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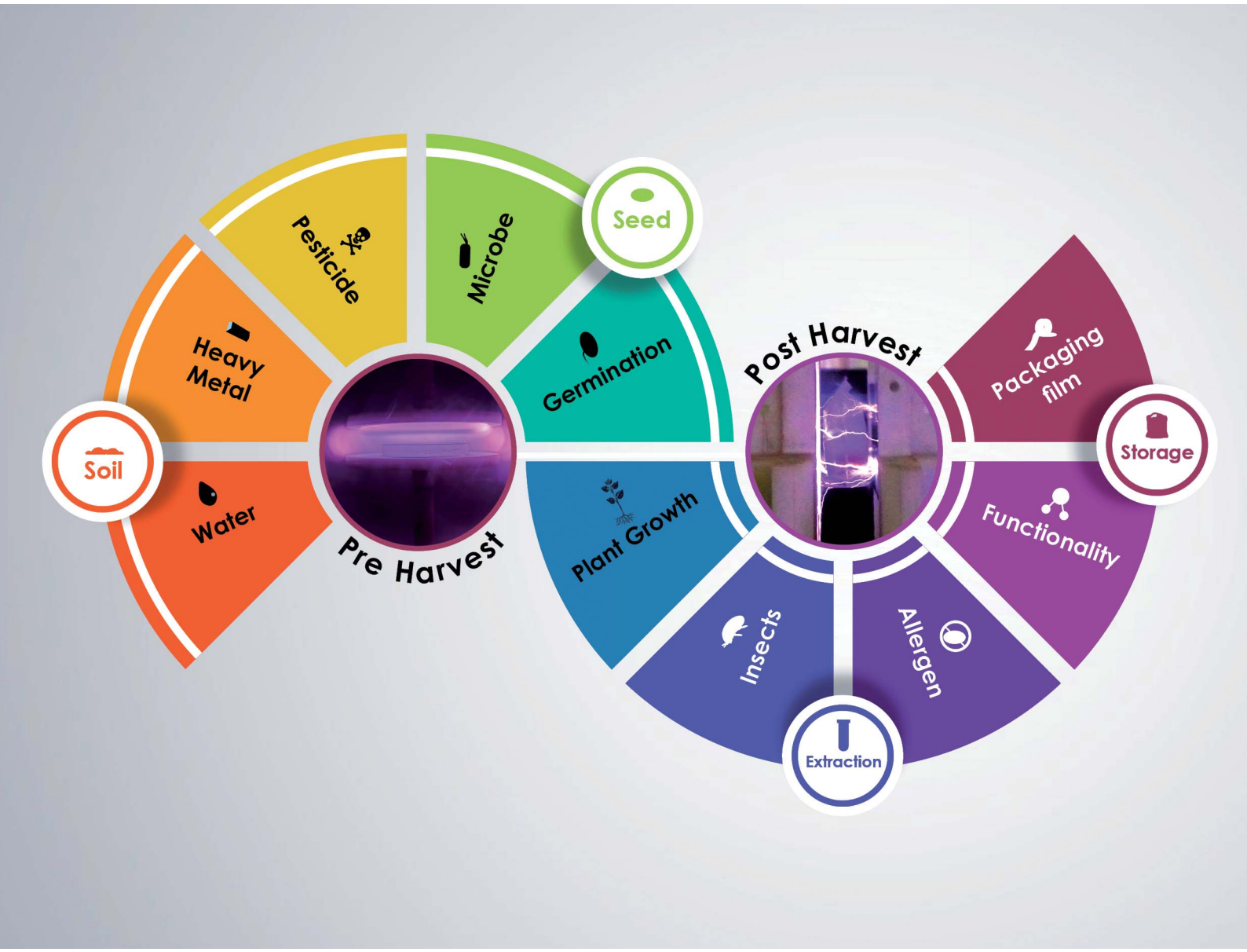

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Plasma processing: a sustainable technology in agri-food processing

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Globalization and rapid urbanization have led to tremendous improvement in the agriculture and food processing sectors to fulfil the food demands. In this context, managing food product safety and quality throughout the agri-food chain (pre-harvest to post-harvest) becomes vital to avoid food spoilage and increase production. Numerous innovative interventions have been investigated to achieve these goals; however, no single technology can be applied at all processing stages and may require different technologies. Nevertheless, cold plasma is a multifaceted solution for most pre and post-harvest issues, including soil/water contamination, microbial spoilage, insect infestation, and prolonged seed dormancy. In addition, the recent applications of plasma to food shape transformation is an evidence of the versatility of this technique in agri-food processing. Advantages, such as on-site production, residue, and toxic-free treatment, make the plasma process more sustainable. Reactive species, UV photons, and electrons are this plasma treatment's major compounds, giving them the peculiar and unique property to tackle most pre and post-harvest challenges. This review provides comprehensive possibilities for utilizing plasma technology throughout the agri-food chain. Various plasma systems have been developed, but their potential is limited to the lab scale. Research on large-scale applications can utilize cold plasma in future.

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1. Introduction

Agriculture and food processing sectors need progressive growth in production and value addition to feed the increasing world population. Nevertheless, the required food production has to be achieved with the available resources without compromising the product quality. Thus, we need a technology that could bring progressive growth in food supply and address food security and quality-related issues. In agri-food processing,

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irrigation and soil preparation are the two significant steps; any issues associated with these steps affect the entire supply chain and reduce product quality and yield. However, due to industrialization and urbanization, effluents are continuously introduced into environment and contaminate soil and water with heavy metals and cause phytotoxicity.[1,2] Further, medical and related waste containing antimicrobial contaminants also affect plant growth based on their type and nature.[3] Therefore, removing these contaminants from soil and water before the farming stage could increase agricultural yield and food safety.[4–7] Nevertheless, the seed germination rate and adaptability to different environments also affect crop yield. In this regard, selecting a suitable seed treatment would also increase seed tolerance against salinity and drought stress.[8,9] However, the real challenge arises at the post-harvesting stage, where the harvested fresh edible agricultural produce needs to be treated to avoid quality deterioration concerning microbes,[10–12] enzymes,[13] insects, and their secondary toxic contaminants.[14] Furthermore, in later stages, most agricultural products reach industries where they will undergo various unit operations before they are stored and distributed to consumers.[15] However, these product rheological properties, microbial/pest safety, functional properties, extract quality, and quantity would be low until these products are treated with suitable processing methods.[16–18] Hence, while selecting the processing method/treatment, we should focus on its ability to address all these issues, irrespective of the product physical nature and intended final use.

Regarding processing, non-thermal technologies are preferred over thermal technologies to avoid undesirable product quality changes. In food processing, non-thermal treatments such as pulsed light, ultrasound, UV, ozone,

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pulsed electric field, and high-pressure processing technologies are considered alternatives for thermal treatments. As the name suggests, these non-thermal food processing techniques are performed nearly at room temperature to produce safe, nutritive products and retain freshness without inducing thermal damage in the product,[19–21] and cold plasma technology is also one among them. Plasma is created by supplying high energy to gas molecules. The supplied energy dissociates molecules into atoms, and a further increase in the energy breaks those gas atoms into wholly or partially charged ions. Irving Langmuir coined the name plasma for this ionized gas in the early 20th century.[22] It is the fourth state of matter and can be generated under atmospheric or vacuum conditions.[23] Photons, electrons, ions, atoms, free radicals, and excited or unexcited molecules are present in this state. Based on energy given to the plasma system and energy transferred to the molecules in plasma, the plasma is classified as equilibrium (thermal) and non-equilibrium (low temperature) plasma.[24] One of the critical advantages of this novel technology is that it can be used for both constructive and destructive applications. Constructive approaches include functional modification,[25] seed germination, plant growth,[26] and quality improvement of extracts,[27] while destructive applications include decontamination,[28] disinfestation,[29] and pesticide degradation.[30] This review explains up-to-date research findings of plasma-assisted agri-food processing studies and the mechanisms involved in each process. Further, the article focuses on pre and post-harvest plasma applications specific to the commodities obtained from different plant parts (leaves, roots, fruits, vegetables, nuts, and spices).

2. Mechanism of plasma in various applications of agri-food processing

2.1. Microbial destruction and inactivation mechanism

Though various plasma-chemical reactions are initiated during plasma generation, O_3, O^+, OH^-, and H_2O_2 are the primary species responsible for microbial inactivation.[31] These RS breaks peptidoglycan (PG) bonds of the cell wall and causes destruction wherein the PG structural bonds like C–O, C–N, and C–C are destroyed by reactive oxygen species.[32] It is also suggested that the intense bombardment of the radicals causes surface lesions leading to etching, severely affecting Gram-negative bacteria.[33]

Firstly, the RS oxidizes lipids, enzymes, and cytoskeletal proteins in the cell membrane and damages the cell wall. In comparison, DNA damage is caused by high-energy UV photons released from excited atoms or molecules at 220 to 280 nm. They form thymine dimers and break plasmid DNA's single and double strands that affect cell replication and other functions.[34,35] In addition, RS in plasma increases the solution's acidity and further inactivates microbes.[36]

2.2. Chemical and toxin removal

Interaction of pesticides with plasma RS results in the oxidation of these chemical compounds and degrades them. Apart from oxidation, other intermediate processes also occur during the degradation and finally end in mineralization.[30,37] Pesticide and other organic or inorganic pollutant removal follows different pathways, where pollutants are converted into simple non-toxic components such as CO_2, H_2O, inorganic carbons, and other organic or inorganic components based on treatment time and reactive species nature. Oxidation, isomerization, and H_2O/CO_2 removal are some essential reactions that take place during this conversion.[38]

2.3. Insect mortality

The nerve toxin effect caused by plasma ROS on the neuromuscular systems of insects induces mortality. These species enter through the respiratory pathway of insects and affect the insect behaviour and immune and circulatory systems.[39–41] Mechanisms for insect mortality vary concerning the insect life stages. Ramanan *et al.*[29] reported the different mechanisms involved in the insect's mortality of egg, larva, and adult stages.

2.3.1. Eggs. Mechanisms, such as disruption of embryogenesis due to ROS, eggshell cell membrane disruption due to electrostatic accumulation, and delay or lack of hatching due to anoxic or hypoxic conditions, are the significant causes of mortality in eggs.

2.3.2. Larva. The ROS creates severe oxidative stress in the larva and damages the cuticle and epidermis of the insect. In addition, oxidation also leads to the melanization of hemolymph and deformation of the body, causing the death of larvae.

2.3.3. Adult. Electrostatic excitation on insects' membranes due to high voltage discharge affects the nerves and neuromuscular system, which causes anoxia conditions (primary mode) and leads to insect death. Another mode of action (secondary mode) is the destruction of C–H bonds present in the cuticular lipid layer of the insect's surface by ROS. Damages in the insect surface layer cause dehydration and death.

2.4. Seed germination

Many factors influence the germination rate of plasma-treated seeds. However, the exact reasons are not clear. However, a few acceptable reasons are etching, the opening of seed coats, increased seed wettability, deposition of small bioactive molecules on the seed coat, and decontamination of seed surface microbes.[42,43]

2.5. Functionality modification

Plasma treatment alters the nature of food constituents and their property. ROS reacts with sulfur and aromatic amino acids in the protein, resulting in oxidation. Sometimes oxidation (carbonylation) also assists enzyme inactivation. In addition, the treatment also changes the secondary structure of proteins and alters their functionality. Further, ROS attacks methyl groups near the double bond regions and oxidizes them in lipids. Meanwhile, carbohydrates, aldose, and ketose form formic acids during oxidation.[38]

This review discusses the applications of plasma treatment on agri-food processing in various stages to enhance the

agricultural production rate, reduce spoilage & waste, and improve the quantity and quality of the final product.

3. Plasma applications in pre-harvest stages

Plasma is used in different stages of pre and post-harvest processing of the agri-food chain (Fig. 1), where the pre-harvest operation includes soil irrigation, soil preparation, sowing, planting, *etc.*, and continues till harvesting (Fig. 2). Each stage has a noticeable impact on final product quality and yield. Hence, plasma technology has been used to obtain the desirable change during pre and post-harvest operations.

3.1. Plasma treatment of water

Water is one of the vital sources for agricultural practices and is usually contaminated by microbes, heavy metals, and pharmaceutical compounds.[44–46] Removing these contaminants can improve agricultural product quality and overall production. The reactive species present in plasma can oxidize and remove the contaminants from water or effluent.[47] Furthermore, plasma-activated water (PAW) can also be used to suppress microbial activity[48] and to remove chemical contaminants from water.[49] The interaction of reactive species with water during plasma treatment and PAW production varies based on the nature of RS (Fig. 3). The degradation of organic and inorganic compounds is shown in eqn (1).

$$\text{Chemical compounds} + \text{RS} \rightarrow \text{simple carbon/nitrogen compound} + CO_2 + H_2O \quad (1)$$

Though degradation follows different pathways, the end product will likely fall under any of those components mentioned in eqn (1). For instance, pesticide degradation (diuron) by OH^- species oxidation releases CO_2 and H_2O after producing organic acids.[50] Similarly, after producing different intermediate components, dimethoate degraded as non-toxic PO_4^{3-} during plasma treatment.[51] In addition to oxidation, mineralization, removal of alkyl groups, CO_2, H_2O, halogens, and isomerization could take place during the degradation process. This degradation mechanism is often similar to colourant and off-odour-producing compounds.[38]

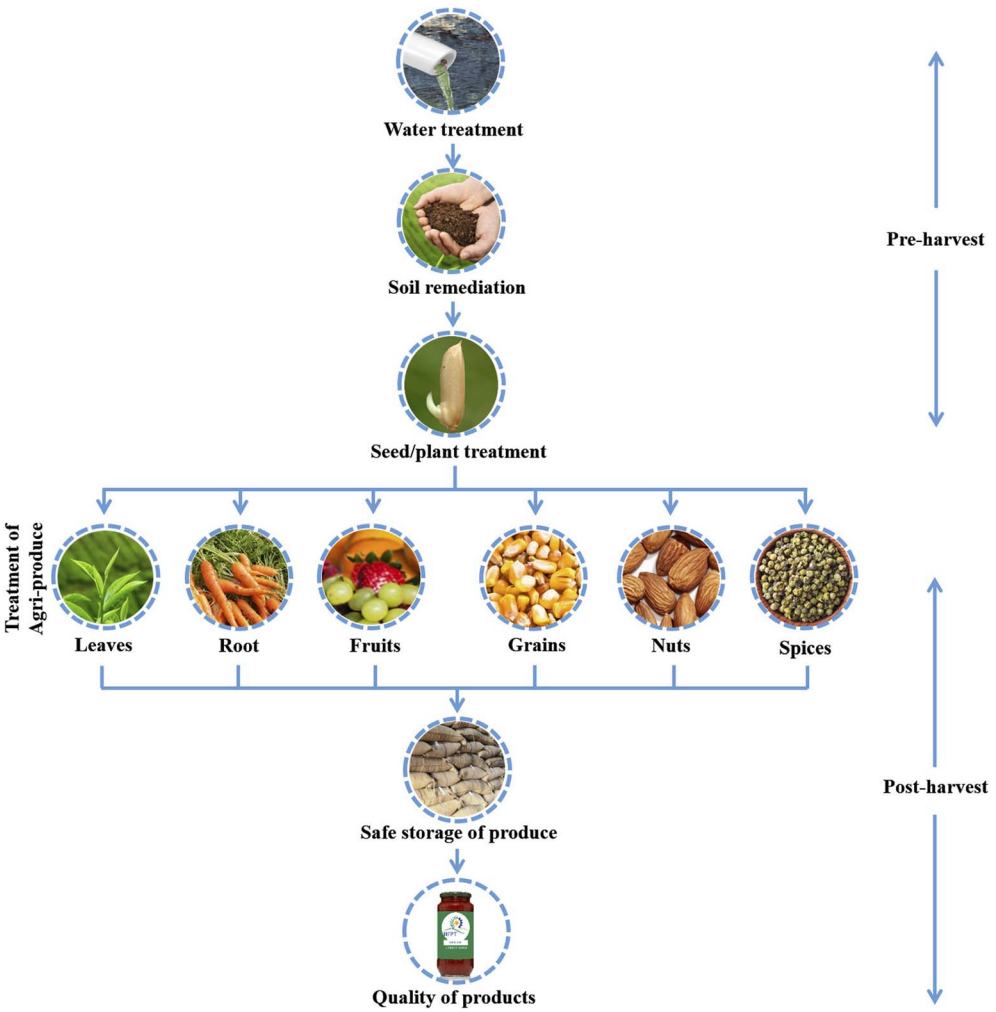

Fig. 1 Application of plasma in different stages of agri-food chain.

