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Plasma Treatment and Seed Quality Advancement: A Review

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ABSTRACT

Plasma also called as 'fourth state of matter' encompasses ionized gas, atoms, free molecules, radicals and free electrons. Considering its discovery in late 19th century plasma is extensively used as low pressure or high pressure plasmas in many applications commercially such as microelectronic technology, textile industry, organic waste management *etc*. When a gas is passed through an electric field in a plasma chamber, three types of collisions are known to take place in it particularly, excitation, ionization and deposition that provide plasma its characteristic glow, ion-electron pair, reactive species respectively. Plasma treatment of different object can change their chemical and physical properties. In Seed Science and Research, many seed quality enhancement techniques are used to improve seed quality in crop plants such as, seed priming, fortification, solid matrix priming, chemical treatment, hardening *etc*. Plasma treatment of seeds is a unique tool that utilizes an ionized gas to modify the physical and chemical properties seed *viz*., wettability, porosity, water absorption, activity of antioxidant enzymes. It can also decontaminate the seed surface off micro flora and convert hydrophobic seeds to hydrophilic. It also enhances soluble sugar content, protein content and causes a reduction in lipid peroxidation. Thus plasma treatment in turn improves seed germination rate, seedling characteristics, seed physical quality and seed health.

Key words: Plasma, Seed health, Seed treatment, Seedling vigour, Sterilization.

Plasma is an ionized gas consisting of faction of free electrons, excited atoms, molecules and radicals and so also called as the fourth state of matter. It integrates about 99 per cent of the visible universe. There are significant charge carriers in plasma that make it electrically conductive and strongly influenced by electric and magnetic fields (Ahn *et al.,* 2019, Ding *et al*., 2011). It forms structures *viz*., beams, filaments and double layers under the influence of a magnetic field, (Nalwa *et al*., 2018). Plasma is also known as St. Elmo's fire. For the first time in 1879 Sir William Crookes (1832-1919), a British chemist discovered a radiant matter created in glass container having two electrodes that ionize the gas inside. In 1928 this matter was later called plasma by American chemist Irving Langmuir (1881-1957) who thought it looks like blood plasma. (Jiayun *et al.,* 2014). This phenomenon is also visible in the Universe wherein at the high temperature of the Sun, ionization of a large portion of the atoms takes place by collisions between fast-moving atoms and this gas acts as plasma (Schnabel *et al.,* 2012). Examples of plasma are; lightening, Universe, Sun, Stars, neon and fluorescent light and plasma T.V.

What are different types of plasma used nowadays?

Glow discharge plasma is build up by applying low frequency Radio Frequency (less than 100 kHz) electric field in between two metal electrodes. It is a non-thermal plasma generated (Fig 1) *e.g.* fluorescent light tubes (Kumar *et al.* 2019). *Dielectric barrier discharge plasma* is also a non-thermal discharge that is created when high voltages is passed across small gaps (Nishioka *et al.,* 2014) (Fig 1).

Other plasma used commercially

1. Capacitively coupled plasma.
2. Cascaded Arc Plasma Source.
3. Inductively coupled plasma.
4. Wave heated plasma.
5. Arc discharge.
6. Corona discharge.
7. Dielectric barrier discharge.
8. Capacitive discharge.
9. Piezoelectric direct discharge plasma.

Different processes occurring inside plasma

A plasma constitute equal amount of positive and negative ions. It is constructed by applying a potential difference of a few 100 V to a few kV between two electrodes in a reactor (Bormashenko *et al.,* 2012). Inside the reactor (that is having filled with inert gas) due to the potential difference, electrons emitted by cathode hit the gas atoms or molecules to give rise to excitation, ionization and dissociation reaction. (Filatova *et al.,* 2013) The *excitation collisions* generating excited species, contributes to glow nature of plasma (and is therefore also called "glow" discharge). The ion-electron pairs initiated by *ionisation collisions* forms a self sustained

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plasma whereas *dissociation collisions* forms very highly reactive radicals (Fig 1).

Plasma in Seed Science and Research

Nowadays many seed quality enhancement techniques are employed to improve the quality of seed. These techniques as mentioned (Table 1) offers a great advantage to the seed producers in terms of better seed germination, vigour, storability, protection from seed pathogens and insect pest, higher crop productivity. But most of these treatments comprise the exposure of seeds to either high moisture or chemicals that can alter the physiological property of seeds. But this new technique of treating the seeds with plasma (Fig 2) do not exposes seed to moisture but handle seed with ionized gas that improves the seed quality by different processes *viz*, excitation, ionization and dissociation. While treating seeds with plasma factors are to be considered *viz.* seed type:- size, shape, surface, wrinkle or cervices of seed, exposure time, sensitivity of microorganism type, density of fungal loading and type of plasma.

