A REVIEW ON THE TOXIC EFFECT OF ARSENIC INDUCED STRESS IN DIFFERENT CROP PLANTS

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Abstract- **Arsenic (As) is a highly toxic pollutant in the environment. Although both inorganic and organic types of arsenic occur in the environment, the most common inorganic forms of As that adversely affect plants that are arsenite (As III) and arsenate (As V). Arsenic (As) is a common soil contaminant that can be accumulated in plant parts. The ability to detect As in contaminated plants is an important tool to minimize As-induced health risks in humans. Near-infrared (NIR) spectra are strongly affected by leaf structural characteristics. Therefore, quantitative analyses of structural changes in the arrangement of mesophyll cells caused by As will help to explain spectral responses to As. Despite no evidence for Arsenic being essential for plant growth, exposure of roots to this element can cause its acceptance primarily via transporters responsible for the transport of essential mineral nutrients. Arsenic exposure even at low concentrations disturbs the plant's normal functioning via extreme generation of reactive oxygen species, a condition known as oxidative stress leading to an imbalance in the redox system of the plants. This is associated with considerable damage to the cell components thus impairing normal cellular functions and activation of several cell survival and cell death pathways. To counteract this oxidative disorder, plants possess natural defense mechanisms such as chemical species and enzymatic antioxidants. Various approaches to improve As-induced oxidative tolerance in plants such as exogenous supplementation of effective growth regulators, protectant chemicals, transgenic approaches, and genome editing are also discussed thoroughly in this review. Modification of several metabolic pathways, such as glutathione production, has been shown to lead to increased arsenic tolerance in plants. Species- and cultivar-dependent variation in arsenic sensitivity and the remodelling of metabolite pools that occurs in a response to Arsenic exposure gives hope that additional metabolic pathways associated with Arsenic tolerance will be identified.**

Keywords: **Arsenic, Crop plants, Phosphorus, Oxidative Stress, ROS, Phytotoxicity.**

INTRODUCTION:

Arsenic is a chemical element with the symbol As and an atomic number 33. Arsenic occurs in many minerals, usually in combination with sulfur and metals but also as pure-elemental crystals. Arsenic is a non-essential element and it is generally toxic to plants it occurs naturally in the environment through geological activities. The element is most commonly found in two forms of inorganic arsenic, i.e., arsenate [AsV] and arsenite [AsIII] and is easily taken up by the cells of the plant roots. As Arsenic is non-essential and generally toxic to plants. Being toxic metalloid and group I carcinogen, Arsenic (As) poses a threat to plants, especially to crops which are consumed by human beings, and sooner or later results in hyper/hypopigmentation and skin cancer.

The element arsenic (As) is an environmental toxin that is found naturally in all forms of soils [1]. Arsenic becomes a part of the human solid food chain when crops and fodder become contaminated.

Arsenic is non-essential and generally toxic to the plants. Roots are usually the first tissue to be exposed to Arsenic, where the metalloid inhibits root extension and proliferation. Upon translocation to the shoot, Arsenic can severely inhibit plant growth by retardation or arresting expansion and biomass accumulation, as well as compromising plant reproductive capacity through losses in fertility, yield, and fruit production [4]. At sufficiently high concentrations, Arsenic interferes with critical metabolic processes, which can lead to death. Most plants possess mechanisms to retain significantly of their Arsenic burden in the root. However, a genotype-dependent proportion of the Arsenic is translocated to the shoot and other tissues of the plant. Arsenic contamination is widespread due to its anthropogenic activities such as smelting operations, and fossil fuel combustion [2]. Arsenic-based agrochemicals, fertilizers, and disposals of municipal and industrial wastes [3]. Plants' intake of Arsenic can hardly be downregulated, as it is often mediated by essential element transporters [4]. Arsenic exposure harms the morphological (e.g., chlorosis), physiological (e.g., growth processes inhibition), and biochemical (e.g., oxidative stress) responses of plants [5,6].

Plant cells, both As(V) and As(III), including their conversion, induce oxidative stress by enhancing the production of reactive oxygen species, which affects the regulation of a diverse range of metabolic pathways [4,7]. The induction of oxidative stress is the main process underlying As toxicity in plants [8]. Furthermore, As acts by impairing mitochondrial enzymes, thereby causing a halt in cellular respiration and uncoupling oxidative phosphorylation [9]. Arsenate does not react directly with the active sites of enzymes [6], but this form strongly interacts with sulfhydryl groups in proteins, interfering with cellular functions [5].