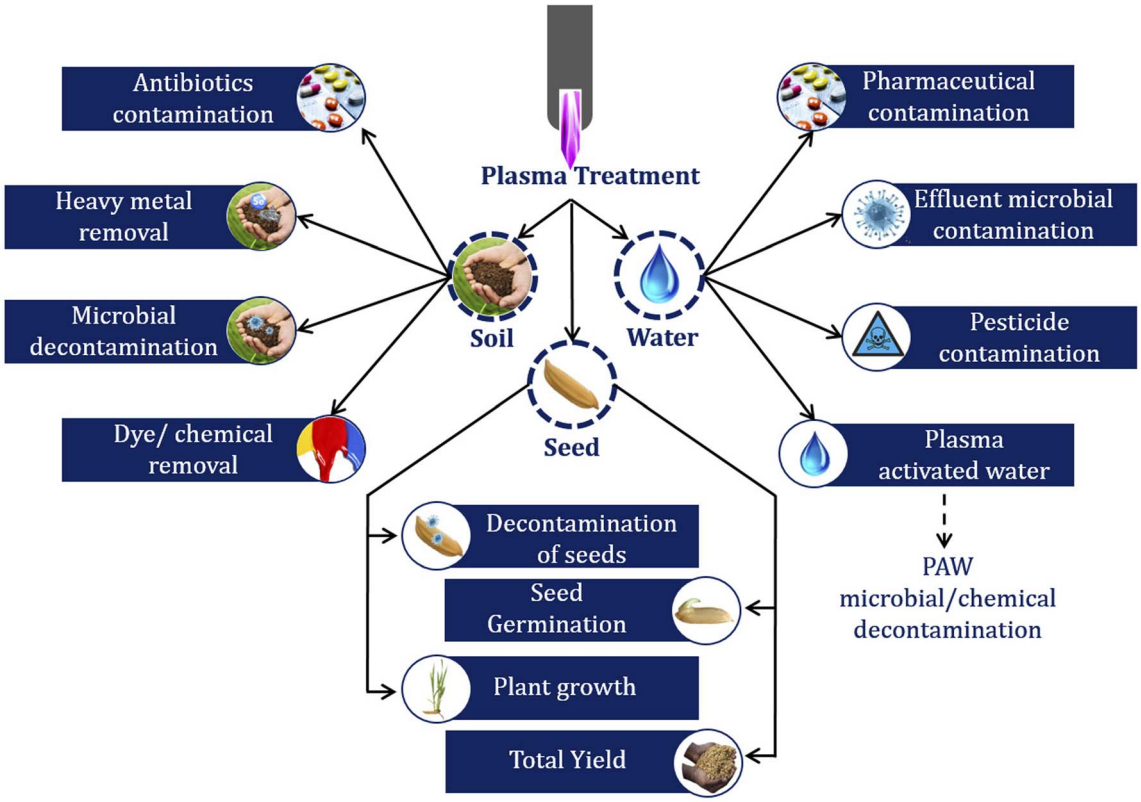

Fig. 2 Plasma application in pre-harvest stages of agri-food chain.

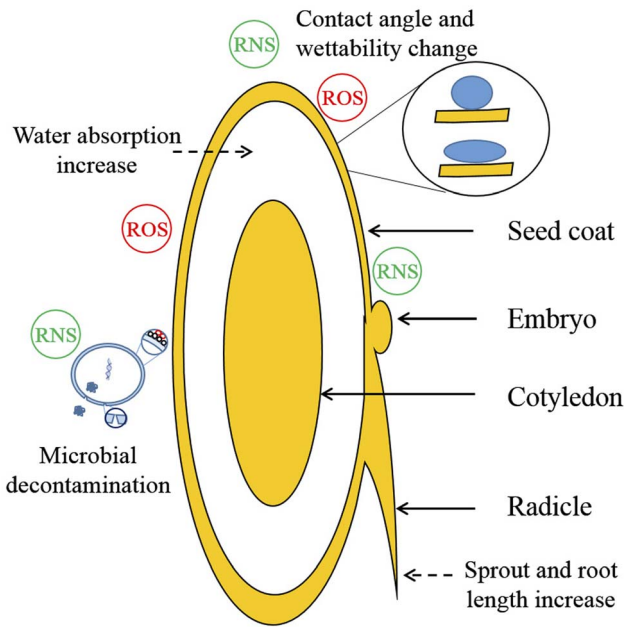

Fig. 3 Effect of plasma treatment on seeds.

Plasma treatment has the potential to degrade individual dyes and their mixtures (*i.e.*, alizarin yellow + orange II + methylene blue) from water.[52] Iervolino *et al.*[53] investigated the effect of plasma on different water pollutants by varying treatment time, power, and gas and identified the lower resistance of methylene blue (MB) and ceftriaxone against plasma (degraded within 5 min). While phenol (15 min), paracetamol (15 min), and caffeine (25 min) took more time for degradation. During this process, MB was almost entirely converted into CO_2. Instead of focusing on degradation alone, Tampieri *et al.*[54] studied the degradation and mineralization efficiency of plasma-treated rhodamine B, phenol, and metolachlor. For low pollutant concentrations, the highest mineralization efficiency of 59% and 20% was obtained for phenol and metolachlor in 30 min, respectively. To understand the combined effect of plasma with any other non-thermal method, Bradu *et al.*[47] combined ozone treatment with plasma to remove organic pollutants from water. Ozone combined with plasma reduced the treatment time by half to remove 50% chlorophenoxyacetic herbicide (2,4-D) with doubled removal reaction rate. This study explains the role of OH^- species on 2,4-D oxidation and the importance of catalytic ozonation for faster pollutant removal and mineralization. Similar to other organic pollutants, Sarangapani *et al.*[55] reported pesticide removal concerning power and treatment time. Higher power and exposure time increased pesticide degradation into simple chemical groups due to the oxidization of active O_3 and OH^- species. Other than organic pollutants and pesticides, microbes can also contaminate water. So, Pavlovich *et al.*[56] reported the effect of plasma on *Escherichia coli* present in water and found that ozone concentration alone had a higher correlation with the antimicrobial activity of the treatment than pH and other species-generated

Table 1 Plasma applications in pre-harvest stages

Sample	Plasma characteristics	Significant results	Reference
(1) Plasma treatment on water			
(a) Effluent decontamination			
Dimethyl phthalate	Self-pulsing discharge (SPD) and multipin corona discharge (MCD) Input – 30 kV, 12 mA Treatment time – 5 to 30 min	MCD was more effective in the degradation of dimethyl phthalate than SPD	184
Methylene blue, ceftriaxone, phenol, paracetamol and caffeine	DBD reactor Gas – air or oxygen (0.09 to 0.36 nL min^{-1}) • Input power – 12 to 38 kV Treatment time – 5 to 25 min	Degradation and mineralization were higher when O_2 was used at 20 kV with a 0.18 nL min^{-1} flow rate	53
Rhodamine B, phenol and metolachlor	Atmospheric plasma reactor Gas – air (flow rate – 100 mL min^{-1}) Input – 5.9 ± 0.7 W Treatment time – up to 30 min	In 5×10^{-4} M phenol solution, 10% residue remained after 30 min. Low concentrations were removed completely Rhodamine B and metolachlor were removed in 15 and 20 min, respectively	54
Chlorophenoxyacetic herbicide (2,4-D)	Pulsed corona discharge with zonation reactor • Gas – oxygen (0.3 L min^{-1}) • Input power – 11 to 31 W • Treatment time – up to 60 min	Plasma with ozone provides >99.8% removal of 2,4-D in 30 min of treatment time	47
Pesticide (dichlorvos, malathion, endosulfan)	DBD plasma reactor • Gas – atmospheric pressure plasma • Input power – 60, 70, and 80 kV_{RMS} • Treatment time – 0, 2, 4, 6, and 8 min	Degradation was maximum for dichlorvos (78.98%), malathion (69.62%), and endosulfan (57.71) at 80 kV_{RMS} after 8 min	185
Bacterial culture mixed water	DBD plasma • Gas – ambient air • Input power – 0.02 to 0.4 W cm^{-2} • Treatment time – 30 to 300 s	*E. coli* – vortex (5 s) increases the microbial reduction up to 5 log in 120 s at 0.2 W cm^{-2} Increased power has less effect on microbial reduction	56
Polluted water (atrazine, chlorfenvinfos, 2,4-dibromophenol, and lindane)	DBD batch reactor (R_1) and co-axial thin-film DBD reactor (R_2) • Gas – helium at atmospheric pressure (5 L min^{-1}) • Input power – 30 W • Treatment time – 0 to 15 min	R_2 was found to be efficient more efficient. For example, 15 min of treatment degraded the pollutant while the byproducts degradation was low	57
Pentoxifylline (in water)	DBD plasma with coaxial configuration • Gas – oxygen (flow rate – 600 SCCM) • Input power – 1.2 W • Treatment time – up to 120 min	92.5% pentoxifylline reduction after 90 min treatment Chemical reduction increases with increased O_3 consumption	45
Poultry wash water	Pulsed-plasma gas-discharge • Gas – sulfur hexafluoride (SF_6)/air (flow rate – 10 L min^{-1}) • Input power – 23.5 kV • Treatment time – 30 s	*Campylobacter* and *Salmonella* contamination was entirely removed to not detectable level	46
Methylene blue (MB) water	DBD plasma with coaxial configuration • Gas – oxygen and air (300, 600, and 900 SSCM) • Input power – up to 1 W • Treatment time – up to 90 min	Plasma treatment of 30 min with O_2 gas removed 95% MB dye Ozone concentration influences the removal rate	186
(b) PAW treatment			
Plasma treated water (PTW)	DBD plasma Gas – air Input – 11 W Electrode gap – 3 mm Treatment time – 1 to 10 min	Mortality rate of PTW, tap water, and reference sample after 24 h was around 85, 8 and 2% for mealybug	40

Table 1 (*Contd.*)

Sample	Plasma characteristics	Significant results	Reference
PTW	Surface dielectric barrier discharge • Gas – atmospheric air • Input power – 3.14 W • Treatment time – 120 min	PTW used sausage with nitrite (782 ppm) that can provide a curing effect	58
Plasma-activated water (PAW)	Indirect DBD plasma • Gas – atmospheric air • Input power – 5 W • Treatment time – 20 min	Anti-microbial declined during storage After seven days, 2.4 logs and no reduction were observed in 3 h and 15 min treated PAW, respectively	59
PAW	Atmospheric non-thermal quenched plasma • Gas – atmospheric air (flow rate – 550 L h^{-1}) • Treatment time – 5 min	Acidification by nitrites in PAW produces a lethal effect on *Hafnia alvei*	60
PAW	Atmospheric pressure gliding arc plasma • Gas – atmospheric air • Input power – 1.2 W • Treatment time – 5 min	*S. cerevisiae* – 3 log reduction after 30 min Without solid substrate *H. alvei*, *Leuc. mesenteroides*, *Staph. Epidermidis* were eradicated after 30 min	48
(2) Plasma treatment on soil remediation			
p-Nitrophenol contaminated soil	Novel spray-type coaxial cylindrical dielectric barrier discharge Input – 0–30 kV, 200 Hz, carrier gas – 20% O_2 + 80% N_2	54.2% of PNP was degraded after 50 s discharge treatment	187
Fluorene	Needle-plate pulsed corona discharge plasma Input – 30 kV Treatment time – 60 min Electrode gap – 20 mm	78.7% fluorene degradation was achieved after 60 min When washing is done to remove oxidation products, 99% degradation achieved in 45 min	64
Non-aqueous phase liquid (NAPL)-mixed soils	*Ex situ* DBD plasma cylinder-to-plane reactor • Gas – atmospheric air (flow rate – 1 L min^{-1}) • Input power ~25 W (energy density 675 to 10 125 J g^{-1}) • Treatment time – 2.5 to 33 min	High energy density eradicates NAPL irrespective of its initial concentration of it	65
Dye-polluted soil (acid scarlet GR)	Plane-to-plane DBD plasma • Gas – atmospheric air • Input power – 15.6 to 19.6 kV (3.51 to 5.72 W) • Treatment time – 0, 5, 10, 15, 20, and 25 min	Degradation efficiency was 93% at 19.6 kV and also at 300 Hz (17.6 kV) after 25 min treatment	66
p-Nitrophenol polluted soil (PNP)	Pulsed discharge plasma-TiO_2 catalytic (PDPTC) • Gas – atmospheric air (flow rate – 0.5 L min^{-1}) • Input power – 23 kV • Treatment time – 45 min	Soil depth increase reduces PNP degradation Quartz sand containing PNP degraded more than sand and sandy soil. Clay soil has the lowest degradation rate	70
Contaminated soil	Ozonizer combined DBD plasma with TiO_2-based surface discharge • Gas – oxygen (flow rate – 0.5 dm^3 min^{-1}) • Input power – 23 kV • Treatment time – 45 min	The microbial load of ozone treated soil reduced from 5.7×10^6 to 1.7×10^2	72
Chloramphenicol polluted soil	Atmospheric pressure DBD plasma • Gas – oxygen, ozone, air, argon, nitrogen (flow rate – 0.15 to 1.5 L min^{-1})	The presence of oxygen improves the degradation compared to air Higher input voltage and flow rate increase the degradation efficiency	67

Table 1 (*Contd.*)

