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A Review on negative impact of F^- on cellular functioning of biological system of plants

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ABSTRACT

Fluoride (F^-) exposure to air, soil, and water had the most detrimental impact on plants of all the halides. The element also had an adverse effect on a variety of physio-biochemical parameters after exceeding its desired limits in plants, with or without overt evidence of injury. Fluoride levels in plants are higher, which also inhibits plant growth by interfering with various pathways involved in photosynthesis, protein synthesis, respiration, nucleotide synthesis, and glucose metabolism. The two processes that plants use to get and use their basic energy are photosynthesis and respiration. Fluoride has a significant role in these two routes. This article explores the detrimental impacts on agricultural trees and crops ability to respire and produce oxygen and making food via photosynthesis.

***Key words :** Fluoride, Toxicity, Respiration, Photosynthesis,Plants.*

Introduction

The most significant member of the halides group is Fluoride. Less is known about the biological significance of fluoride than the effects of chloride and iodide in the halide group on organisms (Jentsch *et al*., 2002; Edwards and Karl, 2010; Zimmermann, 2011). In the halide series, fluoride is the smallest and most electronegative anion. Fluoride possesses distinctive chemical and biological characteristics for its reactivity and size, yet the processes of fluoride-induced cell signalling are still poorly understood. Fluoride is a substance that is found in water, soil, and the air everywhere in the environment (Jagtap *et al*., 2012). It is a very rich element in the planet's crust, present at 0.32g/kg (WHO, 1984; Jaishankar *et al*., 2014). Depending on the area, fluoride concentrations in water and soil differ. A soil sample may include anywhere between 10 and 1000 parts per million (ppm) of fluoride (Jaishankar *et al*., 2014). Depending on whether the water comes into contact with minerals that have large concentrations of fluoride, the amounts in natural water sources vary from l25 μM-100mM (0.5 - >2,000ppm; 1ppm >55μM) (Kanduti *et al.*, 2016). The largest quantities of fluoride of any anion have been found in groundwater (Jagtap *et al*., 2012), making it the most significant phytotoxic air pollutant. Utilizing controlled field plot trials, greenhouse studies, and other scientific techniques, the toxicity of fluoride (F^-) on land plants (terrestrial) has been well investigated and shown (Dando *et al*., 2008). Fluoride damage to vegetation is caused by large concentrations, which typically build up gradually over time in plant tissue (Kebede *et al.*, 2016). It might cause atypical morphological signs such as chlorosis, tip as well as marginal necrosis, among others (Waugh, 2016).

Fluoride sensitivity varies between species and types, according to reports. Fluoride inhibits enzyme activity (Waugh *et al.*, 2016; Westram *et al.*, 2002), the phosphorylation of phosphoproteins in cellular membranes (Kaufman and Chang, 2000), the formation of photosynthetic pigments (Ranghar and Baunthiyal, 2014) and other metabolic processes.

The harmful effects of fluoride exposure on the photosynthesis and respiration of trees and agricultural crops were critically explained in the present review.

Basics of fluoride

The earth has a lot of fluorides, which is the 13th most common element (Jordan *et al.,* 2008). F^- is a gas with a light-yellow colour. At standard pressure and temperature, it has an atomic weight of 18.9984 and an atomic number of 9. According to the Periodic Table of Elements, fluorine is categorized as a halogen and is found in Group VIIA. Chlorine, fluorine, iodine, astatine, and bromine make up the halogens. These are all electrically charged substances. They are designed for existing as diatomic molecules in a free state. Due to their electromotivity, they can react with substances that have a lower electromotive force.

As the chemical element fluoride mixes with other chemical elements, fluoride compounds are created. That doesn't happen in nature in a free state (Kurdi, 2016). The biological characteristics of fluorides may be thought to be comparable to those of other halogenated substances. This presumption might be somewhat true. In an aqueous solution, inorganic fluorides dissolve like other halogen members and release a monovalent fluoride anion (F^-) and the cation that goes with it. Yet fluoride has a variety of unusual chemical characteristics. These characteristics had a significant influence on the unique biochemical and physiological characteristics of fluorides. F^- may impact the mechanisms and metabolism of action inside the biological system for these reasons (Kurdi, 2016).

