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# Cold Plasma Therapy an Alternative to Chemical Pesticides for Managing Post-Harvest Pest in Agriculture

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**Abstract**

Post-harvest losses due to infestation of insect pest and pathogens poses a significant threat to agricultural food security. Although several synthetic chemicals and preservatives are found effective but their toxic residues may posses long term affect to the humans and ecosystem. Cold plasma technology has emerged as an advance solution for managing post-harvest losses and also have plant growth promoting activities. In is a non-thermal plasma technology which generates reactive oxygen species (ROS) and reactive nitrogen species (RNS) that inactivates pathogens and insect pest during storage conditions. Beside this, cold plasma also enhances the seed germination, promotes plant growth and extends shelf life of perishable food products. Owing to its high efficacy, low environmental impact and multifunctional mode of action, cold plasma represents a promising technology for sustainable post-harvest pest management and future smart agricultural systems.

**Keywords:** Defence signalling, free radicals, non-thermal technology, spore inhibition

## Introduction:

With the rapid increase in the global population, agricultural industries play a crucial role in meeting the food demands in the developing countries. However, there is significant losses in the yield of agricultural crops occurs during the post-harvest conditions due to biotic and abiotic stresses. Among biotic stresses, infestation of insect pest and pathogens radially causes 10-30% crop loss (Hasan *et al*., 2025). Although several management practices have been implemented for the management of post-harvest pests, but use of chemical pesticides is common as it has quick actions against the pathogens and insect pests. But these chemicals have showed adverse effect on both human health as well as environment. In recent years, several alternatives like use of microbial based metabolite products, encapsulates products of microorganisms and nanotechnological based products have shown effective against key pests during post-harvest conditions. Along with these management approaches, cold plasma technology has emerged as a promising sustainable alternative tool for post-harvest pest management. It is a non-thermal plasma, well ionized which is generated under atmospheric or vacuum at temperature range of 30-60°C. This is generally ionised form of gases which contains reactive oxygen species (ROS), Reactive Nitrogen Species (RNS) and other electrons and free radicals. These compounds can damage microbial cells via oxidative burst mechanism and thus prevents growth of microbial pathogens (Singh *et al*., 2024). Beside this, it can also cause physical damage to the insect pests which results in high mortality of larvae, pupae and adult insects. Several thermal technologies have been developed so far for managing post-harvest pest, but it has some limitations like physiochemical degradation and also creates taste alternation to food items. By addressing these limitations, cold plasma therapy offers better sterilization, enzymatic deactivation and functional modification of the food products. Due to its low operating temperature requirement, high efficiency and minimal negative impact to the environment, this technology has gained a popularity among the food processing industries (Nikzadfar *et al*., 2024). Beside the pest management attributes, this therapy can also increase the germination rate, triggers the production of plant growth hormone like auxin and gibberellins and also helps in promotion of seedling growth. Additionally, this technology can also activate the defence systemic signalling pathways for plant which makes them resistance against biotic stresses (Dilip *et al*., 2026).

**How cold plasma works against post-harvest pests?**

When agricultural pest come in exposure to the cold plasma, the ROS and RNS interact with the macromolecules and causes oxidative burst. Due to this, it causes lipid peroxidation in the cellular membrane components and also degrades nucleic acids and inactivates enzymatic actions. Due to the damage of the cellular components, the metabolic process inside the pest body also fails and ultimately results in death. In fungal pathogens, these reactive species cause membrane damage and leads to leakage of cellular components (Siddique *et al*., 2028). Various studies also confirmed that, cold plasma treated seeds can germinate vigorously and also reduces infestation of fungal seed borne pathogens (Mravlje *et al*., 2021). The atmospheric cold plasma technology can also reduce the pathogen pressure by inactivating the spore germinations (Umair *et al*., 2022). In insects, this plasma therapy can damage the surface cuticular layer and also reduces per cent egg development in insect pest. Pathan *et al*. (2022) reported that, cold plasma treatment on pulse beetle (*Callosobruchus chinensis*) can significantly manages this insect pest during post-harvest conditions. The ROS released during the cold plasma therapy can act as powerful oxidant that can break down the toxin released by pathogens. Plasma generated ROS oxidize the hydrocarbons and lipids present at the cuticular layer of insects and thus inhibits their growth and development (Dilip *et al*., 2025).

