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Application of Non-Thermal Atmospheric Pressure Plasma to Control Plant Diseases

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INTRODUCTION

Non-thermal plasma (NTP) is being explored as an alternative to traditional disinfectants for controlling microbial growth, especially in food industry settings. While NTP's effects on bacteria and yeasts are well-studied, its impact on filamentous fungi is less understood. NTP could serve as a viable alternative to existing disinfectants within food industry production facilities to eliminate the development of fungal contamination (Rabachova *et al.*, 2024).

POSSIBLE MECHANISM(S) OF PLASMA ACTION IN DISEASE CONTROL

It is generally known that non-thermal atmospheric pressure plasma can produce several RONS in addition to UV, charged active species, electric field, and electromagnetic rays. The most common way to describe RONS among these factors is as important figures in the inactivation of microbes. Specifically, RONS are significant elements in plasma-treated water or other media that are regarded as therapy with indirect plasma (Figure 1). Most people know about plasma. in order to produce singlet oxygen and other reactive oxygen species (ROS), superoxide, ozone, reactive nitrogen, and hydroxyl radicals organisms, including nitric oxide and nitric dioxide. One way to employ plasma as an antibacterial tool is through the combined effects of different RONS and additional physical elements.

PLASMA Technology's Benefits and Drawbacks for Plant Disease Control

Numerous investigations have shown that inactivating plant-pathogenic bacterial and fungal cells can be accomplished with non-thermal atmospheric pressure plasma. As a substitute instrument for managing illnesses, plasma has demonstrated numerous benefits and drawbacks in contrast to conventional control instruments. Plasma here is significantly less chance for technology to elicit resistance from pathogens, a significant issue with chemical-based controls.

Furthermore, plasma is capable of effectively inactivating chemical-resistant infections and non-resistant pathogens alike, as it lacks selectivity about pathogen species. Given that numerous species produced unstable reactive species produced by plasma, and its effects on the The environment is transient. Consequently, it's regarded as an a tool that is safer for the environment. In comparison, plasma is safer than ionizing radiations, like X-rays and gamma-rays, as a result of its reduced intensity.

ATMOSPHERIC-PRESSURE NONTHERMAL PLASMA TECHNOLOGY

Ionized gas known as plasma is sometimes called the fourth state of matter. When gas is exposed to high energy, it changes into a plasma state. Actually, the It is possible to create a plasma state by using a high electric voltage. to fuel. UV radiation, charged species, reactive species, and free In the plasma, electrons and an electric field are produced. state, and these elements have a significant impact on the biological procedures. Since it is possible to make non-thermal plasma at air pressure, and its use in biology has been intensively researched in the domains of agriculture and medical. Plasma possesses been repeatedly shown to be efficient in microbiological demise of cancer cells and inactivation.

Role of RNS and ROS in Plant Immunity

Rabachova *et al*. (2024) examined the influence of NTP on fungal spore regrowth, biofilm metabolic activity and morphological changes of four different fungi (*Alternaria alternata*, *Aspergillus niger*, *Fusarium culmorum* and *Fusarium graminearum*) using scanning electron microscopy (SEM). Results showed that NTP treatment reduced biofilm extracellular matrix, damaged hyphae and altered biofilm structure from layered to sparse and monolayered. Out of the 4 filamentous fungi studied, *Alternaria alternata* exhibited the most significant morphological changes and decrease in metabolic activity post-NTP treatment.

PLASMA TECHNOLOGY TRANSFER TO AGRICULTURAL INDUSTRY

Nacheva *et al*. (2024) investigated the use of cold atmospheric plasma (CAP) technology for decontaminating plum plants (*Prunus domestica* L. *cv*.'Kyustendilska sinya') infected with plum pox virus (PPV), the causative agent of Sharka disease. Nodal segments from *in-vitro* cultured plum plants were treated with an Argon plasma torch and an underwater diaphragm discharge. The study found no significant differences in shoot number and length between treated and control plants *in- vitro*, although treated plants exhibited greater stem length *ex-vitro*. There were no significant growth differences among plants with varying treatment frequencies. However, three years post-treatment, CAP-treated PPV-negative plants showed no Sharka symptoms, CAP-treated PPV-positive plants exhibited only mild symptoms, while non-treated controls displayed typical Sharka symptoms.

