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RESEARCH ARTICLE

TOXIC EFFECTS OF MERCURY ON CROP PLANTS AND ITS PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES - A REVIEW

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Abstract

The harmful effects of mercury lead to the inhibition of the growth and changes in biochemical constituents of food crops. Plants that are hyperaccumulators accumulate the mercury present in the air or in the soil which leads to growth retardation as well as affects the metabolic pathway regulation in plants. Several biochemical reactions happen due to the metallic accumulation such as lipid peroxidation, enzyme activation, chromosomal aberrations, and untimely cell death. Mercury causes a decrease in photosynthetic rate which turns the colour of the plants to pale yellow. Chlorophyll synthesis in the leaves was suppressed by mercury toxicity and increases the rate of oxidizing enzymes. Mitotic behavior as well as leakage of metabolites was adversely affected due to mercury toxicity. This review intends to understand the toxic effects occurring due to mercury accumulation and morphological, physiological, and biochemical changes occurring in different food crops.

Introduction:-

Heavy metals are universally present either naturally or by human-induced processes in the environment [1]. They also occur in the environment through human exploitation ie. waste disposal, atmospheric deposition, excessive use of chemical fertilizers and pesticides, smelter stacks and disposal of activated sewage sludge in the agricultural fields leads to the decomposition of heavy metals in the soil. The heavy metal contamination by soil, water, and air has triggered extreme environmental risk within the biosphere because of rapid industrialization and urbanization [20]. Earth is the most fitted planet where life exists. It gives a suitable atmosphere that favours plant growth since it provides mineral such as iron, calcium, and copper which are much needed for plant growth and development. Most plants grow in soil but the soil itself is not necessary to promote plant growth. Plants need nutrients and water within the soil but in recent eras, the soil or the surface which is promoting its growth is impaired by heavy metal accumulation. Heavy metals such as Zinc, Mercury, Lead, Cadmium, Chromium, Nickel, Manganese, etc have significant toxicity leading to low germination rate, lower hypocotyl elongation, and other toxic impacts. At elevated levels, these heavy metals are posing deterioration in human and animal health as well as enormous loss in yield. Plants have a very good transportation system. They have the capability to accumulate and transport toxic substances through their vascular systems as well as roots since they are very closely associated with the soil. Some of the plants are excellent hyper-accumulators that can efficiently accumulate heavy metals through their root

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system and show negative impacts on the food crops. An increase in the contents of heavy metals leads to phytotoxicity and then they finally enter into the food chain. Thus, the concentration of heavy metals varies in different food crops depending on the soil composition, selectivity, adsorption ability, water, metal permissibility, and nutrient balance of the plant.

Metals are those materials with excessive electrical conductivity, malleability, and luster, which voluntarily lose their electrons to shape cations. Metals are observed clearly within the earth's crust and their composition ranges among exclusive localities, ensuing in spatial versions of surrounding concentrations. The constituent of heavy metal in the soil can cause phytotoxicity and enter through crop uptake and soil ingestion which will ultimately affect the human diet. The foliar uptake of heavy metals directly from the environment occurs during the growth of the plant. The cereal crops may get affected in the edible parts which also can lead to health risks if cultivated in contaminated soil. Therefore, it is necessary to evaluate the concentration of heavy metals in the soil where crops are intended to cultivate. Since prehistoric times, cereals have been the primary human diet due to their quality, blend of flavors, vast cultivation, and their great variety. To determine which one is toxic and which one is non-toxic we must know about those heavy metals which are toxic to cereals or plants and which are non-toxic or essential to crops. For Example: - Iron (Fe), Zinc (Zn), Copper (Cu), and Chromium (Cr) are essential for crops but at certain concentrations, due to its elevated level they can also act as a toxic substances. While, Lead (Pb), Arsenic (As), Mercury (Hg), Cadmium (Cd), and Nickel (Ni) are considered as toxic at different levels.