Sample	Plasma characteristics	Significant results	Reference
	• Input power – 16.4, 18.4, and 20.4 kV • Treatment time – 0, 5, 10, 15, 20, and 25 min		
p-Nitrophenol polluted soil (PNP)	Pulsed discharge plasma – TiO_2 catalytic (PDPTC) • Gas – atmospheric air (flow rate – 0.5 L min^{-1}) • Input power – 20 kV • Treatment time – 30 min	Plasma alone caused 78.1% of PNP degradation, while PDPTC caused 88.8% degradation at 20 kV (10 min)	68
Pentachlorophenol (PCP) in soil	Pulsed corona discharge plasma • Gas – oxygen, air, argon, nitrogen (flow rate – up to 8 L min^{-1}) • Input power – 12 to 18 kV • Treatment time – up to 60 min	An increase in voltage from 12 to 18 kV increased PCP degradation from 64 to 90% (60 min)	69
Pentachlorophenol (PCP)	Pulsed corona discharge plasma (PCDP) • Gas – air (flow rate – 3 L min^{-1}) • Input power – 11.6 to 17.6 kV • Treatment time – up to 60 min	11.6, 13.6, 15.6 kV, and 17.6 kV degraded PCP up to 62, 77, 83, and 87%, respectively, after 60 min	71
Kerosene polluted soil	Cylinder-to-plane DBD plasma • Gas – air (flow rate – 1 L min^{-1}) • Input power – 15 to 20 kV • Treatment time – up to 60 min	An energy level of 960 J g^{-1} degrades the kerosene by 90%	188
Contaminated soil	DBD plasma • Gas – oxygen and air (flow rate – 1, 2 L min^{-1}) • Input power – up to 30 W • Treatment time – 60 min	Ozone produced during the process reduced the microbial count and pH Increased the mineral content of the soil	62
(3) Plasma treatment of seeds/plants			
Rice seedling	Non-equilibrium atmospheric pressure plasma Plasma activated ringer's lactate solution Treatment period of solution – twice a week Input – 60 Hz, 9 kV	15% increase in grain yield when the plant was treated in direct plasma during the early period and no change in the later stage	189
Maize grains	Diffuse coplanar surface barrier Input – 400 W with air, oxygen, and nitrogen Treatment time – 0, 30, 60, 90, 120, 180, and 300 s	Wettability increased – the amount of water imbibition was higher 90 and more had a negative effect on growth and production indices	190
Buckwheat seeds	Low-pressure radiofrequency system Input – 30 W Treatment time – 15, 30, 45. 60, 90, and 120 s	A shorter exposure time of up to 45 s was safer for the application The longest exposure of 120 s affected the fungal colonisation	191
Carrot seed	DBD Input – 12.5 kV and 50 Hz Treatment time – 1 to 4 min	3 min had a great quantity of flavonoids, phenolics, and plant extracts had high radical scavenging activity	192
Pea seeds (*Pisum sativum* L.)	DCSBD plasma unit with a silver electrode and Al_2O_3 as the dielectric material • Gas – atmospheric air (flow rate – 3 L min^{-1}) • Input power – 400 W • Treatment time – 60 to 300 s	DNA damage – 240 s treatment reduces the damage by 28 to 30.5%, 3.5%, and 21% for zeocin, distilled water, and hydrogen peroxide treated sample, respectively	90
Wheat	DBD plasma with 3 mm electrode distance Gas – Ar	Plasma treatment of 15 and 90 s increased HSFA4A by six and four folds after 3 h in the root	91

Table 1 (*Contd.*)

Sample	Plasma characteristics	Significant results	Reference
		However, for the shoot after 6 h, a ten-fold increase was observed in the 30 s treatment	
	Input – 80 W Treatment time – 15, 30, 60, and 120 s		
Wheat	Atmospheric DBD plasma Gas – dry air Input – 13 kV Treatment time – 4 min	After treatment, GP and GR in drought stress increased from 39.3 to 50.0% and 62.7 to 80.0%, respectively	92
Radish (*Raphanus sativus*)	Double DBD reactor with plate-to-plate configuration for seed treatment	Seed GR was 40, 60, and 100% for control, PAW-15 and PAW-30, respectively	42
Tomato (*Solanum Lycopersicum*)	Gas – air (flow rate – 1 L min^{-1})	In tap water (TW), growth was higher for control, P10, and P20 tomato plant than PAW watered plants	
Sweet pepper (*Capsicum annum*)	Input – 57 mJ per pulse (max) Treatment time – 10 (P10) and 20 (P20) min Double DBD reactor with cylindrical configuration – water treatment Gas – synthetic air (flow rate – 1 L min^{-1}) Input – 7 mJ per pulse (max) Treatment time – 15 (PAW-15) and 30 (PAW-30) min	More growth in PAW-30 watered plants than TW	
Rapeseed (*Brassica napus* L.)	CDPJ generation system • Gas – dry atmospheric air (2.5 m s^{-1}) • Input power – direct current of 20 kV (1.5 A) • Treatment time – 0 to 3 min	Germination was 7.7% higher after 1 min of treatment The microbial load of the treated sample was maintained lesser than the control sample (1–2 log reduction)	86
Wheat seed	DBD plasma Gas – air (flow rate 1.5 L min^{-1}) Input – 1.5 W Treatment time – 0, 1, 4, 7, 10 and 13 min	GP, GR, and GI increased in 4 min treatment from 62.5 to 77.5%, 88.0 to 95.3% and 36.7 to 41.0% compared to control	74
Broccoli seed (*Brassica oleracea* var. *kialica plen.*)	CDPJ generation system • Gas – atmospheric air • Input power – 20 kV DC • Treatment time – 0 to 3 min	Plasma reduced microbes in seed and sprout Less exposure increased germination rate, sprout length, and weight	75
Peanut (*Arachis hypogaea* L.) seed	Cold helium plasma • Gas – helium (150 Pa pressure) • Input power – 60, 80, 100, 120, and 140 W • Treatment time – 15 s	After 15 s treatment at 80, 100, and 120 W, germination potential increased by 128, 128, and 150%. Finally, at 120 W germination rate was found to be maximum	78
Wheat seeds (*Triticum aestivum* L. *cv. Eva*)	DCSBD – cold atmospheric pressure plasma (CAPP) • Gas – atmospheric air • Input power – up to 100 W cm^{-3} • Treatment time – 10 to 600 s	Water uptake increased with soaking time and dosage Bacteria and fungi load on seeds reduced with treatment time	76
Wheat seeds (*Triticum aestivum*)	Atmospheric pressure surface discharge plasma reactor with glass plate • Atmospheric air (flow rate – 1 L min^{-1}) • Input power – 2.7 W • Treatment time – 5, 15 and 30 min	Germination rate was similar for plasma treated (98%) and control (95%) wheat seeds	77
Peas (Pisum sativum 'Salamanca')	CAPP – surface dielectric-barrier air-discharge • Atmospheric ambient air • Input power – 9 kV_{pp}	5 and 10 min CAPP treatment increased germination to 42 and 50%, respectively, after 24 h Germination rate reached a maximum (5 min treatment) of 65% after 48 h	82

Table 1 (*Contd.*)

Sample	Plasma characteristics	Significant results	Reference
	• Treatment time – 1 to 10 min		
Bean (*Phaseolus vulgaris*)	Cold radio frequency air plasma • Atmospheric air (pressure – 6.7 × 10^{-2} Pa) • Input power – 20 W • Treatment time – plasma treatment (2 min), vacuum treatment (3 min)	Water absorption increased in plasma treatment. hence, germination time reduce in plasma-treated samples	85
Pea seeds	Coplanar surface discharge – low-temperature plasma • Input – 370 W • Time – 60 to 600 s	Seed germination increased from 77.5 to 95% after 120 s treatment	84
Pre germinated rice (*Oryza sativa* L.)	Plasma jet with quartz tube covered inner electrode	Control – 97% germination	87
	• Argon and oxygen	Treated – 93 and 91% after 5 s at 10 W power with 8, 5 mm distances, respectively	
	• Input power – 10–14 W	High γ-aminobutyric acid (GABA) content achieved in 96 h pre-germination	
	• Treatment time – 5 to 10 s • Distance – 5, 8 mm		
Soybean (*Glycine max* (L.) Merr)	CDPJ generation system	Maximum germination (G) potential, G rate, G index, and vigour index were observed after 80 W treatment	81
	• Dry atmospheric air (2.5 m s^{-1})	Water uptake increased by 14.03%	
	• Input power – 0 to 120 W • Treatment time – 15 s		
Tomato (*Solanum Lycopersicum* L.) seed	Capacitively coupled plasma (CCP) • Helium (150 pa) • Input power – 80 W • Treatment time – 15 s	Germination potential and rate increased by 8 and 11% Bacterial wilt severity was reduced by 25% in the treated sample	80
Wheat (*Triticum* spp.)	Cold helium plasma • Helium (150 Pa pressure) • Input power – 60, 80, 100 W • Treatment time – 15 s	Germination potential and the rate increased by 6, and 6.7%, respectively, after 80 W treatment	26
Poppy seed (*P. somniferum* L.)	Panasonic – microwave generating RF plasma Input – 500 W • Time – 180 to 5400 s • Gas – O_2 (50 mL min^{-1}) and Ar (50 ml min^{-1})	Germination was 115% in 3 min treatment Plasma treated seedlings were longer than the control seedlings	89
Maize seed (*Zea mays* L.)	DCSBD plasma treatment • Atmospheric air • Input power – 370 W • Treatment time – 60 and 120 s	Plasma treatment for 60 s increased the root length, root fresh, and dry weight by 21, 10, and 14%, respectively Soluble protein content in the root increased after 60 s treatment	83
Paulownia tomentosa seeds	Glow discharge plasma treatment • Air and argon (200 mTorr) • Input power – 50, 100 and 200 W • Treatment time – 1 to 40 min	Air plasma treatment at 50 W, 100 W and 200 W produced maximum germination at 15, 5, and 1 min, respectively When glass plates covered the seeds, germination was reduced	88

acids. This study concluded that 5 s plasma treatment was enough to reduce *E. coli* to a not detectable level and suggested the importance of mixing on the antimicrobial effect of plasma species. In order to evaluate the effect of plasma on the removal of different pollutant mixes, Hijosa-Valsero *et al.*[57] conducted a study where atrazine, chlorfenvinfos, 2,4-dibromophenol, and lindane pollutants were mixed with water and treated in DBD batch reactor (R_1) and co-axial thin-film DBD reactor (R_2). Results showed a decrease in the degradation efficiency of chemicals when their concentration increased, and even after pollutant degradation, byproduct removal took more treatment time. Similarly, pentoxifylline and its intermediates removal were analyzed by Magureanu *et al.*,[45] and the author reported that removal was high at a lower concentration of pollutant (100 mg L^{-1}), higher power, high pulse rate, and higher frequency. Intermediate components produced during this

Table 2 Plasma applications in post-harvest stages

Sample	Plasma chamber	Purpose of study	Research goal	Reference
(1) Plasma treatment of different agricultural produces				
(a) Plasma treatment on leaves				
Baby spinach	High voltage atmospheric cold plasma Input – 30–130 kV Treatment time – 2 min and 5 min	Inactivation of *Salmonella enterica* and *E. coli* O157:H7	Significant inactivation after 24 h through 14 days post-treatment After 7 days of refrigerated storage – 2.6 log CFU per g – 2 min 3.5 log CFU per g – 5.0 min	193
Date palm leave	Radiofrequency plasma Input – 80, 100, 120 W, gas pressure – 0.95 torr Treatment time – 1, 5, and 8 min	Surface modification	Wettability of leaf surface increased Surface roughness was increased due to the removal of the waxy layer and impurities	194
Green tea leaves	DBD Input – 5, 10 and 15 W Treatment time – 5, 10, 15 min	Antioxidant activity	15 W and 15 min, the TPC and antioxidant activity increased by 41.14% and 41.06% Catechin increased by 103.12%	195
Radicchio (*Cichorium intybus* L.)	Dielectric barrier discharge (DBD) • Atmospheric air • Input power – 15 kV Treatment time – 15 to 30 min	Microbial inactivation	*L. monocytogenes* – 2.20 log CFU per cm^2 reduction after 30 min *E. coli* O157:H7 – 1.35 log MPN per cm^2 reduction after 15 min	94
Black and green tea	Plasma jet with the copper electrode and Pyrex tube • 99.99% argon (flow rate – 1 L min^{-1}) • Input power – 10 kV • Distance – 1.5 cm • Treatment time – 0 to 7 min	Microbial inactivation	*E. coli* – complete removal in black and green tea after 3 and 4 min, respectively Coliform – inactivated after 5 min in both samples Yeast and mould – inactivated after 7 min in both the samples	95
Romaine lettuce (*Lactuca sativa* L. *var. longifolia*)	Atmospheric pressure plasma with nickel coated steel needle array • Argon (flow rate – 455.33 standard cm^3 min^{-1}) • Treatment time – 30 s to 10 min • Input power −3.95 to 12.83 kV	Microbial inactivation	*E. coli* – 10 min treatment at 12.83 kV reduces the microbial count to 1.5 logs	93
Corn salad leaves	Atmospheric pressure plasma jet • Argon (flow rate – 20 L min^{-1}) • Input power – 10, 20, 30, and 40 W • Treatment time – up to 5 min	Microbial inactivation	The effect of plasma on microbes was higher (3.6 log reduction) at lower level surface contamination (10^4 CFU per mL) after 15 s treatment at 20 W	97
Lamb's lettuce (*Valerianella locusta*)	Atmospheric pressure plasma jet • Argon (20 cm^3) • Input power – up to 35 W • Treatment time – 0 to 120 s (overall)	Bioactive compounds	Chlorogenic acid, caffeic acid luteolin diosmetin content were reduced as time increased at 30 W plasma treatment	98
Lamb's lettuce (*Valerianella locusta*)	Low-pressure oxygen glow discharge plasma • Oxygen (0.5 mbar) • Input power – 75 and 150 W • Treatment time – 20 to 300 s	Flavonoid content	Flavonoid content increased in freeze-dried leaves after 120 s exposure	99
(b) Plasma treatment on root				
Baby carrots (Daucus carota L.)	Atmospheric pressure plasma with nickel coated steel needle array • Argon (flow rate – 455.33 standard cm^3 min^{-1}) • Treatment time – 30 s to 10 min • Input power – 3.95 to 12.83 kV	Microbial inactivation	*E. coli* – inactivation was less than 0.5 log	93
(c) Plasma treatment on fruits				
Strawberry	DBD Input – 7% and 14% duty cycle Treatment time – 5, 10, and 20 min	Decontamination	14% duty cycle and 20 min effective 1.46 log CFU per g – total aerobic mesophilic bacteria 2.75 log CFU per g – yeast and mould	196
Litchi	DBD Input – 50 kV, 1.5 A Treatment time – 0, 2, 4, 6, 8, and 10 min	Enzymatic browning	Residual activity of litchi peroxidase decreased to 47.16% on 10 min treatment	197