The isotopic makeup and chemical properties of fluorine have had a significant effect on our knowledge of the therapeutic, toxicity, as well as metabolism actions of F^-. The half-life of this isotope is incredibly short (Leech, 1956; NCBI, 2017).

It has significant phototoxic effects on vegetation at higher levels of F^-. The weathering of volcanic ashes, the use of phosphate fertilizers in agriculture, and other industrial sources (Mackowiak *et al.,* 2003; Cronin *et al.,* 2003) all contribute to its release into the environment. Several types of soil contain significant amounts of natural fluoride. It may move from the soil to the roots, which then move it to the above-ground sections, or it may be taken up by leaves from surrounding. Tree leaves contain toxic levels of F^- (Ruan and Wong, 2001; Shu, 2003). The passive diffusion procedureis the mechanism used for F^- uptake by roots. By using gentle washing techniques, the majority of the absorbed F^- is still exchangeable as well as easily extractable from the root (Larsen *et al.,* 2005; Garrec and Letoureneur, 1981).

Experimental research revealed that the majority of F^- was located in the apoplast, with minor amounts occasionally also present in the tonoplast or plasmalemma. F^- levels are low in the shoot because the endodermis serves as a reliable barrier. F^- skips the endodermis to enter the circulatory system in a non-selective manner (Singh *et al.,* 1995). F^- is more readily absorbed from the air than from the soil. It was discovered that roots contain less fluoride than leaves (Groth, 1975; Pitman, 1982).

It is possible to infer the fluoride absorption mechanisms in plants from the whole of this research. A few experimental studies on plants' ability to accumulate F^- have been emphasized. The species of the plant and the ionic strength of environment in which it is developing are the main factors that affect a plant's ability for absorption and accumulation. If there is a high concentration of F^- in the environment, then there will also be a higher concentration of F^- (Kebede *et al.*, 2016; Stevens, 1998; McCune, 1965). The F^- accumulation in plants is influenced by the kind of soil. Higher soil Ca concentrations prevent soil-derived F^- from building up in plants (Sheldrake *et al.,* 1978).

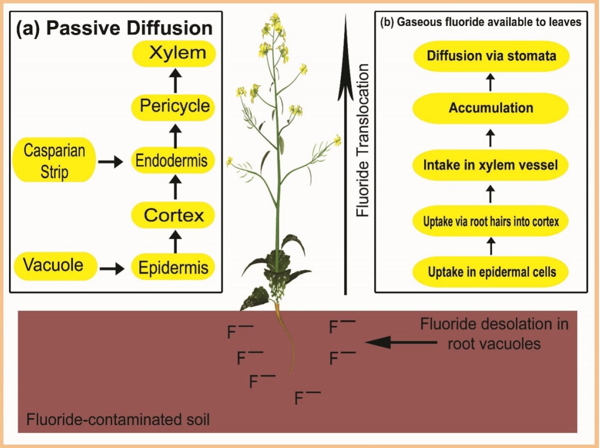

Fig. 1. Fluoride Source, uptake, translocation and accumulation by plants

Effects of fluoride on Photosynthesis

The production of agricultural crops may be hampered by multiple metabolic pathways and processes as a result of the various air contaminants (Arndt *et al.,* 1995). The reaction of plants to pollution is influenced by the chemical element's toxicity, the length of exposure, and the sensitivity of the species (Oguchi *et al.,* 2005).

Due to its electro- negativity, electromotivity, and strong phytotoxic potential, F^- stands out among the contaminants. Above all of these things, it is capable of entering via the stoma more often (Franzaring *et al*., 2007). Ultrastructural and structural damage to the leaves' tissues and cells was caused by F^- buildup. After the damage to cells and tissues, the stomatal conductance and gas exchange of plants will be substantially impaired (Alves ES *et al.,* 2008).

Photosynthesis was also impeded by fluoride buildup. F^-mostly affects photosynthesis by lowering chlorophyll production, degrading chloroplasts, and inhibiting the Hills reaction. Moreover, the amount of chlorophyll is reduced, which impairs the ability of plants to photosynthesize. In the end, these led to a decrease in CO_2 generation and assimilation (Yamauchi *et al*., 1983; Domingues *et al.,* 2011).