Properties of plasma

- Plasma Etching (*Etching:* German *ätzen*, from a base meaning 'cause to eat): plasma is used as an etchant instead of strong acid to cut metallic surfaces. High speed plasma of appropriate gas mixture is shot at a sample. It modifies the physical properties of the surface by reaction of radicals.
- Surface sterilization by reactive species produced in plasma.
- Plasma gasification: process which converts organic matter into synthetic gas and electricity using strong electric current.
- Plasma pyrolysis generation of a torch's with temperature ranging from 2,200 to 13,900°C.
- Plasma gasification means plasma torch is powered by an electric arc that is used to ionize gas and catalyze organic matter into synthetic gas and solid waste (slag).

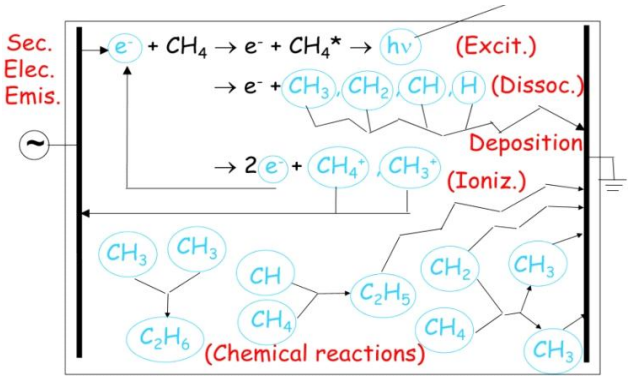


Fig 1: Different processes occurring inside a plasma.

Where plasma treatment can be done?

Other Application of Plasma Technology in science and technology

1. Lights and Microelectronic technology.
2. Medicine (dental cavities, sterlization of various surfaces, treatment of skin diseases, delicate surgeries).
3. Food processing- decontamination.
4. Ion implantation to material modification in metal industry.
5. Textile industry.
6. Decontamination of grains (Meral *et al.* 2008).
7. Surface sterilization clinical devices off microorganism.
8. Rubber industry.
9. Waste treatment by gasification of biomass and solid hydrocarbons, such as coal, oil.

Cold radiofrequency plasma treatment **c**an mutate the wettability of surface in seeds *viz*. *Triticum* spp., *Lens culinaris* and *Phaseolus vulgaris* (Bormashenko *et al.* 2012) by decreasing the apparent contact angle of seed surface with water. Lower contact angle encourage more water imbibition and speed of germination. Similar results are obtained by (Basaran *et al.,* 2008, Jiang *et al.,* 2014 and Kumar *et al.,* 2019). Seed surface gets oxidized by plasma treatment as during this treatment seeds get in contact with oxygen containing functional groups that boost radical emergence (Sera *et al.,* 2008). Seeds treated with plasma impose anti-microbial and antifungal activity and also increased hydrophilicity of the treated seeds. It can be proposed to save a significant amount of water which is

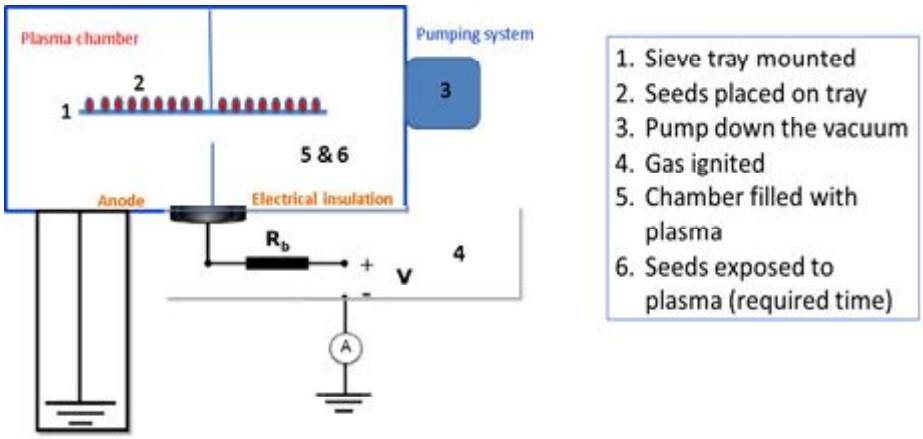


Fig 2: Set up of plasma chamber for seed treatment.

wasted in flood irrigating the sown fields. Similar results are observed by (Stone *et al.,* 1973, Krapivina *et al.,* 1994 and Dubinoy *et al.,* 2000). Atmospheric air plasma excited at some volts, can improve the permeability of the seeds by seed etching *i.e*. formation of many tiny holes on the surface of the seeds. The roughing of surface may accelerate seed germination and seedling emergence, longer root length and higher the strong seedling percentage (Jiayun *et al.,* 2014). Plasma is also known to increase antioxidants *viz*., the catalase (CAT) activity and catalase isoenzyme expression. Also malondialdehyde (MDA) that is generated when seedling is in environmental stress may also decrease with plasma treatment of such seeds. Plasma treatment modified the physiological and biochemical characteristics of *Andrographis paniculata* seeds by eroding the seed coat off the hydrophobic wax layer that induced deeper penetration of plasma-induced UV-B radiation (Jiayun *et al., 2*014). It can further favour the biochemical reactions for modifying the seed coat.