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
Blueberry	Atmospheric cold plasma Input – 12 KV, 5 kHz Treatment time – 0, 30, 60, 90 s	Improving antioxidant activity and microbial inactivation	Reduced the decay rate of blueberries Antioxidant activity increased but maintained at a low ROS level 60 s is the best exposure time	198
Cavendish banana	DBD Input – 15 kV, compressed air Treatment time – 0.5, 1, 2, and 3 min	Post-harvest crown rot	0.5 min optimum duration Colletotrichum musae inhibition – 51.89% for 0.5 min	199
Tomatoes	DDP with aluminium-coated electrodes • Gas – atmospheric air (50–75 mmHg) • Input power – 2 to 5 W Treatment time – 4 to 6 min	Pesticide degradation	Chlorpyrifos reduced up to 89.18% at 5 W in 6 min Lycopene (84.86 to 15.38 mg kg^{-1}), beta carotene (22.82 to 6.61 mg kg^{-1}) and firmness were reduced	37
Blueberries	Circular aluminium electrodes with 2 and 10 mm thick perspex dielectric material at ambient temperature (25 ± 2 °C) • Atmospheric air • Input power – 60 and 80 kV • Treatment time – 0, 2, and 5 min	Pesticide degradation	Plasma treatment of 5 min at 80 kV degraded pesticides (75% of boscalid and 80% of imidacloprid)	104
Strawberries	DBD atmospheric CP with Al electrode and polypropylene dielectric material (in pack treatment) • G_1 – $O_2 : N_2 : CO_2$ of 65 : 16 : 19 ratio • G_2 – $N_2 : O_2$ of 90 : 10 ratio • Treatment time – 5 min • Input power supply 60 kV_{rms} voltage (50 Hz)	Microbial inactivation	G_1 and G_2 produced 3.1, 3.4 and 3.7, 3.3 log reduction of mesophiles, yeast/mould, respectively	100
Cocktail tomatoes (Lycopersicon lycopersicum)	Atmospheric pressure plasma with nickel coated steel needle array • Argon (flow rate – 455.33 standard cm^3 min^{-1}) • Treatment time – 30 s to 10 min • Input power – 3.95 to 12.83 kV	Microbial inactivation	*E. coli* – 12.83 kV input reduced microbial count to 1.7 log after 10 min	93
(d) Plasma treatment on nuts				
Peanut	Novel CAP with rotary jet system Input – 180 W, 200 W Treatment time – 5, 7.5, 10 min	Inactivation of fungi	*Aspergillus flavus* – not detected at 180 W for 7.5 min and 200 W for 5 min *Aspergillus niger* – not detected at 180 W for 10 min and 200 W for 5 min Aflatoxin concentration after 29 days of storage – 16.5 ppb	200
Pistachio nut	DBD • Air plasma system • Input – 130 W, 20 kHz, and 15 KV • Treatment time – 15, 30, 60, 90, 120, 150, 180 s	Decontamination of aflatoxin	4 log reduction after 180 s of treatment Maximum reduction of 52.42% of AFB 1 after 180 s	201
Pistachio nut	Cold plasma jet Input – 10, 15 and 20 kV and agon/gas ratio – 0, 50 and 100	Pest management	Plasma exposure time – 14.04 min, voltage – 19.99 kV and Ar/air ratio – 51.65% caused increased mortality of *Plodia interpunctella*	202
Dried walnut kernels	Radiofrequency low-pressure cold plasma • Air plasma • Input – 20, 30, 40 and 50 W • Treatment time – 10, 15 and 20 min	Microbial load reduction	The highest log reduction occurred at 50 W 1.09 log CFU per g – total viable count, 0.97 log CFU per g – coliform 0.89 log CFU per g – mold	203
Cashew nut	Low-pressure plasma-glow discharge Air plasma Input – 80 W and 20 kHz	Allergenicity	Did not affect the allergenicity Improved lipid extractability Anacardic acid content was higher	204
Almond slices	Atmospheric argon plasma Input – 17 V, 2.26 A current Treatment time – 5, 10, 15, and 20 min	Surface disinfection	20 min treatment was effective 2.29 log CFU per g – total count 1.81 log CFU per g – yeast and mould 2.72 log CFU per g – *S. aureus*	205

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
Whole peanut (WP) and defatted peanut flour (DPF)	DBD plasma Input – 80 kV Gas – air Treatment time – 0 to 60 min	Allergen reduction	The protein intensity of the Ara h 1 band was unaffected by plasma treatment With increased time, Ara h 1 band intensity for IgE binding decreased for WP and DPF Antigenicity was reduced by 44 and 9.3% for DPF and WP after 60 min	115
Tiger nut milk	DBD Input – 1.22 A and 30 V Treatment time – 2, 4, 6, 8, and 12 min	Microbial inactivation	Undetectable microflora in 12 min pH reduction after 8 and 12 min protein decreased beyond 4 min	206
Peanut (*Arachis hypogaea* L.)	Coplanar – multi hollow surface DBD unit • Atmospheric air with 20 to 30% humidity (flow rate – 0.5 to 20 L min^{-1}) • Input power – 10 to 40 W Treatment time – 1 to 15 min	Quality characteristics	Oleic and linoleic acid content was reduced from 43.47 to 35.74% and 32.56 to 24.49% for fresh and treated peanuts Input power, treatment time, and gas mixer used in the study directly affected peanut quality	114
Unpeeled almonds	DCSBD plasma Input – 350 W Gas – dry air, O_2, N_2, CO_2 and CO_2/Ar mix (90% + 10%) Gas flow rate – 0.8 L min^{-1} Treatment time – 15 min	Microbial decontamination	Air, O_2, and N_2 plasma reduced microbial count by 5, 4.8 and 2 logs after 15 min	107
Hazelnuts	Atmospheric pressure fluidized bed plasma (APFBP) reactor Input – 460 to 655 W Gas – dry air and N_2 (flow rate – 3000 L h^{-1}) Treatment time – 1 to 5 min 1st reactor – 49 mm diameter, 2nd reactor – 65 mm diameter	Aflatoxin removal	1st reactor: *A. flavus* and *A. parasiticus* count reduced by more than 4 log in 5 min at 655 W 2nd reactor: both microbes count reduced by more than 3 log A similar trend was followed in both reactors when N_2 gas was used	108
Walnut fruits (*J. Regia* L.)	Plasma jet with a copper electrode and Pyrex tube • Argon (1 L min^{-1}) • Input power – 15 kV DC supply • Treatment time – 3 to 11 min	Microbial decontamination	The fresh and dried walnut microbial load was removed after 10 and 11 min treatment, respectively, for all walnut types	109
Hazelnuts	DBD plasma Input – 0.4 to 2 kW Gas – pure N_2 or N_2 and air mix (flow rate – 120 L min^{-1} with 7 bar) Treatment time – 1 to 12 min Distance – 50 mm	Aflatoxin removal	Pure N_2 or N_2 with O_2 (0.1%) provided higher toxin removal After 12 min exposure, residual AFB_1 and AFs in nuts were 29.1 and 30.4% at 1150 W	116
Hazelnuts	APFBP reactor Input – 460 to 655 W Gas – dry air (flow rate – 3000 L h^{-1}) Treatment time – 1 to 5 min	Microbial decontamination	At 655 W (25 kHz) within 1 min exposure, 2 log reduction was achieved, and the natural flora was reduced by 3.45 log in 2 min	110
Almonds	Gliding arc plasma • Input – 590 W • Gas – air and nitrogen (60 psi) • Time – 0, 10, and 20 s • Distance – 2, 4, 6 cm	Microbial decontamination	Plasma reduced 1.34 log CFU per mL of *E. coli* O157:H7 C9490 after 20 s treatment with 6 cm distance	111
Hazelnut, peanut, and pistachio nut	Low-pressure CP (LPCP) sterilization unit • Air or sulfur hexafluoride (SF_6) • Input power – 300W • Treatment time – 5 to 20 min	Microbial decontamination	In hazelnuts, SF_6 plasma reduces *D*-value (1.1 min) compared to air plasma (4.2 min) 5 times more log reduction was observed in SF_6 than in air plasma (5 min)	113
Almonds	DBD plasma Input – 16 to 30 kV	Microbial decontamination	4 to 5 log reduction in *E. coli* was observed in all almond varieties after 30 min	112

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
	Discharge gap – 10 mm			
(e) Plasma treatment on spices				
Saffron	Low-pressure cold plasma technology Input – 70, 90, and 110 W Treatment time – 5, 10, 15, and 30 min	Decontamination	110 W for 30 min – high microbial reduction 3.52 log CFU per g – TVC 4.62 log CFU per g – coliforms 2.38 log CFU per g – mold 4.12 log CFU per g – yeast	207
Black pepper corn	Low-pressure cold plasma technology Input – 150 W and 250 W Treatment time – 10 min and 20 min	Decontamination	250 W for 20 min showed the highest decontamination 0.88 log CFU per g – aerobic plate 3.66 log CFU per g – yeast and mould	208
Black pepper	DSCBD – DBD Input – 400 W Gas – ambient air Treatment time – 60 to 300 s	Decontamination	*B. subtilis* count reduced by 5.06 log after 5 min exposure *B. subtilis* spores, *E. coli* and *S.* Enteritidis *D* – values were 142, 47 and 58 s	117
Saffron	Plasma jet Input – 8 and 12 kV Gas – Ar with 5, 10, and 20% O_2 (flow rate – 1 L min^{-1}) Treatment time – 6 and 8 min	Bioactive compound	Safranal content was reduced by 14% and 21% at 8 kV and 12 kV, respectively However, isophorone (4 and 8%) and 4-ketoisophorone (2 and 6%) increased by 8 min Ar plasma at 8 kV and 12 kV, respectively	118
Red pepper flake	Microwave integrated CP treatment with high (HMCPT) and low microwave density (LMCPT) Input – 900 W Gas – He (flow rate – 1 std L min^{-1} with 0.7 kPa) Treatment time – 20 min	Decontamination	1.8 and 0.6 log per cm^2 reduction was observed in spore count in HMCPT and LMCPT Based on particle size, the microbial reduction was more for flakes (1.4 and 2.7 log per cm^2) than particles (0.8 and 1.2 log per cm^2) in LMCPT and HMCPT	119
Onion (*Allium cepa* L.) powder	Microwave-powered CP treatment with HMCPT and LMCPT Input – 400 to 900 W Gas – He (flow rate – 1 L min^{-1} at 0.7 kPa) Treatment time – 10 to 40 min	Microbial reduction	*B. cereus* spores reduction was more in HMCPT (2.1 log per cm^2) than LMCPT (1.2 log per cm^2) For microbial reduction, vacuum air drying of the sample was superior to hot air drying	120
Onion powder	DBD – CP treatment Input – 9 kV Treatment time – 20 min	Microbial reduction	*E. coli* and *L. monocytogenes* count reduced by more than 1 log after 20 min at 9 kV, while more than 2 log reduction was observed in *S.* Enteritidis	121
Whole black pepper	Radiofrequency (G_1) and microwave (G_2) generated plasma jet • G_1 used argon (10 L min^{-1}) • G_2 used air (18 L min^{-1}) • Input power – 30 W (G_1), 1.2 kW (G_2) • Treatment time – 15 min (G_1) and (G_2) 30 min	Microbial reduction	G_2 plasma was more effective against aerobics and spores than G_1 plasma	28
Black pepper	Atmospheric pressure plasma jet (APPJ) • Argon plasma (flow rate – 20 L min^{-1}) • Argon (0.5 L min^{-1}) + CO_2 (20 L min^{-1}) plasma 0.5 (argon) + 20 (CO_2) 0 • Air plasma (20 L min^{-1}) • Argon + H_2O plasma (20 L min^{-1}) • Input power – 280 V (8 A) • Treatment time – 0 to 10 min	Microbial reduction	Argon and CO_2 gas mixer plasma treatment inactivated *B. subtilis* after 5 min of treatment	122

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
Black pepper	Fluid bed APPJ treatment • Air and argon (flow rate – 20 and 14 L min^{-1}, respectively) • Treatment time – 0 to 80 s	Microbial reduction	Microbial reduction of 1.5 and 5 log reduction of *Salmonella* was observed after 20 and 80 s of treatment	123
Black pepper	RF – low-pressure cold plasma Input – 300 and 400 W Gas – O_2, N_2, air, and Ar (0.3 and 9 mbar) Treatment time – 15 to 60 min	Microbial reduction	H_2O_2 usage (60 min) reduced microbial count by 1 to 3 logs After 60 min, Ar plasma caused higher microbial reduction than air, O_2 and N_2 plasma (for all microbes)	124
Red pepper (Capsicum annuum L.) powder	Microwave powered CP • Air and argon (267 to 26 680 pa) • Input – 300 to 900 W • Treatment time – 0 to 80 s	Microbial reduction	20 min plasma treatment at 900 W reduced *Aspergillus flavus* (N_2 gas at 667 pa) by 2.5 logs *Bacillus cereus* required heating for inactivation	125
(2) Plasma treatment for safe storage, extraction and quality enhancement				
(a) Grain safety and quality				
Wheat	DBD Input – 30, 40, and 50 kV Treatment time – 4, 8, 12, and 16 min	Degradation of deoxynivalenol	50 kV and 5 min degraded DON by 83.99%	209
Chickpea	Atmospheric cold plasma Input – 40, 50, 60 W Treatment time – 10, 15, and 20 min	Increased storage period to study the occurrence of *Callosobruchus chinensis*	In vishal – 40 W, 15 and 20 min – grain damage – 1 to 3% In other samples, the damage was 0%	210
Canola grain, canola meal and barley grains	ACP DBD and ACP-jet • ACP – DBD – input – 0–34 kV, 1 A and 300 W, 3500 Hz, duty cycle – 70% and output pulse – 10 μs • ACP-jet – 1500 Hz, voltage – 0–22 kV, 70% duty cycle, 10 μs And 0–0.025 A with 75% Ar + 25% N_2 • Treatment time – 0.5, 1, 3, 5, and 15 min	Degradation of Zearalenone	ACP-DBD – 3 min degradation was 91.6%, 83.2%, and 64.8% for canola grain, canola meal, and barley grain ACP jet – 85% Ar + 15% O_2 – high degradation	211
Barley	Atmospheric cold plasma (DBD) • Input – 0–34 kV, 1 A, and 300 W, 3500 Hz, duty cycle – 70% and output pulse – 10 μs • Treatment time – 0, 2, 4, 6, 8, and 10 min	Removal of deoxynivalenol	6 min – 48.9% and 10 min – 54.4%	212
Wheat	DBD plasma jet Input – 90–130 W Gas – Ar (3000 sccm), O_2 (1 to 8 sccm) with Ar, N_2 (0 to 80 sccm) with Ar Treatment time – 10 to 15 min		*T. castaneum* mortality for Ar, Ar + N_2 (20 sccm) and Ar + N_2 (80 sccm) gas mixture were 90, 70 and 46%, and for *T. confusum* 93%, 63% and 57%, respectively. A similar trend was observed for O_2 admixture	126
Wheat, barley	CP with DBD • Atmospheric air • Input power – 80 kV • Treatment time – 5 and 20 min		Long-time exposure reduced microbes on the surface Wheat germination was affected due to the long exposure time	127
Wheat germ	DPD plasma Input voltage – 20 and 24 kV		Lipase activity was 27.11 and 25.03% at 20 and 24 kV plasma voltage after 25 min Lipoxygenase activity was 55.18 and 49.98% for the same condition	129

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
	Treatment time – 5 to 35 min Distance – 1.5 and 2 cm			
Winter wheat	CP with DBD • Atmospheric air • Input power – 80 kV • Treatment time – 3, 10, and 30 s		Total isolated colonies were reduced to 27 from 250 after 10 s treatment	131
Wheat	DBD plasma with polymethylmethacrylate Gas – Ar (flow rate – 2.8 nm) Input – 6 to 10 kV Time – up to 10 min		10 kV pulse voltage removed 3 times more endospores than 6 kV treatment	130
Wheat	Low-pressure plasma circulating fluidized bed reactor Gas – Ar and O_2 (15 norm. L min^{-1}) Input – 700 and 900 W Time – up to 73.5 s		700 and 900 W with 10% O_2 mix reduced 1.91 and 2.59 log microbes after 10 min	132
Grains and legumes	Low-pressure CP • Air gases or SF_6 (300 torr) • Input power – 300 W • Treatment time – 30 s to 30 min		Microbial contamination reduced below 1% for *Aspergillus* spp. and *Penicillum* spp.	133
(b) Flour safety				
Wheat flour	Bell jar type of plasma apparatus Input – 40 and 60 W Treatment time – 20, 25, and 30 min	Pest control	60 W and 30 min showed complete inhibition of larvae, pupae, and egg	213
Refined wheat flour	DBD CP treatment • Atmospheric air (1 mbar) • Input power – 1 to 10 kV • Treatment time – 2 and 20 min	Insect inactivation	The maximum mortality rate was found for 15 min exposure times for eggs (93.33%), larvae (93.33%) and adults (100%)	29
Refined wheat flour	DBD atmospheric CP • Atmospheric air (flow rate – 1 L min^{-1}) • Input power – 500 to 3000 V • Treatment time – 0.5 to 7 min	Insect control	Complete mortality was achieved by increased voltage or increased time, or reduced electrode distance for *Tribolium castaneum* adults	134
Maida flour	DBD plasma Input – 500 to 3000 V Atmospheric air (1 mbar) Treatment time – 0.5 to 7 min Electrode distance – 2 to 6 min	Insect control	An increase in exposure time and input power or a decrease in electrode distance gave 100 mortality of *T. castaneum*	135
(c) Flour quality				
Quinoa flour	ACP Input – 50 kV and 60 kV Treatment time – 5 and 10 min	Functionality study	Results in protein polymerization and starch depolymerization Treatment time and voltage affects technological properties	214
Jackfruit seed flour	Pin-to-plate ACP Input – 170, 200, and 230 V Treatment time – 5, 10, and 15 min	Functionality modification	Higher input voltage and exposure time cause starch and protein modification and loss in crystallinity (25.75% to 21.31%) The hydration properties, like water solubility, increased from 9.65 g g^{-1} to 14.11 g g^{-1} water absorption – 6.39 g g^{-1} to 7.66 g g^{-1} Swelling power – 7.28 g g^{-1} to 8.79 g g^{-1} Water holding – 2.93 g g^{-1} to 3.48 g g^{-1}	215
Little millet flour	Multipin electrical discharge atmospheric cold plasma Input – 13 and 24 W Treatment times – 10, 20, and 30 min	Functional property modification	24 W and 30 min resulted in increased functional properties Water absorption, oil absorption capacity, swelling, and solubility increased A decrease in the viscosity of cooked paste, colour, and dispersibility was observed	216
Wheatgrass flour	Radiofrequency CP treatment Input – 120 W Gas – Ar and CO_2 (flow rate of 10 and 25 cm^3 min^{-1})	Functional modification	No change in protein solubility Starch damage increased, and water absorption was affected after treatment Solvent retention of different flour types increased	137