All plant tissues are prone to be adversely affected by As. However, leaves are key interfaces between plants and their surrounding environment and are important to photosynthesis. In the context of As stress, the level of photosynthetic apparatus damage is chiefly related to the dosage of As treatment and application form. Furthermore, leaf structural properties, such as mesophyll thickness, mesophyll surface area, and leaf reflectance, are adversely affected by As.

Properties of Arsenic:
Arsenic (As) is a **chemical** element in the nitrogen group (Group 15 [Va] of the periodic table), existing in both grey and yellow crystalline forms. Arsenic occurs in many minerals, that are usually in combination. Arsenic (atomic number 33, atomic weight 71.9216µ). And its chemical properties are shown in (Table 1).

Physical properties	**Values**
Symbol	As
Group	15
Period	4
Atomic Mass	74.9216µ
Block	P
Atomic Number	33
Electronic Configuration	$3d^{10}4S^{2}4P3$
Relative Atomic Mass	74.922
Electronegativity	2.18
Boiling Point	613 °C

Table 1: Properties of Arsenic

MORPHOLOGICAL CHANGES IN PLANTS CONCERNING EFFECT OF ARSENIC:
The roots are frequently the first tissue to be exposed to arsenic [As], whereas the metalloid inhibits root extension and proliferation [4]. Upon translocation to the shoot Arsenic [As] can be severely inhibit plant growth by slowing or arresting its expansion and biomass accumulation, as well as it including plant reproductive capacity through losses in fertility yield and in fruit production.
Arsenic availability in the soil can disturb the normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity [10,11]. Soil contamination with Arsenic in poses a severe threat to human and environmental health [12], thereby affecting thousands of people with Arsenic perniciousness throughout the world. Research in the past has indicated that trace amounts of Arsenic have a stimulatory effect on plant growth, but high As concentrations are harmful and may begin to outweigh beneficial ones [13]. Arsenic toxicity in plants: morphological (Reduction of leaf number, chlorosis, necrosis leaf senescence, and defoliation. (Figure No.-1)

PHYSIOLOGICAL CHANGES IN PLANTS CONCERNING THE EFFECT OF ARSENIC:
High geogenic arsenic (As) content or anthropogenic activities like (e.g., mining, smelting, and agrochemical application) uplift Arsenic concentrations in biota and abiotic media, which poses direct or indirect ecological and human health risks. Arsenic causes phytotoxicity in several plants, including rice (*Oryza sativa* L). [1,15] Soil– and water–plant systems also bound the transfer of excessive metals to the food chain. Even so, food from terrestrial and aquatic plants can be a primary source of metals for humans. Rice is the main food source of inorganic Arsenic for humans, compared to other dietary staples, [15] because the unique physiology of rice plants for living in flooded conditions facilitates Arsenic accumulation from water. Rice-dominated diets present a chronic exposure route that may cause global health concerns because rice nourishes about half of the world's population.[16] The relationship between Arsenic concentrations in human hair and those in rice and agricultural soils supports the soil–plant exposure pathway of humans to As and the involved linkage between ecosystems and humans. Arsenic toxicity in plants: physiological (reduction in shoot and root growth, restricted stomatal conductance and nutrient uptake, chlorophyll degradation, and limited biomass and yield production). (Fig.-1)
Exposure to arsenate is causes considerable stress in plants, with inhibition of growth and finally death it is reviewed by [17] and causes physiological disorders.

ARSENIC TRANSPORT AND METABOLISM IN PLANTS:
When considering the effects of Arsenic on plant cellular metabolism, it is significant to deliberate that Arsenic species present in soils, the capability of these chemical species to enter plant cells, the ability of the plant to convert one Arsenic species to another, and the several Arsenic transport pathways that are available within the plant. During the movement of Arsenic through the plant tissues, some cell types are likely to be visible that need to respond to relatively high levels of particular Arsenic species, while others will be exposed only to low levels of the metalloid. The cell types that are exposed to high levels of particular Arsenic species are a defining difference between Arsenic hyperaccumulators and non-accumulators.
When plants were supplied AsV, typically more than 90% of the Arsenic in the roots and in the shoots was found to be in the form of AsIII [18]. Thus, AsV is voluntarily reduced to AsIII by plants. This reduction is accepted as the first step in the major Arsenic detoxification pathways found in various plants [18]. The reduction of AsV to AsIII arises both enzymatically and non-enzymatically.