Plants act as an accumulator and can accumulate essential as well as nonessential nutrients, metals, and ions [2]. The higher concentration of heavy metals can change the topography of the soil which later accumulates in different tissues of the plants [3]. Different environmental factors such as air, water, and soil can lead to the accumulation of heavy metals that risks every living organism. Plant accumulation can be better understood by studying the effects of metals on roots since roots are the first ones to be exposed to them. [4]. Different effects of heavy metals are seen in plants such as Cd directly affects the structural and functional properties of DNA in plants and also a decrease in mitotic index occurs under Cd stress [5]. The high amount of Cu has changed the nucleic acid contents in plants [6]. Similarly, it was observed that Zn is less toxic than Pb on the basis of higher concentration and it reduces the frequency of cell division [7].

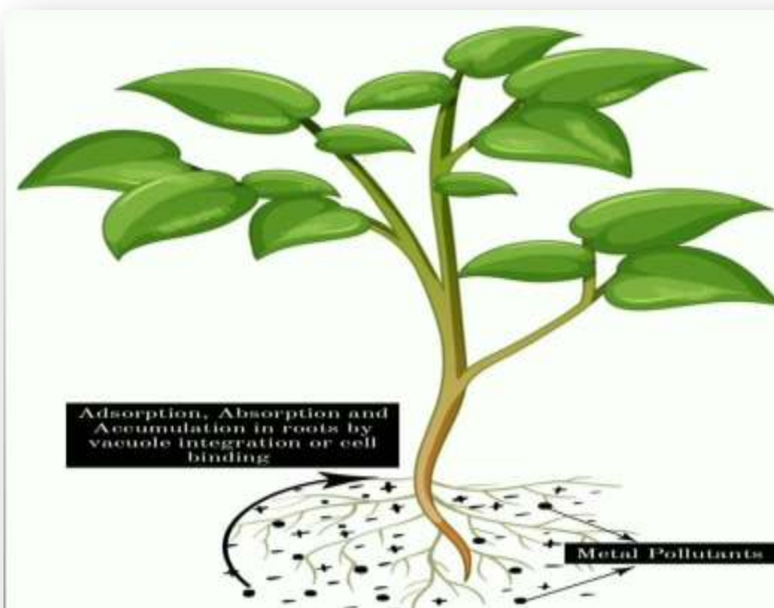

Fig 1:- Plant depicting the accumulation of heavy metals at the roots.

Mercury as a heavy metal and how toxic it is:-

Due to expeditious industrialization and evolution happening around releasing untreated chemicals and activated sludge after secondary treatment in sewage plants which interacting with the environment causes different reactions such as they affect the chemical composition of air, water, and soil and hampers the productivity and growth in plants. Mercury is considered as the most toxic element released in the environment which retards the growth of plants [8]. Mercury is even considered an effective pest control in certain agricultural sectors [9]. They pose harmful effects on the leaves where transpiration and photosynthesis are mainly carried out, causing biological, morphological, anatomical, and physiological substitution by inhibiting pollen germination and pollen tube formation and ultimately affecting fruit production [9],[10]. For the successful cultivation of seeds, these factors act as their hindrance [11]. A review was done by scientists who claimed that a quantity of 5 µM $HgCl_2$ acts as a general blocker of aquaporins in different organisms which was observed to inhibit the rate of seed germination and also induced retardation in the maternal seed coat (testa) rupturing process and emergence of radical by 8-9 hrs and 20-30 hrs proportionately. The stress caused by mercury resulted in the shrinking of foliar chlorophyll contents and damage to the internal leaf structure [13]. The contamination of mercury is ubiquitous in distinct ecological compartments such as the atmosphere, soil, and water.

Mercury accumulation is a big threat to plants:-

Mercury has a tendency to accumulate in the roots of plants as the roots become first exposed carrier of mercury uptake. It has been observed that mercury uptake by plants results in foliar changes. Mercury accumulation has been observed in specific plants such as lichens, bryophytes, wetland plants, and woody and crop plants. There are some factors that affect the plant uptake i.e. soil or its organic content, carbon exchange capacity, its oxide and carbonate content, redox potential, the formulation used, and total metal contents. It has been seen that aquatic plants act as the main bio accumulators of mercury. In plants, Hg produces SHgS [23] after being tightly attached to the sulfhydryl/thiol groups of proteins. The binding of Hg to protein SH groups, the displacement of necessary components, and the alteration of the protein structure all contribute to Hg toxicity in plants. Thus, the uptake rate of the plant species, seasonal growth rate, and the metal ion absorbed differ in freshwater aquatic vascular plants. In some cases, it has been seen that the plant leaves absorb the mercury released in the atmosphere from a source and then they transmit it into the humus through those fallen leaves. There are some examples regarding the absorbance of mercury by the leaves of plants: -