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
	Treatment time – 1 h (2 × 30 min)			
Rice starch	Bell jar CP reactor • Atmospheric air (0.15 mbar) • Input power – 40 to 60 W • Treatment time – 5 and 10 min	Functional property modification	Amylose content, pH, turbidity, and starch hydrolysis percentage were reduced At maximum power level and time, GT is reduced	138
Wheat flour	Continuous atmospheric pressure cold plasma Input – 15 and 20 V Treatment time – 60 and 120 s	Fatty acid profile	FFA and phospholipid were reduced after 60 and 120 s treatment at 20 V Pasting properties were unaffected	139
Rice flour (short and long rice)	DBD plasma ozone treatment Input – 60 and 70 kV Gas – atmospheric air Treatment time – 5 and 10 min	Functional property modification	Higher transmittance and swelling power for treated rice pastes and grains, respectively Syneresis increased for both flours	140
Grain pea (Pisum sativum)	Surface DBD air plasma • Input – 8.8 kV_{PP} • Gas – air • Time – up to 10 min	Functional property modification	PPI solubility increased with plasma treatment time up to 191% (10 min) in distilled water. PPF solubility reduced from 71 to 33% for the same treatment time	141
Wheat flour (soft, hard)	DBD atmospheric CP • Atmospheric air (flow rate – 1 L min^{-1}) • Input power – 60 and 70 kV • Treatment time – 5 and 10 min	Functional property modification	Peak time and peak integral of soft and hard flour increased significantly when voltage and treatment time exceeded 60 kV and 5 min	25
Wheat flour	Counter flow – cold plasma generated Gas – O_3 at 1000 ppm (flow rate – 2.5 L min^{-1}) Treatment time – 30 and 45 min	Functional property modification	Wet gluten (34.2 to 32.1%), dry gluten (9.7 to 7.9%) and gluten softening (13 to 10 mm) values decreased after 45 min, while sedimentation (56 to 61 cm^3) and bread-making strength index (50 to 56) values increased compared to control	142
(3) Plasma treatment on minimally processed and processed fruits products quality				
(a) Minimally processed fruit products				
Fresh-cut cantaloupe	DBD Input – 40 kV Treatment time – 90 s	Quality and flavour	CP treatment inhibited the growth of bacteria and mould during 10 days storage	217
Banana slices	DBD reactor • Input voltage: 4.8 to 6.9 kV and 12 to 22 kHz • Treatment time: 0.6 to 2.6 min	Enzyme activity	Polyphenol oxidase and peroxidase activity decreased to 70% and 100% Total phenol and flavonoid content increased to 50% Vitamin B6 increased	218
Carrot discs	DBD reactor • Gas: atmospheric pressure plasma • Input voltage: 60 kV, 80 kV, and 100 kV Treatment time: 0, 1, 2, 3, 4, 5 min	Surface decontamination	2.1 log CFU per g reduction in total aerobic mesophiles and yeast and mould at 5 min and 100 KV	219
Fresh-cut pitaya fruit	DBD reactor • Input voltage: 40, 50, 60, and 70 kV Treatment time: 1, 3, 5, and 7 min	Accumulation of phenolics and antioxidant activity	60 kV for 5 min reduced the total aerobic bacteria and increased safety The content of individual phenolics increased, resulting in increased antioxidant activity	220
Fresh-cut pear	Atmospheric cold plasma Input voltage: 45 kV, 65 kV Treatment time: 1 and 5 min	Microbial inactivation	65 kV for 1 min was effective in achieving a shelf-life of 7 days	221
Fresh-cut apples (Pink Lady®, Fuji, Modì®, Red Delicious (RD))	Double barrier discharge type gas plasma with three brass electrodes • Atmospheric air • Input power – 150 W • Treatment time – 30 (15 + 15) and 60 (30 + 30) min	Enzymatic browning	Browning area – 17% reduction in RD and 50% in other samples (30 min). Whereas 60 min treatment gave 86% and 58% reduction in Pink Lady® and Modi®	143
Apples (*Malus domestica* cv.)	Dielectric barrier discharge (DBD) CP • Atmospheric air	Polyphenol content	No significant change in total phenolic content	145

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
			Extracted polyphenol did not affect the cell viability	
	• Input power – 150 W • Treatment time – 30 (15 + 15) and 120 (60 + 60) min			
Fresh-cut apples	Dielectric barrier discharge (DBD) chamber with brass electrodes • Atmospheric air • Input power – 9 V (15 kV measured potential difference) • Treatment time – 10, 20 and 30 min (5 + 5, 10 + 10 and 15 + 15 min each major slice side)	Polyphenol content	Polyphenol oxidase activity – reduced by 12, 32, and 58% after 10, 20, and 30 min treatment	144
(b) Processed fruit products				
Apple juice	DBD and glow discharge plasma	Browning enzyme activity, antioxidant capacity, and total phenolic content	Both systems inactivated polyphenol oxidase and peroxidase and increased total phenolic content and antioxidant activity	222
	DBD Input – 50–900 Hz Glow discharge Input – air plasma flow rate: 10–30 mL min^{-1} Treatment time – 10–30 min		DBD – better at increasing total phenolic and antioxidant capacity	
Cashew apple juice	ACP	Bio accessibility of vitamin C	Malic acid and phenylalanine increased for ACP 700 Increased the vitamin C bio accessibility at ACP 700	223
Camu–camu juice	DBD Input – 24 kV and frequency – 200, 420, 583, 698, and 960 Hz	Bioavailability of vitamin C	Higher excitation frequency increased the availability of ascorbic acid Degradation of anthocyanins and peroxidase enzyme at a higher frequency	224
Kiwi turbid juice	DBD Input – 10, 25, and 40 kV Treatment time – 1, 3 and 5 min Volume – 10, 15, and 20 mL	Microbial inactivation and quality changes	• 12 kV, volume – 18 mL and discharge time – 1 min was the optimum condition • Polyphenol content – 0.18 mg g^{-1}, chlorophyll content – 3.47 • Sterilization rate – 18.03%	225
Siriguela juice	Low-pressure plasma processing Nitrogen gas flow rate – 10–30 mL min^{-1} Treatment time – 5 to 15 min	Bioactive component	Enhanced the bioactive component content Highest pigment increase – 10 min – 10 mL min^{-1} Highest antioxidant activity – 15 min – 20 mL min^{-1}	226
Blueberry juice	Cold plasma jet Input – 11 kV, 1000 Hz and oxygen gas concentration – 0, 0.5 and 1 Treatment time – 2, 4, and 6 min	Bioavailability of vitamin C	2 min exhibited high anthocyanin Long treatment decrement of vitamin C 1% concentration of O_2 resulted in the reduction of Bacillus by 7.2 logs CFU per g	227
Apple juice	Dielectric barrier discharge (DBD) plasma chamber with 2 mm electrode distance from sample surface at 23 ± 2 °C temperature • Atmospheric air • Input power – 30, 40, 50 W • Treatment time – 0 to 40 s	Microbial inactivation	4.0 log CFU per mL at 30 W (40 s) 4.2 log CFU per mL at 40 W (40 s) 4.34 log CFU per mL at 50 W (30 s)	146
Banana starch	Corona electrical discharge (CED) plasma Input – 30, 40, and 50 kV Treatment time – 3 min	Starch modification	No changes in amylose and resistant starch contents. The crystalline to amorphous ratio increased after CED plasma treatment	150
Sour cheery nectar	APPJ setup		*E. coli* – 3.34 log reduction at 650 W after 120 s	148
Tomato juice Apple juice Orange juice	• Atmospheric dry air (flow rate – 3000 L h^{-1}) • Input power – 650 W • Treatment time – 0 to 120 s	Microbial inactivation	*E. coli* – 1.43 log reduction at 650 W after 120 s *E. coli* – 4.02 log reduction at 650 W after 120 s *E. coli* – 1.59 log reduction at 650 W after 120 s	

Table 2 (*Contd.*)

Sample	Plasma chamber	Purpose of study	Research goal	Reference
White grape juice	High voltage atmospheric pressure CP with plexiglass and polypropylene dielectric barrier • Atmospheric dry air (Ziploc bag) • Input power – 80 kV (peak) • Treatment time – 1 to 4 min	Microbial inactivation	*S. cerevisiae* population reduced to 7.4 logs (80 kV for 4 min)	149
(4) Plasma treatment on essential oil extraction and quality				
Hyssop	DBD Input – 17, 20, and 23 kV Treatment time – 1, 5 and 10 min	Changes in essential oil content during storage	Trichomes were vulnerable to plasma treatment Increased treatment duration reduced the EO content	228
Fennel and spearmint leaves	DBD Input – 17–23 kV Treatment time – 5–15 min	Essential oil yield	19 kV and 10 min yield 1.89% (v/w) for fennel and 1.81% (v/w) for spearmint leaves	229
Lemon peel	Low-pressure DBD cold plasma • Gas – atmospheric air (1 mbar) • Input – 1 to 2.5 kV • Treatment time – 10 min	Essential oil yield	Plasma treatment for 10 min at 2.5 kV increased the extraction yield by 149.34%	152
Lemon verbena (*Lippa citriodora Kunth.*)	Low-pressure CP connected with vacuum pump • Nitrogen, argon, oxygen • Treatment time – 0, 1, 3, and 5 min	Essential oil yield	Essential oil (EO) content increased by 36.7% during the first 1 min of treatment and later decreased due to higher exposure time	153
Sweet basil (*Ocimum basilicum*)	APPJ CP • Air/helium • Treatment time – 5 s	Essential oil yield	Plasma treated basil EO produced more antioxidant activity (94.82%) than untreated (90.64%) basil at a 250 μg mL^{-1} concentration	27
Lemon peel	DBD plasma treatment • Argon, oxygen, nitrogen, or air (10–20 mL min^{-1}) • Input power – 30 kV (peak) • Treatment time – 1 to 15 min	Essential oil yield	Maximum EO yield was obtained in the argon plasma (flow rate – 15 mL min^{-1}) after 1 min Argon plasma of 1 × 1 × 1 cm size lemon peel produces maximum EO extraction efficiency	154
Clove oil	Plasma jet with pyrex glass tube at atmospheric pressure • Argon (flow rate of 10 L min^{-1})	Essential oil yield	The minimum concentration required for microbial inhibition (*A. niger*, *Penicillium* sp., and *Rhizopus* sp.) was reduced to 20 times for clove oil and 8 to 9 times for eugenol after 10 min at 40 W	151

degradation were entirely removed after 120 min. Industrial wastewater with higher microbial contamination might also affect the water quality of agri-farms. So, industrial wastewater needs decontamination studies, and Rowan *et al.*[46] conducted a study on poultry wash water to investigate microbial decontamination. In this study, other than RS and UV photons, nitric and carbonic acids formed during plasma treatment resulted in pH reduction (acidified) that helped in microbial destruction. These components resulted in the microbial reduction of 8 logs (less than or equal) to complete removal after 30 s of treatment, and the sensitivity of treatments varied for different microbes (*Bacillus cereus* endospores < *Listeria monocytogenes* < *Salmonella enterica Typhimurium* < *Salmonella enterica* Enteritidis < *E. coli* < *Campylobacter jejuni* < *Campylobacter coli*).

Apart from using plasma units for treating different water samples, it is also possible to carry the plasma species in water by which the treatments can be done. Ten Bosch *et al.*[40] reported the effect of plasma-treated water on insect mortality (Mealybugs). Though Plasma Treated Water (PTW) and Classically Acidified Water (CAW) had no significant difference, the CAW mortality rate was higher than PTW at the same pH due to the complexity of RS present in PTW. This PTW can also be used as an alternative for sodium nitrite in sausage curing with similar sensory, microbial, and peroxide values as that of control.[58] Even though plasma-activated water (PAW) possesses antimicrobial properties, its effectiveness reduces during the storage period. Traylor *et al.*[59] reported that PAW prepared with 15 min and 3 h dosage intervals were found to have a similar antimicrobial effect of more than 5 logs. However, after 30 min, the effectiveness of PAW prepared with 15 min exposure time reduced from 5.6 logs to 2.4 logs, while the other was stable for 2 days. Similarly, the lethal effect of stable RS on Hafnia alvei was reported, and among NO^-, NO_2^-, and H_2O_2 species, acidification of PAW by NO_2^- species acted as a primary factor in microbial reduction.[60] Kamgang-Youbi *et al.*[48] reported the influence of pH reduction and substrate absence on

saccharomyces destruction and found that due to its cell size, initial population, and adhesiveness of substrate surface, their resistance was higher against plasma treatment.

Table 1 shows the different plasma generation methods and significant results achieved in water treatments. However, further research must be explored to characterize the degradation process's end product. Since the future industrialization of PAW usage may produce a massive quantity of used PAW, there is a need for research on its recyclability and toxicity.

3.2. Plasma treatment for soil remediation

Industrial and agricultural-related wastes such as heavy metals, pesticides, petroleum, and its products cause soil contamination, which could affect humans and the ecosystem.[61] These contaminants' concentration in soil has to be reduced to avoid losses in production and cross-contamination in agricultural produces. Plasma technology has already gained popularity at the industrial level as an emerging technology for different treatments. Hence, this technology can be used in soil decontamination.[62]

In plasma assisted soil remediation, factors such as soil thickness and its type affect the treatment voltage, frequency, soil thickness, and air flow rate. The effectiveness of the method was identified against different types of soil (sandy soil and loam soil).[63]

Soil pollutant removal varies depending upon the nature of the soil as well as the pollutant. Zhan *et al.*[64] studied the influence of treatment parameters such as time and washing, soil properties such as pH, moisture, and initial concentration of pollutants on fluorene removal from soil. The study showed a significant increase in fluorene degradation (from 33.8 to 57.9%) while reducing the soil moisture content from 20 to 0.6%. In addition, the efficiency increased from 60.6 to 71% when the pH of the soil rose from 3.0 to 9.0. Washing, increasing treatment time, and reducing initial pollutant concentration are reported to be critical factors for pollutant removal. Aggelopoulos *et al.*[65] studied the non-aqueous phase liquid (NAPL)-mixed soil decontamination with high and low energy density plasma treatment to avoid this influence of initial pollutant concentration. When the *ex situ* DBD plasma treatment energy density was around 10 000 J g per soil, NAPL was obliterated, irrespective of the initial concentration. However, low energy density was affected by its increased concentration. Lu *et al.*[66] included the effect of frequency, gas flow, and input power in removing acid scarlet GR dye from the soil. It was found that an increase in DBD plasma input power (3.51 to 5.72 W), frequency (200–300 Hz), and gas flow rate (0.5–1.0 L min^{-1}) improved dye degradation. At the same time, a higher air flow rate (1.5 L min^{-1}) reduced efficiency and O_3 and OH^- reactive species were reported as critical factors in this degradation. However, to find the effectiveness of different gas sources on degradation other than flow rate, Lou *et al.*[67] used O_2 and air for chloramphenicol degradation, where the efficiency of O_2 (41%) was higher than air (26%). For better efficiency, optimum moisture content (≤10%) and Fe^0 addition were needed, and that can increase reactive species and discharge channels, respectively. Similarly, Wang *et al.*[68] used a pulsed discharge plasma-TiO_2 catalytic (PDPTC) reactor to enhance the reactor performance for organic component removal. In this study, TDPTC (55.1%) removed higher organic components than the plasma reactor performed without TiO_2 (42.9%).