Cytoplasmic Arsenate interferes with the metabolic process that involves Phosphate, giving it the potential to be toxic to plants, but it is probably reduced in the cytoplasm to arsenite [17]. When Arsenite reacts with the sulfhydryl group (-SH) of its enzyme and tissue proteins, that inhibits its cellular function and causes death [19].

IMPACT OF ARSENIC ON THE PHOTOSYNTHESIS OF PLANTS:

Arsenic is widely reported to inhibit the rate of photosynthesis in plants [20,21]. After As absorption by plants, light harvesting apparatus can be affected with a reduction in chlorophyll concentrations and photosynthetic activity-II or by suppressing a few of the key events of the above processes [22]. A remarkable reduction in chlorophyll pigment synthesis was reported due to a shortage of the adaptive adjustments of photosystems-I and -II as a result of high As levels. Similarly, a decrease in chlorophyll biosynthesis in Zea mays [23], Trifolium pratense L, and Lactuca sativa seedlings were reported due to As-induced stress.

Toxic effects of As on the photosynthetic process could occur either in photochemical or biochemical steps or even in both stages. Arsenic caused injuries in the chloroplast membrane and disorganized functions of the fundamental photosynthetic process. Under As exposure, the rate of carbon dioxide fixation and functionality of PS-II also reduced considerably. Arsenic has been shown to negatively affect the photochemical efficiency and heat dissipation capacity of a plant, thereby promoting changes in the rates of gas exchange and fluorescence emission. These results are mainly consistent across studies and suggest that As may cause a decrease in both leaf and root growth, subsequent in the appearance of toxicity symptoms such as wilting and violet coloration of leaves.

THE TOXICITY OF ARSENIC:

The results from many hydroponic experiments agree that Arsenic phytotoxicity depends on the chemical species supplied to the plant, but disagree on the identity of the most phytotoxic form of Arsenic [24,25,14]. The inconsistent order of phytotoxicity of the various Arsenic species could be a sign that Arsenic has consistent differently with the available nutrients, or that the phytotoxic form of Arsenic is plant species dependent. Alternatively, the deceptive variation of the above results may be due to our incomplete understanding of the relative importance of the various Arsenic species to the mechanism of Arsenic toxicity. After all, the mechanism concluded by which Arsenic causes phytotoxicity has not been definitively identified and the exact species of Arsenic that is the primary cause of toxicity is unknown. In this regard, the finding of MMA^{III} in plants [26,27] is particularly fascinating Another issue that needs to be involved when considering the toxicology of Arsenic is that some forms of Arsenic may be under-represented or even missing from the evaluations of Arsenic speciation in plants. In a study on sunflowers, 15–20% of the total tissue Arsenic was not recovered from the plant tissue, depending on the tissue and post-harvest storage time [28]. Arsenic toxicity is that the plant growth is stimulated at low Arsenic [As] concentrations [29][25]. The fact of this phenomenon is that occurring under the axenic condition in cultured plants, such as *Arabidopsis thaliana* [30] indicates the trait is not based on Arsenic troublesome plant biotic interaction, instead, it results either from a direct interaction of nutrients. Studies on Arsenic toxicity have been concentrated mainly on arsenate because it is the dominant form in aerobic soils.