**Role of cold plasma in pest management and plant growth promotion**

Cold plasma therapy in agricultural products act like a single bullet with multiple target actions. This technique can be used as seed treatment, disinfection of post-harvest products and also can be used for enhancing the shelf life of perishable products (Mani *et al*., 2023). During post-harvest conditions, contamination with harmful microbes occurs when the products are kept at contaminated packing materials. Treating the packing materials with cold plasma can reduce the chance of contamination during the post-harvest conditions (Pankaj *et al*., 2014). The surface sterilization of fruits and vegetables by cold plasma therapy can eliminate the inoculum of post-harvest pathogens. Beside this, seed treatment with cold plasma can effectively manage pathogens attack. Jiang *et al*. (2014) Reported that, cold plasma treatment can improve the growth of tomato crop and also increase the production of $H_2O_2$ which can reduce the severity of *Ralstonia solanacearum* causing bacterial wilt in this crop. Presence of preadult insects at the storage conditions can be killed quickly by this therapy while the adults takes longer duration of exposure to get eliminated (Zizuzina *et al*., 2021).

Cold plasma treatment in plants can also activate the defence mechanism in plants which protects the plants from pest attack. Cold plasma can upregulate the pathogenesis related genes which leads to the accumulation of PR proteins such as chitinases, glucanases etc. in plants. Beside this, cold plasma treatment can also activate the salicylic acid and Jasmonic acid signalling pathways in plants which provides systemic acquired resistance (SAR) and induced systemic resistance (ISR) in plants upon pathogen attack. Moreover, cold plasma generates ROS and RNS molecules that triggers endogenous ROS production in plants. This ROS activates the calcium influx and defences related genes in plants (Adhikari *et al*., 2019).

Thus, cold plasma technique can be used for managing the biotic stresses and alternatives to chemical free management approaches during post-harvest conditions. Some of the common plants pathogens and store grain pest managed by cold plasma therapy and its mode of action are highlighted in table 1.

**Table 1:** List of some plant pathogens and insect pest managed by cold plasma and its mechanism of action

| Plant disease/insect pest | Host name | Mechanisms adopted by cold plasma | References |
|---|---|---|---|
| Fusarium head blight (Co.: *Fusarium graminearum*) | Wheat grains | ROS and hydroxyl radicle disrupt cell membrane and inhibits spore germination | Ju *et al.* (2023) |
| Bakanae disease (Co.: *F. fujikuroi*) | Rice | Seed treatment with plasma reduces disease severity by decontaminating the pathogen also inhibits its spore germination | Hoppanová and Kryštofová (2022) |
| Fusarium wilt (Co.: *F. oxysporum* f. sp. *basilici*) | Sweet basil | Depending upon the exposure time in cold plasma treatment reduces the disease severity. | Homa *et al.* (2021) |
| Grey mould (*Botrytis cinereal*) | Blue berry | Inactivates mycelial growth and spore germination through oxidative damage. | Hoppanová and Kryštofová (2022) |
| Banana anthracnose (Co.: | Cavendish banan | Inactivates mycotoxin production and kills microbial | Doshi and Šerá. |

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|---|---|---|---|
| *Colletotrichum musae*) | a | contaminants present on the surface of the fruits and reduces spore viability. | (2023) |
| Stored grain pest (*Tribolium castaneum*) | Stored grains | Rapid mortality of insect pest via oxidative stress. | Ziuzina *et al.* (2021) |

Note: Co.: Causal organism

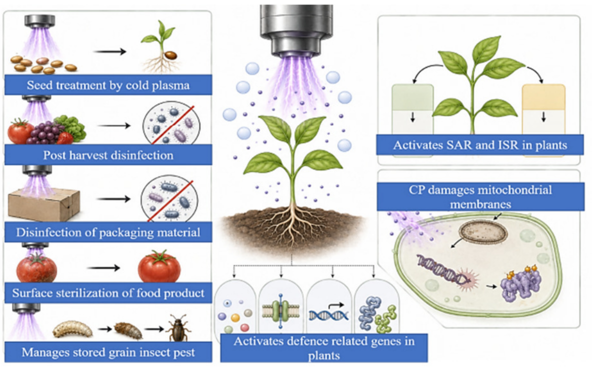


**Fig 1:** Different mechanism of action of cold plasma in plant growth promotion and diseases and insect pest management

**Conclusion:** Cold plasma technology provides a modern and sustainable approach for managing pest during post-harvest condition. The effective management approaches of this therapy technique can extend the shelf life and also reduces the dependency on chemicals for managing pest, making it a tool for ensuring food safety and security. While challenges like cost of implementation and lack of awareness exist, ongoing research and development are likely to overcome these constrains, paving the way of wide spread use of this technology.

**Conflict of Interest**: The authors declare no competing or conflict of interest

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