For pentachlorophenol (PCP) degradation, Wang *et al.*[69] used an optimum flow rate (3 L min^{-1}) and a high O_2 environment to increase the degradation rate. However, it was found that prolonged exposure of pollutants (4 to 96 h) to soil reduced the degradation by 13.4% as the pollutant gets into the soil granules deeply. So, apart from process parameters and other soil properties, the depth of the soil also decides the degradation efficiency. To understand this, Wang *et al.*[70] studied *p*-nitrophenol (PNP) degradation at a different depth from the surface of the soil using plasma. From this study, it was found that an increase in soil depth reduces the degradation rate from 77.9 (0–2 mm depth) to 52.8% (10–12 mm depth), and the removal of PNP in moist clay soil (44.1%) was higher than dry soil (11.3%) with increased discharge voltage. Similarly, Wang *et al.*[71] studied the effect of the size of the soil granule on the degradation of pentachlorophenol (PCP) and found higher degradation in 20 mesh size granular soil (87%) than in 10 mesh size granular soil (72%). In addition to granule size, the high pH of the soil also assists the PCP degradation. Unlike other studies, Stryczewska *et al.*[72] focused on microbial decontamination and plasma-induced soil property change. Here, the soil pH and temperature changes occurred with changes in O_3 concentration and treatment time, resulting in decontamination. A similar study was carried out with different electrode configurations, and this study reported the importance of screw or pyramid-shaped electrodes on higher O_3 production. O_3 and NO^- produced in this process altered the soil conductivity (34 to 79 mS m^{-1}) and microbial population.[62] Later, Redolfi *et al.* (2010) studied the RS oxidation effect on kerosene-mixed soil to analyze the pollutant residues in the plasma exhaust gas and its bioavailability. Results indicated that only a negligible amount of organic components came along with the gas outlet, while most of them were retained in the soil and did not convert from a solid to a gas state. Hence the bioavailability of kerosene byproducts increased in the soil.

Extended research is needed to understand the effect of plasma treatment on soil mineral content, residue toxicity, and their effects on plant growth and crop yield after treatment. Apart from the decontamination of soil, the effect of plasma on desirable organisms present in it also needs to be addressed.

3.3. Plasma treatment of seeds/plants

Improving germination rate and agricultural yield is the primary concern in increasing food production,[73] and plasma treatment has the potential to improve these two aspects of agriculture processing by altering the germination rate (GR), germination potential (GP), vigor index (VI), water absorbance, contact angle, wettability, and growing tolerance of seed. At optimum process conditions, these changes can influence the overall production of food produce by favouring seed and plant growth.

3.3.1. Germination and plant growth. Since germination is a crucial factor in deciding seed quality, efforts were made to increase the germination behaviour of seeds through plasma technology. Li *et al.*[74] reported an increasing trend in GP, GR, GI, and VI of wheat seeds up to the treatment time of 4 min, while the root and shoot lengths had a positive response during germination. Kim *et al.*[75] treated broccoli seeds in a corona discharge plasma jet (CDPJ) to know the additional benefits of this treatment. They found microbial reduction on the seed surface along with increased germination rate and growth; meanwhile, the sensory and physicochemical parameters were unaffected. Different factors are involved in seed germination (Fig. 3), and water absorption is one among them, Zahoranová *et al.*[76] highlighted this in a wheat seed germination study and found an increase in water absorption of each seed at 2 h (6.41 to 9.60 mg) and 8 h (12.53 to 16.07 mg) of soaking times with respect to the control. In addition to this, GR (21%), VI-I (28%), VI-II (36%), and surface microbial reduction (2 logs) also increased. Along with germination and water absorption, Dobrin *et al.*[77] reported the average increase in root length (32.89 to 36.49 cm), sprout length (4.26 to 4.34 cm), root weight (0.78 to 1.06 g), and root to shoot ratio (0.88 to 1.2) of treated wheat seeds after 15 min treatment. Though most research shows a positive impact on germination and physical characteristics, morphological changes and yield of crops during the growth periods were unidentified. So, Ling *et al.*[78] decided to work on peanut (*Arachis hypogaea* L.) seed with helium plasma and recorded the increase in yield, plant height, stem diameter, shoot and root dry weight, area, thickness, water, and nitrogen content of leaf at 120 W power level. Not only seeds but plants such as basil showed more growth in height, around 10 mm, than the control.[27] Apart from plasma treatment, PAW also helped in the growth of seeds, and Sivachandiran[42] reported about a 28% to 45% increase in the stem length of radish after PAW watering. For tomato and pepper plants, plasma and PAW combined treatment showed positive plant growth with healthy leaves. Similarly, a synergistic effect was observed in the germination of mung bean seeds when they were treated with plasma and PAW. The germination percentage reached up to 100% (from 94%) when plasma and PAW (CO_2) were used; however, the PAW generated using O_2 [PAW(O_2)] inactivated more microorganisms than the other PAW.[79]

Apart from germination enhancement, plasma also has the ability to change the minerals, pigments, enzymes, and other nutritional compositions of the seeds. For example, in capacitively coupled plasma (CCP) treated tomato seeds, calcium (7.73%) and boron (11.53%) contents were increased;[80] whereas in soybean, nutrient fractions such as soluble protein and soluble sugar and enzymes such as peroxidase (POD) and phenylalanine ammonia-lyase (PAL) activities increased after CDPJ treatment.[81] In helium plasma-treated wheat (*Triticum* spp.), chlorophyll content increased by 9.8% more than that in the control.[26] However, photosynthesis efficiency and flavonoid content in peas are reduced due to UV-C production.[82] Similarly, time-dependent reduction of dehydrogenase (27%) and catalase activities (75%) were observed in the roots of germinated maize seeds.[83] In comparison, structural changes were observed with increased indolyl acetic acid (13.7%) in peas.[84] For beans, germination time (44 to 40 h) and exotesta contact angle were reduced after plasma treatment.[85]

In contrast to other research works, Puligundla *et al.*[86] analyzed the negative impact of plasma over dosage on rapeseed germination and suggested the optimum treatment time for better germination since 1 min treatment showed better results in this study. However, the study on pre-germinated brown rice by Sookwong *et al.*[87] showed a reduction in germination rate after the treatment and explained the dependency of treatment time and distance. Along with other dependent variables, gas used in treatment also has a considerable impact on seed germination, and studies by Živković *et al.*[88] on paulownia tomentosa seed proved that by showing maximum germination at 15 min for air plasma, unlike argon plasma. It also noted that the impact of plasma on seeds could not be carried out for a long time since poppy seeds treated at 500 W plasma showed higher GR on the first day of germination but reduced on the sixth day. *i.e.*, 13% reduction was observed in 3 min treated sample.[89]

3.3.2. Plasma-induced seed tolerance. In recent times, plasma-induced seed tolerance has been getting researchers' attention, which led to experiments on different stress parameters such as drought, heavy metals, toxins, and salinity against plasma treatment. For example, Kyzek *et al.*[90] reported the adaptive response of plasma-treated pea seeds (*Pisum sativum* L.) against zeocin and found an increased tolerance against drought and heavy metals due to the interaction of RNS with seeds. However, the most common problem of salinity-induced stress was investigated by Iranbakhsh *et al.*[91] for wheat, and this study showed an increase in heat shock factor (HSF) A4A and salinity tolerance after plasma treatment. Further, it increased the wheat plant's immunity, shoot weight, and enzyme activity (peroxidase and phenylalanine ammonia-lyase). In addition to saline tolerance, drought tolerance also increased for wheat due to the production of abscisic acid. Subsequently, proline (12.7%) and soluble sugar (16.4%) contents also increased with the treatment.[92]

Seed treatment results and their effects vary based on the plasma characteristics used in the respective treatments (Table 1). Many studies have shown a significant increase in the germination of seeds, but detailed studies are required to identify the effect on the quality and yield of the final product. In addition, the negative impact of plasma treatment on seeds needs to be addressed with the evident mode of action, which could provide the limitations of plasma treatment for seeds (Table 2).

4. Plasma applications in post-harvest stages

4.1. Plasma treatment of different agriculture produces

Some of the edible products, such as leaves, roots, fruits, nuts, and spices, are either contaminated by microbes or will have allergens. Plasma treatment can decrease the contaminant level

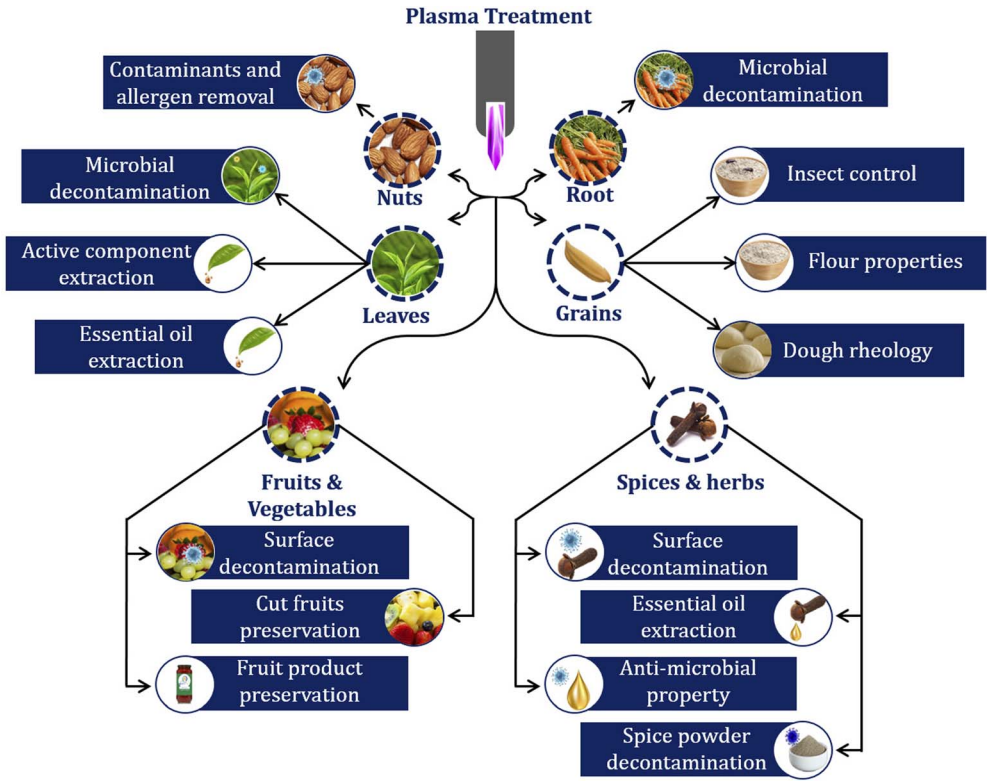

Fig. 4 Plasma application in post-harvest stages of agri-food chain.

and increase the active component percentage in food products. However, based on the surface morphology of different commodities, the effect may change and usually produces a smooth surface that will have more microbial removal rate than the unevenly surfaced one, and this could be due to the improper penetration of plasma species into the porous structures.[93] Decontamination and disinfestation of grains, higher extraction of EO, and functional modification of flours are some advantages of plasma treatments that will be discussed in this section. However, like any other treatment, plasma produces minor undesirable changes that will also be covered here. Different post-harvest applications of plasma are shown in Fig. 4.

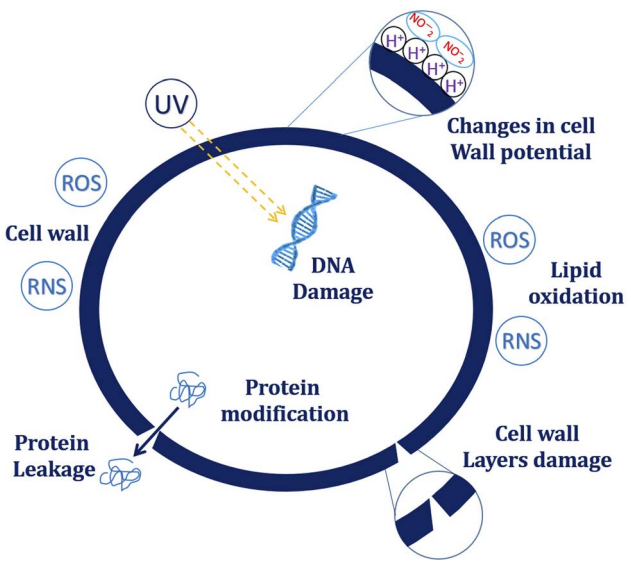

Fig. 5 Effect of plasma treatment on microbial cell.

4.1.1. Leaves. Interaction of plasma species with microbes causes itching, and thus inactivation occurs, while DNA damages caused by UV photons further enhance this effect (Fig. 5). So, microbial contamination on freshly harvested leaves can be reduced by plasma treatment. Pasquali *et al.*[94] reported the microbial decontamination of radicchio leaf (*Cichorium intybus* L.) after DBD plasma treatment and found a significant removal of microbial load. However, the sample stored after treatment had less chroma (C*) value at 4 °C. In order to improve the inactivation efficiency, different gas mixes were suggested, and the Ar–O_2 gas mix is one among them. In romaine lettuce, Ar and O_2 gas mix gave better decontamination efficiency without altering the texture of the produce.[93] However, this gas combination is not ideal for decontaminating all microbes since they have different physical and morphological characteristics. For example, black and green tea were treated with an argon plasma jet, where *E. coli* and coliform were removed within 5 min, while yeast and mould took more time. Further, it also increased the total phenolic content (TPC) of black tea (10.77 to 11.38 g GAE/100 g) and green tea (14.94 to 16.02 g GAE/100 g), but caffeine and colour values were not affected significantly.[95] Similarly, microwave plasma reduced

the microbial (viable) count of dried peppermint, stinging nettle, and lemongrass leaves by up to 1.6 logs within 7.5 min of treatment time.[96] Though decontamination of leaves was the primary goal of these studies, Baier *et al.*[97] found a permanent reduction in photosynthetic efficiency (F_v/F_m) of corn leaves when a higher power level was used. Nevertheless, in the case of lamb's lettuce, the interaction of reactive species caused the reduction in bioactive phenolic components and not in the photo- or thermo-desorption processes. Further reductions such as protocatechuic acid (16%), chlorogenic acid (29%), and caffeinic acid (35%) were observed during the treatment, along with some structural changes.[98] Similar reductions were observed in flavonoids, phenolic acids, and the contact angle of lamb's lettuce.[99]

4.1.2. Roots. Surface morphology is one of the critical factors in deciding the decontamination efficiency of plasma treatment, Bermúdez-Aguirre *et al.*[93] reported that the surface morphology of baby carrots restricted the penetration of plasma into the porous surface areas, and hence the microbial log reduction was found to be less.