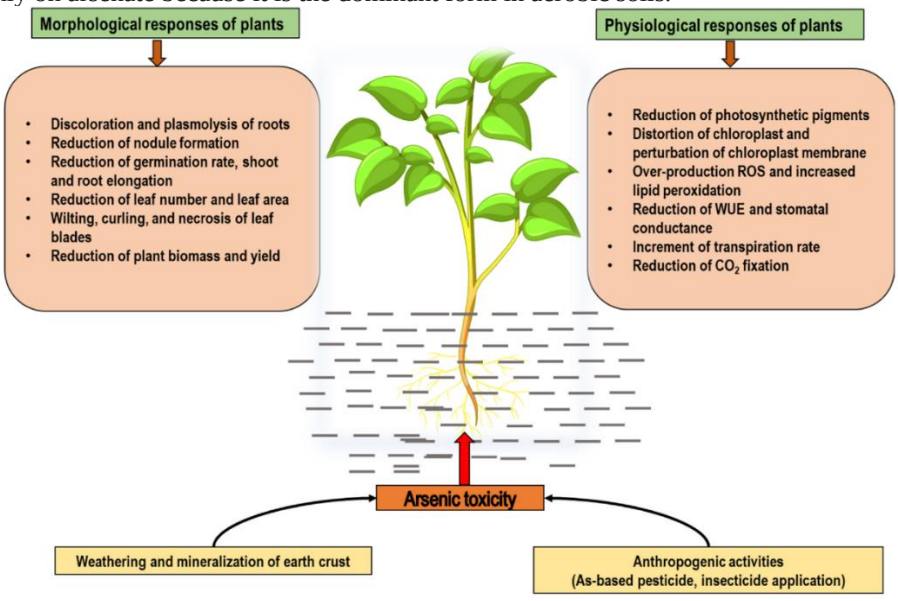

Fig.- 1 Mechanism of Arsenic Toxicity in plants)

OXIDATIVE STRESS OF ARSENIC IN PLANTS:

Oxidative stress is a complex chemical and physiological phenomenon that convoys virtually all biotic and abiotic stresses in higher plants and that develops as a result of overproduction and accumulation of reactive oxygen species.

Environmental Stresses negatively affect plant growth development and crop productivity. This adverse condition after the metabolism of reactive oxygen and nitrogen species (ROS and RNS, respectively). The high concentration of these reactive species that exceeds the capacity of antioxidants defense enzymes, disturb redox homeostasis, which could trigger damage to macromolecules such as membrane lipid, proteins, and nucleic acid, and ultimately results in nitro-oxidative stress and plant cell death.

On the other hand, plant cells develop an antioxidant defense mechanism, which includes non-enzymatic and enzymatic antioxidants for the purification of ROS Regulation on Plant Development. However, if the ROS production is higher than the ability of the antioxidant systems to scavenge them, it can lead to oxidative stress, and finally to cell death. In this context, Dr. De Maio's group used citrus plants to investigate the modulation of poly (ADP-ribose) polymerase and antioxidant enzymes, using leaves in different developmental stages, including young, mature, and senescent. Their work talked about the physiological, biochemical, and molecular changes that occur in plant cells during leaf aging.

ROS REGULATION OF PLANT AND DEVELOPMENT:

Plants are subjected to numerous environmental stresses throughout their life cycle. Reactive Oxygen Species (ROS) play important roles in maintaining normal plant growth and improving their tolerance to stress. This review describes the production and removal of ROS in plants, recapitulates recent progress in understanding the role of ROS during plant vegetative apical meristem development, organogenesis, and abiotic stress responses, and some of the novel findings in recent years discussed. It is well known that improving crop yield and productivity requires an improved understanding of the coordinated growth of plant tissues and organs. Plant morphologies are regulated by both intrinsic genetic programs and external environmental factors. Reactive Oxygen Species (ROS) that are regarded as by-products of plant aerobic metabolism and are generated in several cellular compartments such as chloroplast, mitochondria, and peroxisomes [31]. ROS not only causes irreversible DNA damage and cell death, but also functions as important signalling molecules that regulate normal plant growth, and responses to stress. This suggests that ROS has a dual role in vivo depending on different levels of reactivity, sites of production, and potential to cross biological membranes [32]. As the source of all ROS (Reactive Oxygen Species), oxygen (O_2) is stable and not very reactive in plants. However, it can be converted into high-energy ROS in numerous organelles by various processes that affect plant metabolism. The ROS such as superoxide radicals (O^{2-}) hydroxyl radicals (OH^-) and hydrogen peroxide (H_2O_2) are strong agents that cause oxidative damage to biomolecules such as lipids and proteins that eventually causes cell death [33]