1. C_3 species such as oats, barley, and wheat has higher absorbance.
2. C_4 species such as corn, sorghum, and crabgrass have five-time lesser absorbance than C_3 species.[14]

Similarly, there is distinct uptake by C_3 and C_4 species which basically attributes to inner resistance to the mercury-vapor binding. Thus, it can be seen that airborne mercury contributes extensively to the contents of crops and ultimately affects the intake of food. Mercury accumulation, its toxicity response, and its distribution differ distinctly between plants species exposed via shoots or roots even if the inner mercurial concentration in the plant which has been treated is the same.

Mercury affecting the seedling germination and growth rate in plants:-

Seedling growth inhibition has been observed in many plants on treatment with Mercuric Chloride ($HgCl_2$). The concentration of $HgCl_2$ played an important factor in the inhibition rate of germination. It can be said that the concentration of $HgCl_2$ is directly proportional to the inhibition of seedling growth. Root elongation is a crucial growth variable that is found to be affected by mercury treatment. A review explained the inhibition rate observed in *Vigna radiata* under mercurial treatment which will help to understand the inhibition caused by germination rates of plants. The seed germination rate, as well as the growth rate, were compared with different concentrations of $HgCl_2$ compared with the distilled water control. Mercury treatments were done in a dilute form of mercuric chloride with different concentrations and were observed that with a lesser concentration of $HgCl_2$, there was less or no significant inhibition but as the concentration of $HgCl_2$ increased there was a reduction in root length. Therefore, a conclusion was drawn that an increase in the concentration of mercury treatment caused significant reductions in the seedling length of mungbean seeds as compared to the control. A piece of evidence was provided that on the treatment of $HgCl_2$ with a high percentage there was a decrease in seed germination which lead to inhibitory responses in plant growth and development.

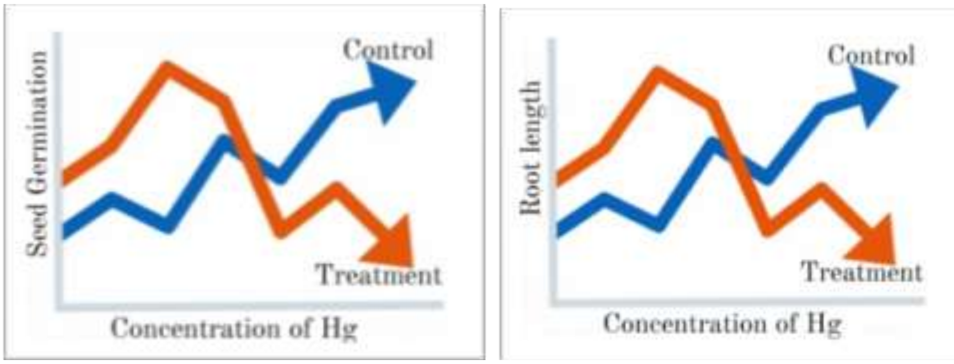

Fig. 2:- Effects of mercury treatment on seed germination and root length for *Vigna radiata* as compared to control.

Morphological parameters upon treatment with Mercury (Hg): -

Morphological characteristics are the features of a plant that determines its shape, size, and color which gives the plant its identification and characterization. Morphology is the first thing that gets exposed to foreign particles such as the accumulation of heavy metals or any other factors. Plant growth can be studied according to morphological characteristics. The morphology of the plant gets affected after $HgCl_2$ treatment which can be measured according to the plant height, leaf number, and dry weight of shoots and roots. Plants' height is measured from the base of the stem to the growing point which gives the data about how the morphology of the plants gets affected by the invasion of heavy metals.

Fig 3:- Effect of heavy metal stress on morphology of plant.