4.1.3. Fruits. Freshly harvested fruit surfaces can either be contaminated by microbes or by pesticides. For microbial removal, similar to Amini and Ghoranneviss's[95] study, strawberries were treated in DBD atmospheric cold plasma at 60 kV_{rms} voltage in high oxygen (G1) and high nitrogen (G2) environments. The results showed that G2 was more efficient against mesophiles, whereas G1 was effective on yeast/mould. To maintain more firmness and L^* value, G_1 was preferred since it produced more ozone (G_1 – 2800 ppm) than G_2 (600 ppm).[100] For cocktail tomatoes, along with *E. coli* inactivation, an increase in a^* value was observed with respect to the treatment time. However, at a fixed treatment time of 10 min at 12.83, 11.18, and 6.90 kV power levels, a slight reducing trend of a^* value was observed.[93] However, to achieve the desired microbial reduction from fruit surfaces, it is essential to select a suitable feed gas. A recent study revealed that using air plasma on red currants was only able to reduce fungal population (1.28 log) and not aerobic mesophilic. At the same time, using nitrogen plasma induced up to 1.11 log microbial reduction in aerobic mesophilic without causing any lethal effect on yeast and moulds.[101] Among the various plasma types, cold atmospheric pressure plasma (CAPP) is commonly employed for decontamination of these kinds of fruit and berries.[102] In addition to plasma treatment and PAW, plasma activated air (PAA) also helps in the decontamination of fresh fruits and vegetables (apples cucumbers, tomatoes, and carrots). Interestingly, the commodity with a rough surface (carrot) achieved a higher microbial reduction of up to 5 logs within 5 min of PAA treatment compared to smooth surfaced apple and tomato samples (~3 log reduction).[103]

As pesticides are used extensively in agricultural commodities, their residues remain on the surface of the commodities even after primary and secondary processing. Hence, Ranjitha Gracy *et al.*[37] applied plasma treatment to tomatoes to validate the chlorpyrifos reduction in DBD plasma with different dosage levels. The results showed around 90% pesticide reduction due to the conversion of the phosphorothiol group (P═S) into the phosphoryl group (P═O). After the treatment, considerable changes in firmness, total phenolic content, and colour index were observed. Earlier, Sarangapani *et al.*[104] studied the same with blueberries contaminated with boscalid and imidacloprid pesticides and found at least a 75% reduction in both pesticides. Along with this, ascorbic acid content increased from 8.91 to 14.01 mg/100, while time and power level increases reduced the total flavonoids, anthocyanin, and TPC. Different interactions of plasma with water are shown in Fig. 6.

Apart from plasma treatment, PAW also helps in fruit processing. For example, PAW water can clean the fungicide contaminated tomatoes and can cause up to 85.3% and 79.47% reduction in the chlorothalonil and thiram contents.[105] Further, they are also capable of reducing microbial contamination of fruits and vegetables.[106]

4.1.4. Nuts. Nuts are high-quality oil and nutritive food source; hence, it is susceptible to microbial contamination. In order to remove the contaminants from the surface, it needs to be processed without significant quality deterioration. However, plasma treatment provides surface decontamination with no or minimal quality changes. In unpeeled almonds, air plasma

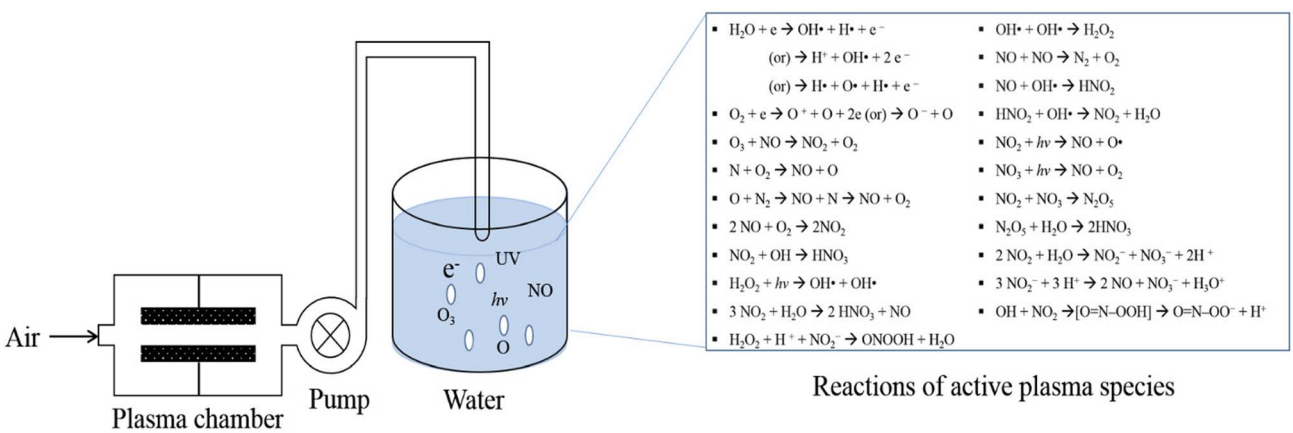

Fig. 6 Interaction of reactive species with water in plasma treatment and PAW generation.

increased the inactivation of salmonella; however, air mixed with N_2 caused browning.[107] A similar decontamination study on hazelnuts showed *Aspergillus* spp. Reduction even after 30 days of storage due to the presence of RS.[108] The effect of moisture content and different cultivars on microbial removal of nuts were experimented with walnut fruits in a plasma jet using argon gas and observed that microbial removal was high in dried walnuts than the fresh ones for the given treatment time. It is due to the low water activity, moisture content, and rugged texture of dried walnuts. After treatment, no further microbial growth was observed till 30 days (4 °C) except in a few (Shahmirzad and Taleghan) walnut types.[109] Apart from product variables, the nature of the microbes present in nuts also has varying responses to the treatment. In Dasan *et al.*[110] report on hazelnuts, *Aspergillus flavus* reduced up to 4.5 log per g, whereas *A. parasiticus* reduction was 4.19 log per g under the same conditions. The difference in morphology, toxic production, and geographical range of these microbial species could not be the factor for the difference in microbial removal. However, molecular research is needed to get more information about this effect. To evaluate the feed gas effect, Niemira[111] reported the microbial reduction in almonds with air and nitrogen plasma and found higher microbial removal in air-treated almonds than the nitrogen treated due to ROS in air plasma. With this, almonds' decontamination can also be increased by higher treatment time, input voltage, and frequency.[112] Likewise, hazelnut, peanut, and pistachio nut were treated in low-pressure air or sulfur hexafluoride (SF_6) cold plasma. Though SF_6 showed higher microbial reduction than air plasma, aflatoxin removal was higher (50%) in air plasma treatment than SF_6 (20%) after 20 min treatment. Peanuts and pistachio nuts were not entirely sterilized after 20 min SF_6 treatment, and hazelnut microbial load reduced linearly till 5 min of SF_6 treatment.[113]

Some quality changes are also associated with nuts during treatment. For instance, peanuts were treated with coplanar DBD plasma; though antioxidant capacity was not changed due to short exposure to ROS, the TPC increased from 200.23 to 341.15 mg (GAE/100 g) after 25 W treatment for 8 min (0.5 L min^{-1}) since phenols protect cells against the damaging effects UV and ROS. However, lipid oxidation and moisture reduction were observed due to the oxidation of strong ROS species.[114] Another problem with peanuts is the Ara h 1 allergens present in them; however, it was reduced in the whole peanut (WP) and defatted peanut flour (DPF) through binding epitope modifications caused by protein and lipid functionality changes after the treatment.[115] Aflatoxins are commonly found in nuts, which is a hazardous toxin, though it was removed about 70% from hazelnut (Aflatoxin B1-AFB1 and total Aflatoxin-AFs) by DBD plasma treatment at 1150 W. Changes in the lactone ring were considered to be the reason for degradation and this effect was increased with power and time.[116]

4.1.5. Spices. Mošovská *et al.*[117] experimented with plasma on black pepper and found that *B. subtilis* spores were more resistant than *E. coli* and *S.* Enteritidis. After treatment, minimal surface damage and moisture loss with unchanged sensory properties were observed. Amini *et al.*[118] reported that the ester and volatile compounds of saffron in response to the plasma treatment. Safranal was degraded by plasma treatment and increased (from 21% to 33% at 12 kV) by adding O_2 (5%) to the plasma gas composition. In contrast, isophorone and 4-ketoisophorone increased by O_2 gas mixer. Plasma treatment reduced crocin esters, and an O_2 gas mixer enhanced the effect in Ar plasma.

Kim *et al.*[119] reported decontamination of red pepper flakes from *B. cereus* in high microwave density (HMCPT) and low microwave density (LMCPT) CP treatment. It was observed that IR drying and flaked samples were suited for microbial reduction. Higher sample water activity (a_W) produced a more lethal effect on microbial reduction. Kim *et al.*[120] treated onion powder in microwave-powered plasma. Microbial inactivation was high in HMCPT than in LMCPT. In addition, the treatment drying method influenced microbial reduction. Onion Aw reduced from 0.26 to 0.16 and 0.12 in LMCPT and HMCPT. Plasma treatment with low temperature (4 °C) storage prevented microbial growth. Quercetin concentration and DPPH activity followed a reducing trend in HMCPT samples, and for the control sample, an increasing trend was observed during storage at both temperatures (4 °C and 25 °C). Won *et al.*[121] reported the effect of He-plasma on onion preservation. In plasma treatment, increased *E. coli*, *L. monocytogenes* and *S.* Enteritidis inactivation by about 2 log per cm^2 when a_W increased from 0.4 to 0.8 was noted, and also, the increase in particle size positively influenced inactivation.

Hertwig *et al.*[28] reported the effect of radio frequency (G1) and microwave (G2) generated plasma jet on black pepper. G1 plasma treatment for 15 min caused 0.7 logs and 0.6 log inactivation of aerobic and spore count, whereas G2 plasma treatment caused 1.7 logs and 1.4 inactivation of an aerobic and spore count for the same time interval. The piperine content of both plasma-treated samples was reduced slightly, and G2 plasma was effective against *S. enterica*. Takemura *et al.*[122] reported the microbial reduction in black pepper in plasma treatment. Argon and CO_2 mixed plasma treatment reduced microbial load better than other combinations. The growth retardation of untreated samples was less than air and argon + CO_2 mixer plasma. Similarly, Sun *et al.*[123] reported APPJ plasma treatment of black pepper on surface microbial reduction. A sample stored at a higher temperature (37 °C) and low RH (33%) reduced the initial microbial count more than that stored at a low temperature and RH. During the treatment, peppercorn surface temperature reached above 120 °C after 80 s exposure. Combined storage condition and 80 s plasma treatment reduced an average of about seven microbial log counts. Grabowski *et al.*[124] treated black pepper with plasma for decontamination. Spore & non-spore forming aerobic bacteria and anaerobic spore-forming bacteria were removed during the treatment. Increased treatment time increased microbial reduction but resulted in water loss. Lumps on pepper were observed after treatment except in O_2 and H_2O_2 plasma. Kim *et al.*[125] reported the effect of microwave-powered CP on the decontamination of *A. flavus* from red pepper powder. The treatments performed at higher power levels reduced the water activity of pepper due to evaporation, which further increased

the ROS concentration. Colour change was insignificant, and He and O_2 gas mix with heating up to 90 °C inactivated *B. cereus* spores.

Research has shown a considerable microbial reduction in most agricultural products and enhancement in active components. However, specific issues, such as colour change, weight loss, and bioactive quality losses, must be addressed by selecting proper plasma characteristics and treatment time. Apart from that, the mode of action of RS or UV produced from plasma treatment on the food components needs to be explained to understand the reason for positive and negative impacts on quality.

4.2. Plasma treatment for safe storage, extraction, and quality enhancement of agricultural products

Removal of microbes and pests during storage is essential to increase the quality of goods. Fumigation and other thermal treatments result in either residue formation or quality deterioration. Plasma treatment facilitates microbial removal and disinfestation without affecting product quality. Meanwhile, it also inactivates the enzymes that reduce the product quality or shelf life. In some cases, plasma treatment improves the functional properties of food constituents.

4.2.1. Grain safety and quality. Carpen *et al.*[126] reported the effect of nitrogen and oxygen gas mixture with Ar plasma on the mortality of *Tribolium castaneum* and *T. confusum* in wheat. When O_2 was added with Ar plasma at the concentration levels of 2.8 and 8.4 sccm, mortality reduced from 88% to 65% and 1.3% for *T. castaneum* and 96% to 51% and 0% for *T. confusum*, respectively. The reduction in mortality was assumed to be due to temperature reduction caused by gas mixing. Similarly, when wheat and barley were subjected to plasma treatment to remove microbial contamination, bacteria and fungi in barley were reduced to 2.4 logs and 2.1 logs after 20 min (24 h retention), while in wheat, it was reduced to 1.5 logs and 2.5 logs after 20 min for bacteria and fungi, respectively. It was found that germination was increased after 5 min treatment with 2 h retention in wheat, and the contact angle was reduced.[127] Apart from insects, microbes and their secondary metabolites also affect grain quality. Hence, Durek *et al.*[128] studied the importance of plasma treatment and its processing variable (feed gas: CO_2 + O_2, CO_2; time: 1–3 min) effect on *Aspergillus niger* and *Penicillium verrucosum* contaminated barley. Though both microbe's counts were reduced in all plasma treatments, the *P. verrucosum*'s produced mycotoxin (ochratoxin A) content reduced only in the CO_2 + O_2 plasma treatment (49.0 ng g^{-1} to 27.5 ng g^{-1} after 1 min and 23.8 ng g^{-1} after 3 min). When CO_2 alone was used on barley, it increased the mycotoxin content upon storage.

Tolouie *et al.*[129] reported the plasma effect on wheat germ enzyme activity to enhance its shelf life. Lipase and lipoxygenase activities were reduced more in 24 kV plasma treatment, while antioxidant activity and total phenols were unchanged. Lipase and lipoxygenase activities were recovered by 1.18 and 6.52 U g^{-1}, respectively, after 30 days. Butscher *et al.*[130] reported bacterial inactivation of plasma treatment in wheat grain where water content was reduced by 10.48 to 9.35% gluten, and the falling number was unaffected. Kordas *et al.*[131] reported around ten times reduction in the fungal colonies of wheat seeds when exposed to up to 10 s of plasma treatment, and it also resulted in more than 98% germination energy. However, the root and leaf length decreased during the same treatment time. Butscher *et al.*[132] reported the effect of power level and O_2 concentration on microbial destruction in wheat. Higher O_2 levels and power levels positively affect microbes, while the extensograph and amylograph parameters such as elasticity, strain resistance, energy, P/L ratio, and gelatinization increased after plasma treatment. Selcuk *et al.*[133] reported the surface structure of grains and legumes on microbial disinfection of air and SF_6 plasma. Cooking quality and water absorbance had no significant effect due to treatments. However, the seed germination rate was maintained above 85% after treatment. Wheat disinfection was 99% in SF_6 plasma treatment.

