Plasma Technology – A Solution to Fungal Contaminants of Maize

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Maize (*Zea mays* L.) is the world's third most significant cereal crop, trailing only wheat and rice (Aldrich et al., 1975). It has significant potential as a cereal crop due to its low production costs, wide flexibility, and numerous uses. A variety of causes contribute to yield loss, with sickness playing a significant role. At the seedling stage, maize is infected with 28 diseases, 11 of which are seed-borne (Fakir, 2001). Several scientists have reported that seed-borne pathogens have a significant impact on seed production and the food industry because they can affect seed germination and plant growth, cause seed and seedling diseases and mycotoxin contamination of grains (Singh *et al*., 2011; Magan and Olsen, 2004; Barros *et al*., 2011). Damages induced by seed-borne infections, such as seed death, seedling and plant deformities, or diminished seed vigour, are not often noticed by users (Mukhtar, 2009).

Rapid seed invigoration and seedling establishment are required throughout the early growth phases of crops to prevent agricultural yield loss owing to unfavourable environmental conditions. Seed germination and early seedling growth are the most vulnerable stages of crop development to a variety of environmental stresses (Jisha *et al*., 2013 and Sharma *et al*., 2015). When stressors influence seeds or plants during the early phases of growth, they can delay the onset, diminish the rate, and reduce the uniformity of germination and seedling emergence. Plant growth and agricultural yield are lowered as a result. As a result, seed invigoration is employed to promote germination and seedling vigour (seedling size, health, and pace of growth). Many efforts have been made to improve seed germination and seedling vigour under both adverse and non-adverse conditions, including the use of chemical treatments such as sulfuric acid, pesticides, and chlorine-based disinfectants (Ashraf and Foolad, 2005; Kimura and Islam, 2012; Jisha et al., 2013; Sharma et al., 2015). Synthetic chemical treatments involve soaking seeds or spraying young plants with chemical-containing solutions. However, the use of synthetic chemical treatments can lead to a rise in chemical pollutants in seeds or young plants, which can have a negative impact on human health and the environment.

Furthermore, pathogenic fungi damage food grains during storage by creating mycotoxins and aflatoxins, threatening their nutritional integrity (Park et al., 2004; Koirala *et al*., 2005; Domijan *et al*., 2005). Aspergillus and Fusarium species were the most common fungus infecting seed germplasm (Askun, 2006; Fandohan et al., 2003). Previously, Anne et al., (2000), Curtui *et al*., (1998), and Susan *et al*., (2005) isolated several Fusarium species from maize seed. Fusarium and Aspergillus species were prevalent maize fungal pollutants that produced high levels of mycotoxins (Bakan *et al*., 2002; Verga *et al*., 2005).

Plasma technology

Plasma technology, a new approach, has been extensively designated as an enhanced oxidation process (Misra et al., 2011; Ekezie et al., 2017; Fan and Song, 2020). Although large-scale uses of plasma technology are still pricey, it has advantages over conventional treatments based on synthetic chemical compounds. The synergistic effects of plasma technology on seed germination and seedling vigour without synthetic chemical residues are a considerable advantage. Plasma treatment has recently gained popularity as a pre-sowing seed treatment method to increase seed quality and decontaminate microorganisms on the seed coat surface. Plasma is a partially ionised plasma that contains positive and negative ions, electrons, neutrals, molecules, photons, and ultraviolet light.

Plasma, commonly known as the "fourth state of matter," is made up of ionised gas, atoms, free molecules, radicals, and free electrons. Since its discovery in the late nineteenth century, plasma has been widely used in a variety of industrial applications such as microelectronic technology, the textile industry, organic waste management, and so on. When a gas is pushed through an electric field in a plasma chamber, three types of collisions are known to occur: excitation, ionisation, and deposition, which furnish plasma with its characteristic glow, ion-electron pair, and reactive species. The chemical and physical properties of several objects can be altered via plasma treatment.