Effect of mercury on Chlorophyll content and suppression of photosynthesis of the plant: -

Heavy metals have always dominated the biota since they are always present in elevated amounts. Heavy metals cannot be decomposed in nature and it can only be translocated into plants and transferred further into the human food chain [14]. The processes by which heavy metals are transferred to plants are (i) phytoextraction (a phytoremediation subprocess in which plants remove dangerous components from contaminated soil), (ii) Phyto stabilization (immobilization and reduction of the mobility of heavy metals in soil), and (iii) rhizofiltration (a form of phytoremediation to use plant roots to absorb the toxic substances). Through transference in the food chain, these metals harm plants and extend to harming human health [24]. Leaves play an important role in capturing light and making their own food via photosynthesis. Photosynthesis is a hypersensitive process that is interfered with by heavy metal invasion which leads to the inhibition of enzymatic steps either directly or by inducing the deficiency of an important nutrient [16]. A report was done on the inhibition of protochlorophyllide photoreduction in homogenates of dark-grown wheat leaves done by Solymosi et al.It has been observed that Hg affects the level of phosphorus and manganese contents in plants which in turn reduces the chlorophyll content and increases the malondialdehyde (MDA) and thiol levels [17]. A report on the chlorophyll contents of wheat upon treatment with Hg showed that in the initial days of treatment, there was an increase in the content of chlorophyll a, chlorophyll b, and total chlorophyll with the increasing concentration of Hg but later on the content of chlorophyll a, chlorophyll b, and total chlorophyll have decreased significantly with the increasing rate of Hg which states that both low and high concentration of Hg will stimulate or inhibit the chlorophyll synthesis level at early stages of the wheat growth while on the later stages of the wheat growth not only less but also a high concentration of Hg will lead to inhibition of chlorophyll synthesis. In the cells of *Chlorella pyrenoidosa* was seen that the color of the leaves turned pale–yellow on treatment with Hg and a significant fall in photosynthetic rate was also observed [18]. So, it has been concluded that both high and low concentration of mercury plays an important role in either increase or decrease of chlorophyll contents.

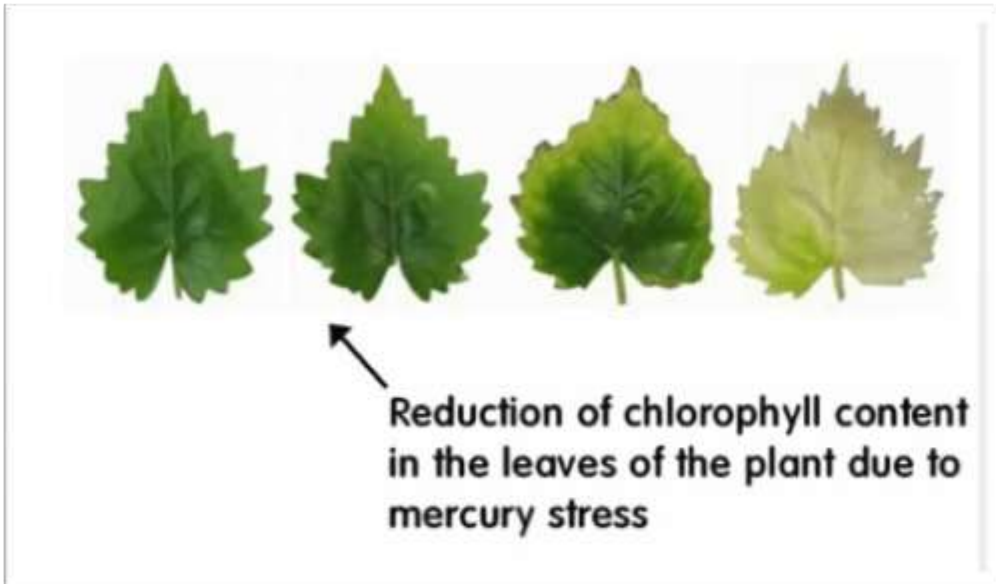

Fig 4:- Effect of mercury stress on the chlorophyll contents of the leaves.