Glow discharge plasma treatment of seeds upto 20 minutes is found to curtail the fungal loads upto 25 per cent thus improving seeds of cereal crops (Brasoveanu *et al.,* 2015). The fungal decontamination of seeds can be firmly related to the type, size, shape, (Schnabel *et al.,* 2012, Preechayan *et al.,* 2010) surface, wrinkle or crevices of the seeds, minimum contact area of the samples with the holder and density of the fungal loading, exposure time and spatial location. Similar results were obtained by (Ding *et al.,* 2011, Dubinov *et al.,* 2000). Also, atomic oxygen and hydroxyl radicals generated in plasma treatment are the apparent



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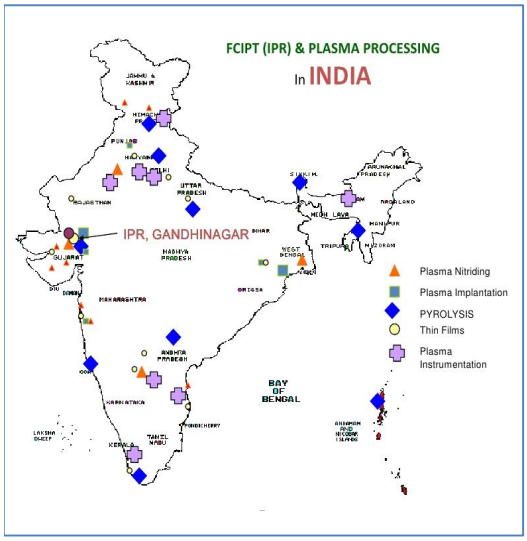


Fig 3: Places where plasma treatment of seeds can be done in India.

Table 1: Different types of seed quality enhancement techniques used in seed science and research.

Particular	Application	Shortcomings
Pre sowing seed treatment	Dormancy breaking Germination and vigour improvement- seed fortification, infusion, seed hardening, seed priming, pre irradiation, magnetic seed treatment, germination of seeds, Seed coating/ pelleting / colouringSeed protection treatments – seed dressing, biological seed treatment, biofertilizer treatments	These treatments expose seeds to some sort of external agents, whether water or air or vapour, it may also be mechanical abrasion of seeds. These treatments alter some of the physical and physiological properties of seeds.
Pre storage seed treatments	Halogenation Antioxidant treatment Seed sanitation Seed fumigation	High salt and chemical concentration can be damaging to seeds
Mid storage seed treatments	Hydration- dehydration Soaking drying Dipping dryingSpraying drying Moisture equilibrium drying	Not meant for moisture sensitive seeds such as legumes
Plasma Technology	Economically sound and pollution free Decontaminating off the pathogens from seeds. Seed quality in unultered Alternative to chemicals causing harm to human health and environment	If cost is effective there are as such no loss in using this technique for seed quality enhancement.

inactivation agents of microbial load while the nitrogen plays an imperative role in the intensification of the biological processes in seeds (Filatova *et al.,* 2013). If seed is under stress conditions, then most of its biological processes are withheld *e.g*. germination and seedling emergence. Cold plasma treatment proves to be remedial measure that can improve germination of seed, seedling growth, increase concentration of antioxidant enzymes, reduced lipid peroxidation levels (by lowering malondialdehyde content) of seeds *e.g*. oilseed rape under drought stress conditions (Li *et al.,* 2015). Not only this cold plasma treatment augment shoot length and dry weights, root length and dry weight and more lateral root number by improving absorptive ability of seeds. Similar results were produced by (Shao *et al.,* 2013, Guimaraes *et al.,* 2015). Higher is the amount of antioxidant enzymes more is the capacity of seeds to tolerate stress. So cold plasma treatment is also meant to elevate the SOD, CAT activities under drought stress conditions that is central for seed growth and germination.

Plasma treatment can be a restorative way to give protection to young seedlings against drought stress damage. It requires short duration of exposure that is commercially attractive. Another advantage is that chemicals are excluded in the plasma process hence there is no chance of pollutants remain after the treatment, which proves it as environment friendly. Seeds after plasma treatment can be

Table 2: Research related to plasma treatment conducted in seed science and technology.