Application of plasma in Seed Science

Many seed quality enhancement strategies are utilised in seed science and research to increase seed quality in agricultural plants, such as seed priming, fortification, solid matrix priming, chemical treatment, hardening, and so on. Plasma treatment of seeds is a novel technique that uses an ionised gas to affect the physical and chemical features of the seed, such as wettability, porosity, water absorption, and antioxidant enzyme activity. It can also cleanse microbial seed surfaces and convert hydrophobic seeds to hydrophilic ones. It also increases soluble sugar and protein levels while decreasing lipid peroxidation. As a result, plasma therapy enhances seed germination rate, seedling traits, seed physical quality, and seed health. Agricultural applications of non-thermal plasma for improving seed quality and crop yields, as well as decontaminating seeds, have received a lot of attention recently, owing to the fact that food shortage is becoming one of the most serious global problems in this century due to the constantly growing population and decreasing arable land (Koga et al., 2015). Numerous studies have shown that non-thermal plasma is a faster, more uniform, cost-effective, and eco-friendly method for stimulating seed germination and seedling growth than conventional seed pretreatment methods such as ultraviolet and gamma radiation, scarification, hot water soaking, and chemical reagent treatment (Li et al., 2014; Randeniya and De Groot, 2015; Mildaziene et al., 2018; Stepanova et al., 2018). Several authors have investigated the use of plasma generators to stimulate seed germination and plant growth (Zivkovic et al., 2004; Sera et al., 2010; Dobrin et al., 2015; Bafoil et al., 2018). Plasma treatment has been shown in some studies to increase seed activity, including earlier germination, higher germination rate, faster growth, and other growth parameters (Sera et al., 2010; Jiang et al., 2014), enzyme activity (Henselova et al., 2012; Surowsky et al., 2013), and plant yield (Yin et al., 2005). However, the detailed processes underpinning plasma's stimulatory effects on seeds remain unknown.

There are several methods for producing plasma, including glow discharge and dielectric barrier discharge from various gases such as air and $O_2^{\bullet -}$. When seed is exposed to plasma, the plasma interacts with the seed surface, changing its topography as well as its biochemical and physical properties. These modifications, in general, impact seed behaviour during the early stages of germination, resulting in significant variations in seed and crop performance later on. Plasma can be generated in a variety of ways, however for seed treatment, the glow discharge method is often utilised due to its qualities such as seed quality improvement, seed enhancement, and pathogen cleaning on the seed coat surface. Plasma is created in the glow discharge method by passing an electric current through a low-pressure gas. A voltage is applied between two electrodes in a glass tube containing gas to produce it. When the voltage in the tube surpasses a particular threshold, the gas ionises and changes into plasma. The ionised gas begins to conduct electricity, which causes it to glow (Mehta, 2002). It primarily increases the physiological and health components of seed quality as a post-harvest element in seed quality. Plasma treatment has been used successfully in agriculture to improve seed quality, boost seed, and inactivate harmful microorganisms (Filatova et al., 2013). Although plasma treatment has yielded promising results in a variety of crops, commercial implementation of this technology has yet to be standardized.

Among the various constituents in plasma, reactive oxygen species (ROS) [e.g., hydroxyl radical (OH), superoxide anion ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2), and singlet oxygen ($^1O_2$)] and reactive nitrogen species (RNS) [e.g., nitric oxide (NO), nitrite ($NO2^{-}$), nitrite ($NO3^{-}$) and peroxynitrite ($OONO^{-}$)] are considered as the major agents for plasma induced biological effects (Iseni et al., 2016). ROS and RNS in plants can be beneficial or harmful depending on the amount (Panngom et al., 2018), activating a variety of physiological and metabolic behaviours (such as breaking dormancy, accelerating germination, and enhancing antioxidant capacity) at low doses while causing oxidative stress in seeds at high doses (Romero-Puertas et al., 2019). To resist oxidative stress, plants have an intrinsic antioxidant defence system that includes enzymatic antioxidants such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), as well as non-enzymatic antioxidants such as ascorbate, glutathione, and proline (Liu *et al*., 2018). These antioxidants are required for the stimulation of physiological and developmental processes as well as the resistance to stress (Liu *et al*., 2007). Plasma-generated reactive species, on the other hand, could directly etch the seed husk, enhancing the seed coat permeability for oxygen, water, and other nutrition species and, as a result, boosting seed growth properties (Zhang and Kirkham, 1994). In addition to ROS and RNS, intracellular Ca^{2+} has been identified as a key signaling component in several physiological processes in plants, including hormone production, seed germination, cell division, cell expansion, pollen tube growth, and fertilization (Demidchik *et al*., 2018).

Plasma pre-treatment of seeds promotes germination while suppressing fungal and bacterial plant diseases. Crop yields are increased by immersing seeds in a low temperature plasma discharge produced by separated electrodes coupled to a high frequency electrical power supply. Scarifying seeds (a technique to soften the seed coat while keeping the seed viable), inactivating seed-borne pathogens, and enhancing antioxidant defence systems in crop plants have all been used independently (Jisha *et al*., 2013; Arajo *et al*., 2016; Antoniou *et al*., 2016; Thomas and Puthur, 2017). During the plasma treatment, the seeds may be damaged by oxygen radicals and battered by ions, resulting in the erosion of oxygen-containing functional groups in the seeds. Changes in the surfaces of plasma-treated seeds may increase the seed's hydrophilic wettability, resulting in faster water uptake. This promotes rapid seed germination. Increased seed permeability is connected with increased nutrient absorption, which may promote seedling growth.

Future research should focus on optimizing plasma seed treatment to improve water absorption and seed vigour, as well as investigating the storability and antioxidant mechanisms of plasma seed treatment on the inactivation of seed-borne pathogens in maize seeds.

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