Much progress has been completed on plants' Arsenic uptake and metabolism since the last Tinsley Review on this topic by [34], which focuses on Arsenic speciation, toxicity, and resistance/tolerance mechanisms. This review will present recent progress in the understanding of physiological, biochemical, and molecular mechanisms of Arsenic uptake, metabolism, and hyperaccumulation by plants, and climax the knowledge gaps that require further research. (Fig.-2)

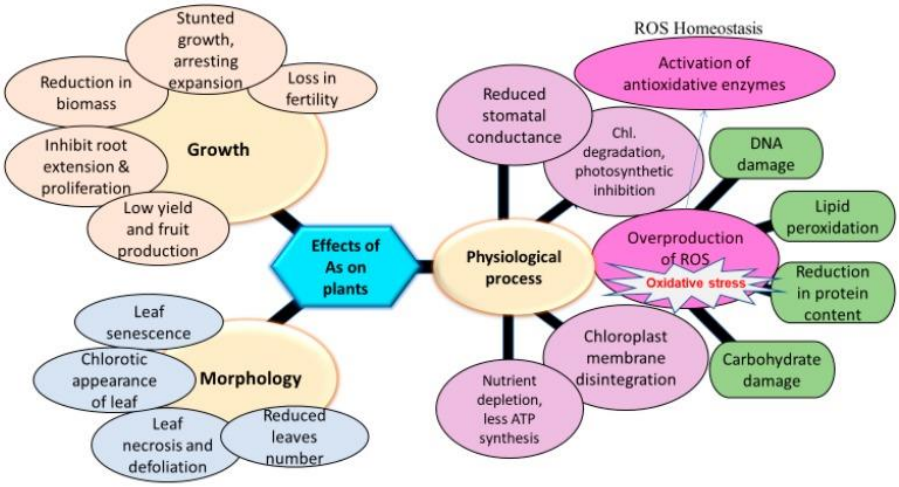

Fig.-2 Regulation of plant growth and development against abiotic stress

ANTIOXIDANTS AND ARSENIC TOLERANCE:

The plant response to As and other abiotic stresses includes key ROS-scavenging enzymes such as: SOD, CAT, APX, MDHAR, DHAR, GR, GST, GPX, and POD [35,36]. The orchestration of antioxidant defenses is performed by the balance of different enzymatic antioxidants, which involve the removal of $O_2^{\bullet-}$ (SOD), conversion of H_2O_2 into water and molecular oxygen (CAT), scavenging of H_2O_2 in the extra-cellular space (POD), conjugation of GSH to electrophilic compounds or hydrophobic compounds (GST), maintenance of the ascorbate pool (MDHAR and DHAR), and scavenging of H_2O_2 to water using ascorbate as a specific electron donor (APX) [36].

Several proteomic investigations have observed the differential accumulation of antioxidant enzymes in plant tissues after As exposure. Findings regarding this subject are important to gain information on As-induced antioxidant regulation at the translational level. However, more studies are needed on this subject in order to elucidate the relationship between antioxidant enzyme concentration and enzyme activity that is modulated by As exposure in plants. Further research is also needed in order to perform the qualitative evaluation involving isozyme profiling by gel-based approaches, which has already been performed by some authors that evaluated As-exposed plants [37]. Knowledge and achievements regarding As-induced oxidative stress tolerance might also be improved by using emerging proteomic approaches in the field of abiotic stress. For example, phosphoproteomics has been used to unravel plant tolerance mechanisms to heavy metals, even though there is a lack of information on this subject related to As toxicity.

CONCLUSION:

Much excellent work has been done on the metabolism of Arsenic in plants: how it is acquired and stimulated over the plants; how it is reduced, detoxified, and sequestered; how its imitators Pi, binds sulfhydryl groups and causes oxidative stress. We have a fairly firm grasp of the mechanism used by Arsenic hyperaccumulators to accumulate large amounts of the toxicant without poisoning. These plants yield up the metalloid more rapidly than non-hyperaccumulators, do not appropriate in the root, but rather transport it quickly to the aerial tissues where it is sequestered in the vacuole as AsIII. The rapid rate of uptake and translocation to the front and a higher antioxidant capacity to preserve lower ROS levels [38,39], perhaps coupled with relatively rapid dilution in the majority of the aerial tissues, together seem to provide the hyperaccumulators with adequate time and resources to neutralize the toxic effects of Arsenic.

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