gratao et al., 2008). Key antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), guaiacol peroxidase (GPX), and ascorbate peroxidase (APX) play crucial roles in protecting cellular and sub-cellular systems from the cytotoxic effects of active oxygen radicals (Siddiqi and Husen, 2017).

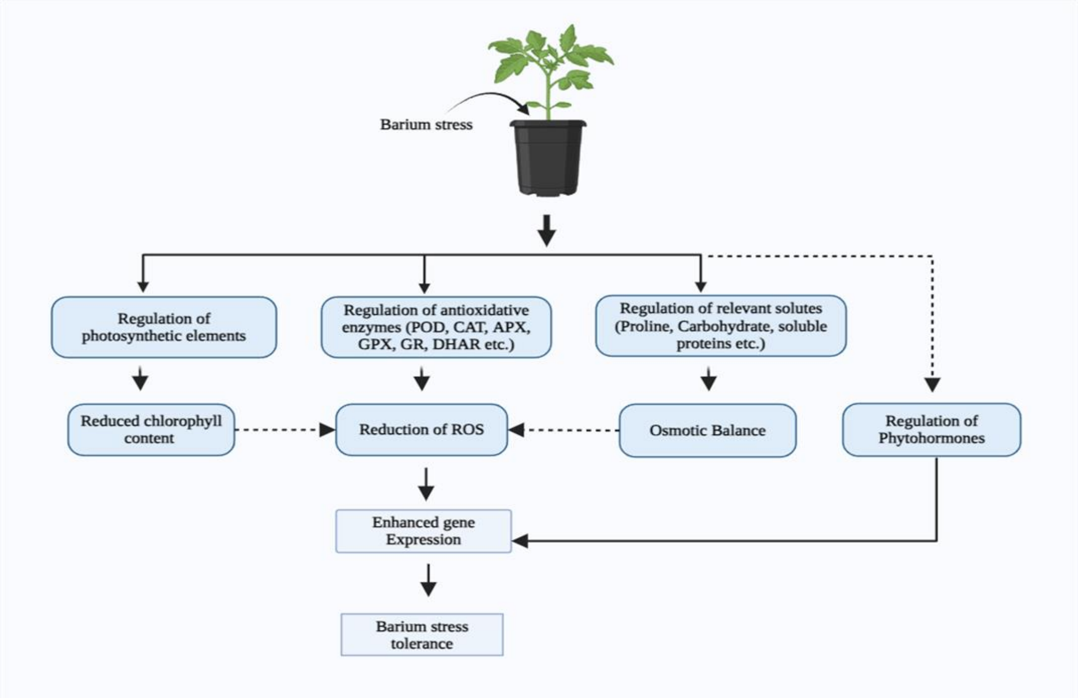

Figure 2. Diagrammatic representation of tolerance mechanism in plants against Ba stress

The treatment of plants with heavy metals significantly enhances the activities of various oxidizing enzymes, including catalase, peroxidase, indole-3-acetic acid (IAA) oxidase, and ascorbic acid oxidase. This increase in enzyme activity is a common biochemical symptom of metal toxicity (Debnath and Mukherji, 1982; Mukherji and Maitra, 1977). Exposure to toxic levels of heavy metals triggers a wide range of physiological and metabolic alterations in plants (Fig. 2). Understanding these mechanisms is essential for enhancing plant resilience against heavy metal stress and improving overall plant health.

Conclusion

Barium represents a significant environmental concern due to its ubiquitous presence and potential health risks. Its sources range from natural processes to anthropogenic activities, leading to its accumulation in soils and water bodies. While Ba in its natural state is generally less toxic, the soluble compounds can have detrimental effects on both human health and wildlife, particularly in aquatic ecosystems. Although Ba is considered a nonessential element for organisms, it can be toxic to plants at specific concentrations. Elevated levels of Ba ions have been shown to inhibit root and shoot growth and reduce both fresh and dry biomass. In response to heavy metal stress, plants employ various adaptive strategies, including the accumulation of proline, the synthesis of heat shock proteins (HSPs), and the production of metallothioneins and phytochelatins. Regulatory frameworks established by organizations like the EPA and WHO highlight the necessity of monitoring Ba levels to safeguard public health and environmental quality. A comprehensive understanding of Ba's sources, distribution, and toxicological effects is essential for mitigating its impact and addressing the broader issue of heavy metal contamination. Ongoing research and regulatory efforts are critical to ensure a safe and healthy environment for both humans and ecosystem organisms.

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Author Contributions

LKC designed and written the original draft; AK conceived the concept and reviewed the draft; both the authors approved the manuscript.

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