Biochemical toxicity of mercury in medicinal plants:-

Plants are the storehouse of natural biochemicals. To produce the necessary biochemicals, plants rely on the most sophisticated metabolism for the regulation of their growth, development, and all those environmental interactions happening around which produces plant hormones, vitamins, and distinct phytochemicals via its primary and secondary metabolic processes. The production of essential phytochemicals has mediated by medicinal plants. Therefore, the proper regulation of the plant biochemical is very necessary but the exposure of plants to heavy metals such as mercury which is considered the most persistent toxic metal causing alteration in the regulatory metabolism happening in the medicinal plants. Mercury present in the medicinal plant stimulates the production of bioactive compounds which interrupt the regulation of the phytochemicals. The oxidative stress induced due to mercury accumulation triggers signaling pathways that eventually affects the production of specific plant metabolites. To be specific reactive oxygen species (ROS), initiated during mercurial stress causes lipid peroxidation which stimulates the configuration of highly active signaling compounds which are capable of triggering the production of bioactive compounds [19]. Inhibition of photophosphorylation involved with non-cyclic electron transport was observed in spinach plants due to mercury addition which also marked the interruption of the photophosphorylation rate by mercury.

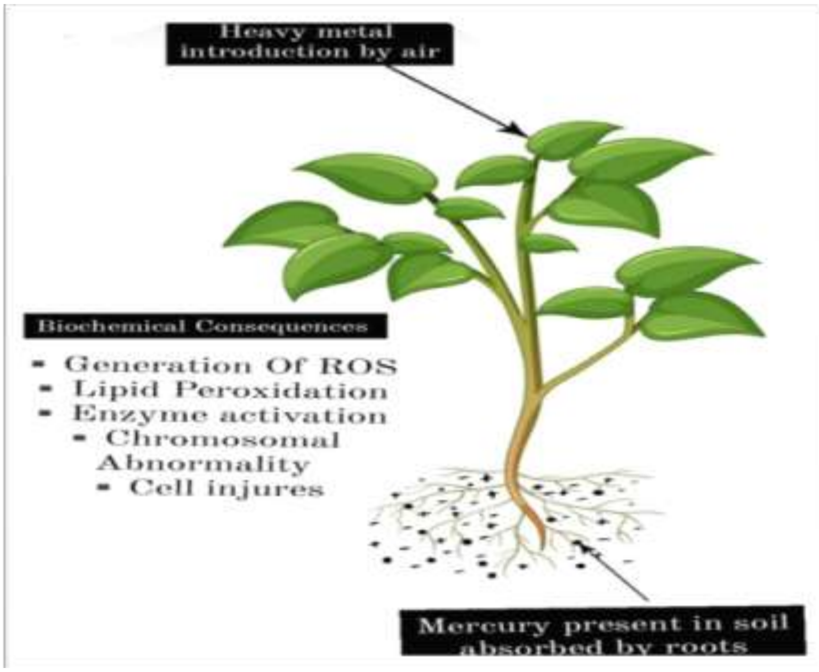

Fig. 5:- Biochemical toxicity of mercury.

Conclusion:-

Heavy metals toxicity is a persistent problem that has been increasing day by day due to continuous anthropogenic activities which are leading to the accumulation of metals in the aerial parts of the plants as well as the root exhudes from the soil. This problem has risen to a level that has caused deterioration in the morphology as well as the physiology of the plants.

Mercury which has been considered a major toxic metal has vivid impacts on plants growth leading to morphological changes in food crops as well as medicinal plants thereby increasing the reactive oxygen species (ROS), and lipid peroxidation which triggers the highly active signaling molecules which produce bioactive compounds. Mercury leads to chromosomal aberration which alters the metabolic process of the phytochemicals. Mercury also reduces the chlorophyll contents and causes photosynthesis suppression which leads to morphological changes in the plants. Direct consequences occurring due to mercury induction are growth inhibition, and mineral uptake, which suppresses the transport of the xylem and interferes the enzymatic activities. Mercury stress also causes water potential reduction and ultimately cell death. Numerous works on the toxic effects of mercury accumulation and understanding its adverse effects on plants has been done. This review has summarized the outstanding contributions and breakthroughs made in the field in course of understanding the adverse effects of mercury in different food crops. The future aspect of this study is to reduce the toxic effects of mercury by detoxifying it through phytoremediation and other plant engineering techniques.

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