After exposure to F^-, the photosynthetic electron transport chain in plant thylakoid membranes was investigated. It was discovered that F^- buildup inhibits the electron transport rate of the PS II (photosystem II), which is followed by an increase in the electron transport rate of the PS I (photosystem I). This finding suggested that the mechanism underlying F^- toxicity may include state changes. According to Ballantyne (1991) study, plants that receive an F^- treatment at 190 ppm have fewer photosynthetic pigments. Moreover, it was discovered in Reddy and Kaur's 2008 investigation.

Reduced photosynthetic capacity, total chlorophyll, chlorophyll-a and chlorophyll-b concentrations leaf area, and carotenoids are all observed in plants cultivated in F^-contaminated soil (Kumar KA and Rao, (2008); Ram *et al.* (2014). It's possible that F^- reduced chlorophyll biosynthesis, which would explain the decrease in chlorophyll content in the plants (Gupta *et al.,* 2009). With the accumulation of F^-, chlorophyllase's amount and activity are likely to increase (Ram *et al*., 2014). The same effects were observed in the semi-arid zone where plants are grown in F^-contaminated soil (Baunthiyal and Sharma, 2014).

Effects of fluoride on Respiration

F^- Accumulation has been blamed for damage to the flora in some industrialized areas due to the well-known dangers that fluoride poses to plant tissues (Thomas, 1961). Alteration in respiratory rates is one of the fluoridebuild-up symptoms (Weinstein, 1961; Yu MH and Miller, 1967). Either stimulation or inhibition might occur varying on several factors, including plant's kind and age, the fluoride concentration, and the length of exposure.Many researchers have noticed that fluoride suppresses respiration in a variety of plant species (McNulty and Lords, 1960). They also discovered that breathing might be stimulated at lower intensities (McNulty and Lords, 1960). At both high and low doses, F^-treatment of soybean leaf tissue caused an initial stimulation followed by an inhibition, according to Yu and Miller (1967). Fluoride presumably reduces tissue respiration in large part by inhibiting respiratory enzymes. For instance, phosphoglucomutase, hexokinase, ascorbic acid oxidase, succinic, malic and phosphoglucomutase, NADH dehydrogenases, hexokinase, enolase, and ATPase are all known to be inhibited by F^-, with exception of ATPase (Lovelace and Miller, 1967; Melchior and Melchior, 1956; Lee *et al.,* 1968; Miller and Miller, 1974).

The reduction in sucrose synthesis in F^-fumigated plants may be attributed to the suppression of phosphoglucomutase, an enzyme involved in sucrose biosynthesis (Yang and Miller, 1963). Due to F^-'s harmful effects, higher plant's energy metabolic pathways were likewise paralyzed. It was shown that accumulating F^- hindered ATP synthase enzymes in ATP-forming organelles such as plasma membranes, mitochondria, and chloroplasts. However, "tonoplast-associated ATPase (V-ATPase)"and "plasma membrane-associated ATPase (P-ATPase)"are key enzymes that have shown the 1st structural modifications under environmental stress conditions. Its structure and function were both affected by F^- accumulation (Rakowski, 1997). These 2 enzymes are the primary early defence enzymes against F^- damage, as was shown by this instance.

The most significant enzyme for glucose metabolism, however, that F^- inhibits is enolase. Fluoride competition with Mg^{+2} caused an enzyme's activity to decline gradually and then completely disappear. Enolase was inhibited by F^- in the most recent studies on 6 planktonic algae (Strunecka *et al*., 2007; Hekman *et al.,* 1984). Less clear are the causes of respiratory stimulation or persistence of elevated respiratory rates in plant tissues treated with fluoride.

According to Ross *et al.* (1962) fluoride treatment of plants caused them to employ the pentose phosphate pathway more frequently. Both fluoride-inhibited and fluoride-stimulated respiration showed this. The increased usage pentose phosphate pathway may have been caused by the inhibition of the glycolytic enzyme enolase.