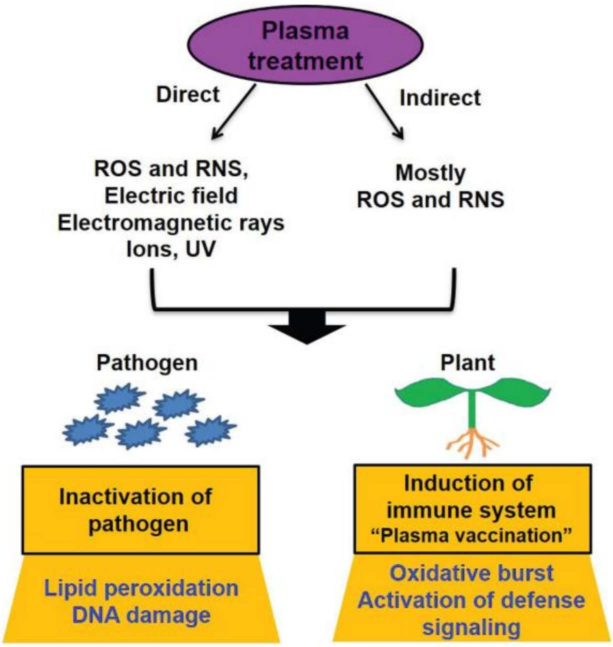

Figure 1- Models of plant disease control by plasma.

Plasma can be applied directly or indirectly (plasma-treated water or media) to plants. Many plasma factors such as ROS, RNS, electric field, electromagnetic rays, active ions, and UV can be involved in disease control in direct plasma treatment whereas ROS and RNS from plasma are major players in indirect plasma treatment. Plasma (direct and indirect treatment) can inactivate pathogens associated with plants and seeds by causing membrane lipid peroxidation and DNA damage. In addition, it can be possible that plasma (direct and indirect treatment) induces plant immune responses by causing oxidative burst and continuously activating defense signaling, leading to the expression of defense genes.

Cold plasmas for biofilms control

A significant amount of chronic infections and illnesses linked to medical devices in humans are caused by bacterial biofilm infections; nevertheless, their natural resistance to antimicrobial medicines makes it difficult to manage them. Cold atmospheric plasma, or CAP, is a potentially useful treatment. The creation of a chemically varied mixture of reactive species and intermediates, and their interaction with a heterogeneous 3D interface formed by the extracellular polymeric matrix of the biofilm, are two complex processes that come together when microbial biofilms are treated with CAP. Therefore, the key to managing pathogenic biofilms effectively is comprehending these interactions and the physiological reactions to CAP exposure.

Plasma-Induced Persistence and Tolerance

Persister cells are transient phenotypic variations in a microbial community that show metabolic inactivity, dormancy, and a brief, high-level tolerance to stress, including starvation and antibiotic assault. Persister cells can be found in biofilms or in the planktonic phase more difficulties in controlling biofilms effectively. Persistence, in contrast to resistant mutations, does not occur not through inheritance but rather through phenotypic variation caused by mutation. This characteristic Variation causes the cell to enter a quiescent, metabolically dormant state in which it neither grows nor passes away when subjected to a fatal stressor. Prior to now, the two states with the best descriptions includes persistent cells, viable but nonculturable (VBNC) cells, and microbial dormancy, which It was often thought that bacteria coexisted because they could survive environmental stress. in microbial populations stochastically (Adhikari *et al*., 2020).

Plasma sciences for plant pathogen interaction

Gas changes into the plasma state when it is exposed to high energy. In actuality, providing a high voltage can create the plasma state. gas to electric voltage. species that are reactive and charged organisms, ultraviolet light, unbound electrons, and an The plasma state generates electric fields. and these elements have a significant impact on the chemical reactions. Several Research has indicated that the antimicrobial Non-thermal atmospheric pressure activity plasma on harmful microbes in plants, concentrating primarily on fungus and bacteria. In those research, plasma therapy was carried out on suspension of microbiological cultures or tainted food supplies, vegetation, and seeds.

Plasma on Bacterial and Fungal Pathogen: Bacterial pathogens are transferred by biological vectors, such as insects and weeds, and physical factors, such as wind and rain, under field conditions. These pathogens invade plants either through natural openings, such as the stomata and lenticels, or by wounding and moving inside the plant through the xylem. Disease symptoms appear in the form of specks, spots, blights, vascular wilts, tumors, rots, and cankers on the leaves, flowers, fruits, stems, roots, and tubers of affected plants (Horst et al., 2001).

CONCLUSION

NTAP shows promise for controlling plant diseases by inactivating pathogens and activating plant immune responses. While plasma inactivation of pathogens is well-documented, emerging research suggests that plasma treatments can also enhance plant immunity by increasing levels of reactive oxygen and nitrogen species (RONS) and defense hormones, without harming plant vitality. Though data on plasma vaccination are still limited, Further research on this environmentally safe approach is essential to utilize its potential for inducing disease tolerance.

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