Crop	Research carried by	Results of plasma treatment
Seed physiological characters		
Cotton	Stone *et al.,* 1973	Electrical treatment induced of germination of impermeable seed coat.
Soybean	Krapivina *et al.,* 1994	Seed germination and seedling growth improved.
Oat and barley	Dubinov *et al.,* 2000	Percentage germination and length of sprout growth improved with plasma exposure.
Foxglove-tree	Zivkovic *et al.,* 2004	Air plasma stimulated the germination in deciduous seed species.
Chenopodium album	Sera *et al.,* 2008	Plasma treated seeds shows 55 per cent more germination then untreated.
Tomato	Gandhare and Patwardhan, 2014	Plasma treatment ameliorated germination in older seed lots.
Spinach	Shao *et al*., 2013	Germination and vigour of old seeds improved significantly by about 150 to 200 per cent respectively
Bell Pepper	Nalwa *et al.* 2018	Seed plasma treatment along with osmopriming showed superiority in growth, fruit and seed character.
Okra	Kumar *et al*., 2019	Pre sowing treatment with plasma improved physiological growth and yield.
Corn	Ahn *et al*., 2019	Higher values of germination in field if alternative to traditional seed treatment is not promising.
Seed biochemical character		
Maize	Henselova *et al.,* 2012	Isoenzyme and antioxidant composition modified in seed by plasma treatment at low temperature
Maize, spring wheat, Lupin	Filatova *et al.,* 2013	Improved water permeability by seed etching for enhanced seed germination.
Radish	Mihai *et al*., 2014	Length and weight of roots and sprouts increased positively up to 11 and 30 per cent respectively.
Seed health character		
Chinese cabbage	Ding *et al.* 2000	Corona discharge plasma sterilized seed infected by *Xanthomonas compestris pv. compestris*
Hazelnut, peanut and pistachio nut	Basaran *et al.,* 2008	Aflatoxin contamination was reduced to half by air gases plasma treatment.
Ginkgo biloba L.	Kalkaslief *et al.,* 2009	Microorganism count reduced on seed *viz*., *Salmonella* spp., *Escherichia coli.*
Corn, bean, garlic and shallot	Preechayan *et al.,* 2010	Contamination of aflatoxin products was brought down to three times by atmospheric glow discharge plasma.
Tomato	Jiang *et al*., 2014	Significant control of tomato bacterial wilt in seeds.
Brassica seeds	Nishioka *et al.,* 2014	*Rhizoctonia solani* fungus survival on seeds reduced to 1.7 per cent from 83 per cent by plasma.
Carrot, Piper, Raphnus spp. *etc*.	Schnabel *et al.,* 2012	Eradication of highly sterilization resistant endospores of *Bacillus atrophaeus*.
Cicer arietinum	Mitra *et al.,* 2014	Health risks associated with contaminated chick pea seeds is reduced.
Blue lupine, honey clover and soybean	Azharonok *et al.,* 2014	Seed coat infection of *Stemphylium botryosum Fusarium oxysporum, Alternaria brassicae,I* reduced by 6-14 per cent.
Wheat	Kordas *et al*., 2015	disinfected seeds off seed borne fungus.

stored again if they are not used for germination since it is not destroyed. Further this treatment recovers absorptive ability and imbibitions in seed and therefore better germination under drought stress. Higher accumulation of reactive oxygen species is cause of drought stress that results in oxidative damage to plants. But if plant is self sufficient in antioxidant system then its resistance to drought stress can be elevated. Plasma treatment is an important tool to increase the levels of antioxidant enzymes, such as SOD, POD and CAT and non-enzymatic compounds. Plasma treatment can also regulating water balance by modulating antioxidant enzymes. Plasma treatment stimulated SOD and POD activity in tomato seedlings (Li *et al.,* 2015). These result are in agreement with findings of with (Meiqiang *et al.,* 2005) who reported that plasma treatment increased peroxidase (POD) isoenzyme content in tomato seedlings. Also accumulation of soluble sugars and soluble proteins retain plant turgidity, compliment its absorptive ability and defends membranes and macromolecules during drought stress. Other advantage of using plasma treatment is that it improves wettability of seed and reduced lipid peroxidation-linked membrane deterioration. Further plasma treatment is conducted in several seed crops (Table 1) in relation to seed physiological, health and biochemical characters.

It can be concluded that plasma is a fast, inexpensive and ecologically sustainable, pollution free treatment that may emerge as a promising alternative technique to be used in agriculture as pre-germination seed treatment to improve seed quality, breaking hard seed coat, protecting seed against drought stress, enhancement of plant growth and performance in different crop species both under stress and normal conditions. This technology helps in improving seed germination rate, enhancing speed of germination in both normal and stress conditions and rejuvenates old seeds. It's a constructive technique to enrich seed surface with micronutrients and inactivation of seed pathogen and decontamination of microbiologically contaminated seeds. It's a quick treatment with no side effect and can prove to be an alternative to traditional seed processing technologies.

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