In a subsequent investigation, Lee (1968) demonstrated enhanced cytochrome oxidase, peroxidaseglucose-6-phosphate dehydrogenase, along with catalase activity in tissues impaired by fluoride. High ATP levels have been linked to fluoride-stimulated respiration in leaf tissue (McNulty and Lords, 1960). It's possible that fluoride-increased mitochondrial ATPase activity is a contributing factor in the phase of accelerated tissue respiration. On the other hand, it is thought that ADP levels regulate respiration (Klingenberg and Schollmeyer, 1961).

Fluoride may be disrupting the mitochondrial membrane, and it is thought that the breakdown of membrane integrity speeds up the activity of the mitochondrial ATPase (Miller and Miller, 1974). Several investigations (Earnshaw and Truelove, 1968; Lee, 1968) have hypothesized a connection between membrane integrity loss and mitochondrial enlargement. The primary location of fluoride action in plants was discovered to be the membrane (Ramagopal, 1969; Miller and Wei, 1974). The observed fluoride stimulation of tissue respiration may be partially explained by the reported increase in extractable mitochondria, as was proposed for pathogen-enhanced respiration in tissue of sweet potato (Asahi *et al.,* 1966). Fluoride treatment appears to cause a variety of physiological as well as biochemical alterations in plant tissue that may support enhanced tissue respiration.

According to Lee (1968) observations, fluoride treatment increases the activities of catalase, glucose-6-phosphate dehydrogenase, peroxidase and cytochrome oxidase. They showed that this behavior was caused by overall F^- damage, with possible glucose-6-phosphate dehydrogenase activity as an exception.

Means of Controlling Fluoride Toxicity

The effects of silicon addition on physio-biochemical and antioxidant enzymes in Mung bean toxicity were experimentally examined by Ahmad *et al.,* 2019. Different NaCl concentrations in mung bean treatment result in a reduction in the length and dry weight of the root and shoot. Salt's negative impact on biomass and growth is reduced when silicon is added to salt-stressed plants. Silicon causes NaCl-stressed plants to produce more antioxidant enzymes.

Experimental research on silicon's impact on maize development under cadmium stress was conducted by Dresler *et al.*, 2015. While silicon supplementation reduces the build up of cadmium in maize roots, cadmium stressed plants exhibit reduced plant development. Hence, silicon inhibits cadmium absorption and exhibits a favourable effect on the growth of maize seedlings.

In an experimental study Zhu *et al.,* 2004 found that silicon improved the activities of antioxidant enzymes in cucumber leaves while attenuating the effects of salt stress. In salt stressed plants, silicon addition increases antioxidant enzyme activity and lowers LPO and H_2O_2 content. A rise in the antioxidant enzyme led researchers to believe that silicon might be connected to metabolic activity in cucumbers under salt stress.

Collivignarelli, (2020) reported using palm leftovers to reduce the amount of fluoride in ground water. Microbes are crucial in the treatment of fluoride toxicity, according to Chaudhary *et al.,* 2019. Recently, Gao *et al.*, 2020 conducted an experiment to remediate harmful fluoride concentrations in shallow ground water bodies, and their results are encouraging.

A further strategy would rely on locating tolerant cousins of important crops and incorporating them into breeding programmes to create the required crop kinds.

Conclusion

In this review, we examined the evidence for the negative impacts of fluoride compounds on the cellular functioning of biological systems of plants. Numerous studies have shown that fluoride may affect the biological processes of respiration and photosynthesis. Even though most of the enzymes participating in such changes in cellular respiration and photosynthesis mechanisms have been discovered, some of the targets and mechanisms involved in these activities are still unclear. Concentration and amount of F^- have a direct impact on how complex these systems are affected. Fluoride, however, regularly coexists with other elements in the environment in a variety of forms, which does not always result in a higher level of toxicity. A few instances of adverse effects have been documented. There is an urgent need for more research on effects of F^-toxicity stress on different plants in order to identify a few tolerant species and reclamation programmes that can be useful in developing future strategies. To combat this, one must understand the molecular, physiological, and biochemical basis of agricultural fluoride tolerance. For the benefit of the researchers working in this specific area, an overview has been provided in this review.

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