4.2.2. Flour safety and quality. Ramanan *et al.*[29] reported the effect of CP on the mortality of *T. castaneum* at different life stages (egg, larva, and adult). Low voltage levels and less electrode distance were found not to affect mortality. However, higher voltage (3000 V) mortality was affected by distance. *T. castaneum* mortality prediction model showed no significant difference with experimental mortality rate values (egg, larva, adult) at a 95% confidence level. At 2500 V, maximum mortality was found at a 3.7 cm electrode distance. Eggs, larvae, and adults had 93.33%, 93.33%, and 100% mortality, whereas the predicted model showed 100%, 80%, and 100% mortality, respectively. Similarly, Radhakrishnan *et al.*[134] demonstrated *T. castaneum* disinfestation using CP. Refined wheat flour treated with plasma produces 100% mortality at 1750 V for 7 min and 3 min with 4 cm and 2 cm electrode distances. While, at 3000 V voltage and 4 cm electrode distance, even 3 min treatment

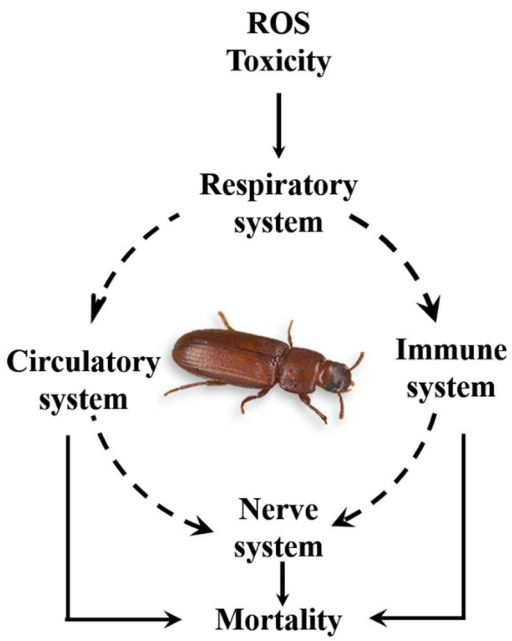

Fig. 7 Mortality of plasma treated insect.

achieved the same mortality. It was also found that there were no significant changes in the colour of the flour after treatment. Likewise, for maida flour, mortality of *T. castaneum* after plasma treatment was reported by Mahendran *et al.*[135] Results indicated that 1750 V at 2 cm for 3 min, 1750 V at 4 cm for 7 min, and 3000 V at 4 cm for 3 min treatments produced 100% mortality. Different mechanisms of insect mortality are shown in Fig. 7. Apart from disinfestation, plasma treatment also assisted in reducing the microbial load (7.22 CFU per g to 4.73 CFU per g) of tenebrio flour and altered the flour properties such as solubility, water and oil binding capacity.[136]

Studies have found the effect of plasma treatment on rheological properties and changes in flours. Held *et al.*[137] reported the flour and dough properties of hard and soft wheat. Secondary structure contribution to protein (β-turns, α-helices, random and β-sheet) was significantly affected after plasma treatment. Peak maximum hard, soft and intermediate flour time increased after plasma treatment while extensibility values decreased. Thirumdas *et al.*[138] reported the changes in rice starch after CP treatment. At 60 W power level, gelatinization temperature (GT) reduced after 10 min of treatment. At the same time, the pasting temperature was reduced for all treatments. An increase in peak viscosity, storage modulus (except 60 W to 5 min) and loss modulus (except 60 W to 5 min) was found. Bahrami *et al.*[139] studied the effect of plasma on the functional properties of wheat flour. It was found that protein fractions in flour changed with a higher dosage, while non-polar lipids and glycolipids fractionation had no difference after treatment, and the dough became strong due to protein and lipid modifications. When short and long rice flours were treated with plasma, it showed an increase in transmittance, swelling power, and gel syneresis. Though rice protein was not affected by plasma treatment, the pasting properties of long rice flour increased due to starch molecules' cross-linkage by ozone oxidation. In contrast, after treatment, amino acids were reduced.[140]

Pea protein-rich flour (PPF), pea starch-rich four (PSF), pea testa flour (PTF), and pea protein isolate (PPI) fractions of pea flour were treated in surface DBD plasma, which led to a mass loss of 2.1, 1.2, 1.3, and 1.1% for PPF, PSF, PTF, and PPI, respectively. Colour changes were increased for PPF and PPI and reduced for PSF when exposure time increased. PPF and PTF water and fat binding increased as treatment time increased to 10 min.[141] Misra *et al.*[25] reported plasma's effect on wheat flour's rheological properties. Peak time and peak integral of soft and hard flour increased significantly when voltage and treatment time exceeded 60 kV and 5 min. Ozone concentration increased with respect to time and input voltage

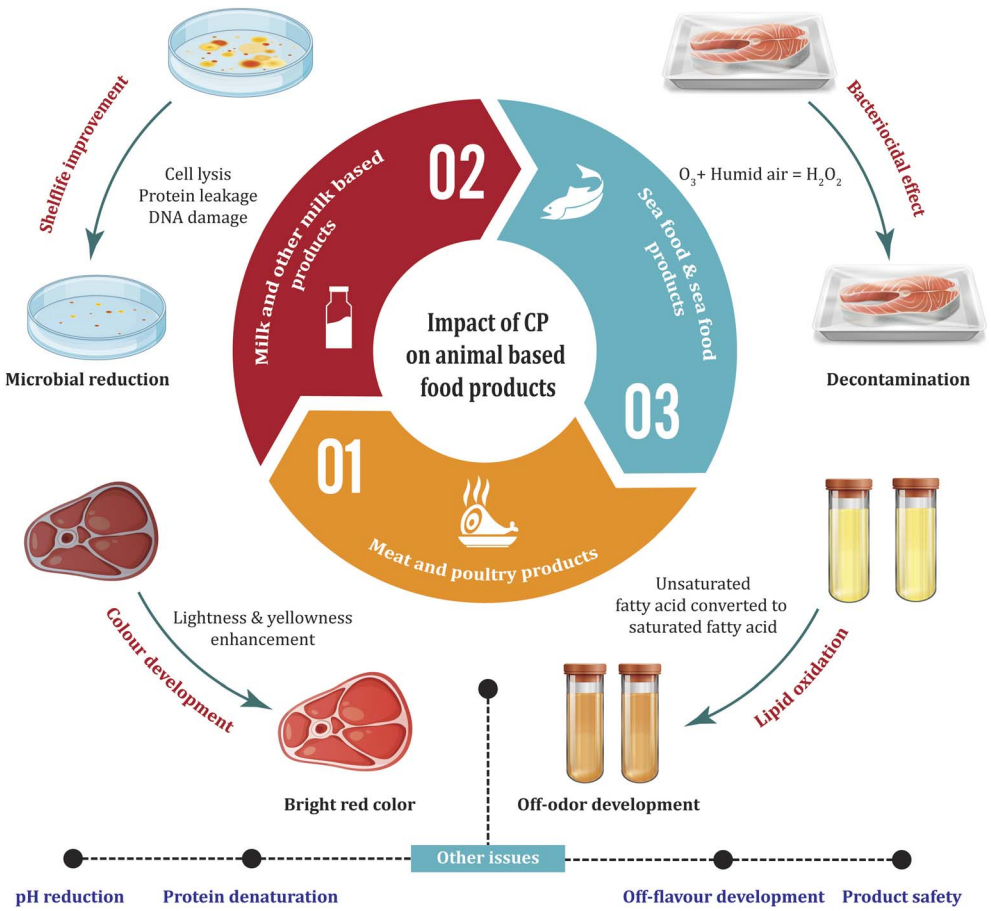

Fig. 8 Impact of cold plasma on animal based food products.

increased. α-helix, β-turn + β-sheet percentage were reduced at 60 kV for 5 min exposure in both samples. However, they increased at 70 kV after 10 min time in soft wheat flour.

Plasma-induced flour functionality changes also resulted in end product quality changes. Menkovska *et al.*[142] reported the effect of plasma on wheat flour and dough quality changes. An increase in farinograph values (except dough softening) was observed with respect to treatment time. Similarly, alveograph values increased (except elasticity) with respect to time. Shape formation ratio, specific and total loaf volumes increased from 0.47 to 0.58 h per day, 3.79 to 4.55 cm^3, and 560 to 657 cm^3, respectively, after 45 min of treatment due to gas retention and crumb cell increase.

Few research studies have focused on the mode of action of ROS on insects, while the effect of UV and RNS on insects is unclear. In addition, PTW and CAW have not produced the same mortality, even though they produced similar pH. Thus, the actual reason behind the mortality of insects in PTW is unclear. Industrial use of PTW has many practical issues since it hydrates/increases the moisture content of produce.

4.3. Processed and minimally processed fruits products quality

The primary reason for minimal processing is to preserve the food with minimal quality changes. However, as non-thermal processing, plasma can help retard browning and microbial activity without adding preservatives and retains the quality of the product. Browning in cut fruit surface is the major problem in preservation. In the case of apples (Pink Lady®, Fuji, Modì®, Red Delicious (RD)), the browning area reduced significantly after plasma treatment due to less residual PPO activity of 10% and 50% in Fuji and Modi, respectively, after 60 min. This could be due to the changes in the secondary structure of proteins and modification of the amino acid side chain of enzymes.[143] Along with browning control, other parameters such as soluble solids, dry matter, acidity, firmness, and rupture strength were increased;[144] however, antioxidant capacity and total phenol index (TPI) were reduced in apples.[145] When the juice was extracted from apples, more than 4 logs of microbial reduction were achieved at 30 W (40 s), 40 W (40 s), and 50 W (30 s) without TSS change. However, the treatment affected total phenolic content (41.7 to 32.4 GAE mg/100 g), antioxidant capacity, pH, and colour values.[146] These data confirmed the study of Surowsky *et al.*[147] in which a plasma jet was applied to reduce *Citrobacter freundii* loads in apple juice by about 5 log cycles after a plasma exposure of 480 s using argon and 0.1% oxygen plus a subsequent storage time of 24 h. Similar effects were found in sour cheery nectar and other juices (tomato, apple, and orange) with a minimum of 1 log reduction in *E. coli* at 650 W after 120 s treatment time. However, in this case, TPC increased by more than 14% except in orange juice (9.52%).[148] However, for white grape juice along with *S. cerevisiae* inactivation, phenols (720.62 to 445.02 GAE μg per mL), flavonoid (265.21 to 231.04 CE μg per mL), DPPH (88.16 to 82.24), and antioxidant capacity (679.35 to 637.61) were reduced after plasma treatment. The degradation of aromatic rings in phenols due to RS causes a reduction in total phenolic content. Thus it is also reflected in DPPH and antioxidant capacity reduction.[149]

Wu *et al.*[150] reported the effect of corona electrical discharge (CED) plasma on banana starch property changes. DSC's onset temperature increased to 60.0, 60.5, and 61.2 °C from 57.2 °C at 30, 40, and 50 kV cm^{-1} intensities due to the cross-linkages created by RS in the polymeric chain of starch granules. This effect was seen in peak and conclusion temperatures increase and gelatinization enthalpy reduction. In terms of pasting behaviour, peak viscosity reduced from 100.4 (control) to 44.4 RVU (50 kV cm^{-1}) while pasting temperature reached 92.1 °C from 74.4 °C (control) due to higher crystallinity and swelling resistance of starch.

Though plasma can reduce the microbial load of food products, it also causes certain quality deteriorations in it. Microbial reduction can be correlated with the changes in the acidity of the plasma-treated sample, but matrix effects have to be considered for clear identification of the inactivation mechanisms, and a focus on evaluating the correlation between the plasma treatment parameter and the subsequent product quality changes is needed.

4.4. Essential oil extraction and quality

Essential oils naturally have anti-bacterial properties; when treated with plasma, the properties can be enhanced and reduce the quantity of EO required to perform the same effect. While the treatment also affects the EO components due to higher oxidation in a few studies.

EO obtained from plasma-treated sweet basil produced more antioxidant activity with higher eugenol content, while the treated seed growth after a month was 40 mm higher than the control.[27] Similarly, an increase in the antimicrobial property of clove oil was achieved after plasma jet processing. Due to this, the minimum concentration required for microbial inhibition (*A. niger*, *Penicillium* sp., and *Rhizopus* sp.) was reduced for clove oil and eugenol.[151] Other than improving EO quality, the extraction yields also increased in microwave pretreated lemon peel at different plasma power levels (1.0 kV, 1.5 kV, and 2.0 kV), and it was reported that the increase in lemon peel EO yield is due to the rupture that happened on the oil glands by etching, and it was confirmed by SEM images.[152] Similarly, Ebadi *et al.*[153] reported the same in lemon verbena (*Lippa citriodora Kunth*.) without any pretreatment after short-time plasma exposure and found an increase in spathulenol (8.1%) and globulol (7.3%) content after 5 min treatment. Earlier, Kodama *et al.*[154] studied the lemon peel with different gases and peel sizes to understand the effect of process and product variables on extraction. The results found that DBD used with Ar gas induced damage in lemon peel oil glands and increased the EO extraction in the initial stages of treatment. However, the surface area increase (size reduction) reduced the limonene, γ-terpinene, and β-pinene concentrations in EO due to overexposure. Similarly, plasma treatment induced both negative and positive effects in the bioactive compounds of essential oil extracted from turmeric powder. However, the treatment reduced the microbial count from turmeric powder by 1.5 logs.[155]

5. Effect on the food products of animal origin

5.1. Dairy products

Milk and its products are highly perishable and often contaminated by bacteria such as *Salmonella* spp., *Streptococcus*, *Coliforms*, *Enterococcus*, *Bacillus*, *etc*. Subjecting the milk to plasma treatment generates free radicals inside the sample and offers antibacterial properties. However, the antibacterial nature of the milk relies on the plasma treatment intensity. Therefore, DBD plasma is the most studied plasma treatment for milk and milk products (fat-free- dry powder and cheese). The treatment was also effective against most milk-contaminating microorganisms (Ex: *E. coli*, *L. monocytogenes*, and *Salmonella typhimurium*). Further, the plasma treatment produced superior quality products compared to pasteurized ones. However, its effectiveness is not superior to UHT treatment.[156,157]

H_2O_2 reactive species are the major cause for the increase of milk's antibacterial properties following plasma treatment. However, few studies suggest direct damage in the microbial cell walls and protein leakage due to plasma species.[158–160] Nevertheless, based on the plasma discharge type, the mechanism of microbial inactivation will vary. Specifically, the microbes present in the liquid of the thin layer will observe more direct cell wall damage than the ones present in the larger volumes. The indirect plasma species effect in the high-volume liquid samples is the plasma species's high reactivity and dissolving property. Therefore, the secondary reactive species generated in the liquid samples will have a greater influence on the microbes when using a larger volume of samples.

Plasma treatment tends to reduce the pH of liquid samples due to the generation of H^+ ions. However, in milk samples, the phosphate and milk casein buffering effect limits the pH change and causes only a mild reduction. Short-time plasma treatments did not affect the milk and milk products' colour. However, long exposure resulted in the reduction of yellowness and lightness. Further, the treatment also increases the saturated fatty acid content in the milk by oxidizing the unsaturated fatty acids. Apart from that, lipid oxidation also increases in milk products due to the oxidation of plasma species. Similarly, the reactive species oxidize sulfonate and nitrate the side chains of amino acids.[156]

5.2. Seafood

Cold plasma is effective against most spoilage-causing microorganisms such as *L. monocytogenes*, *Staphylococcus aureus*, and Enterobacteriaceae. However, depending on the packing conditions, the treatment effectiveness varies for different seafood products. For example, using CO_2 and O_2 gas inside the package of the seafood product enhances CP-assisted microbial reduction. In addition, the natural humidity inside the packaging material allows the plasma reactive species interaction and subsequently provides a bactericidal effect to the microbes post the plasma treatment.[161]

During plasma treatment, the hydrogen in the sample dissociates into H^+ ions and reduces the pH of the sample. The increase in acidity subsequently triggers protein breakdown. In addition, reactive species also denature proteins through oxidation and fragmentation. The oxidation process causes the proteins to form aggregates with cross-linkages. Like other lipid sources, the seafood lipids oxidize due to plasma treatment and induce off-flavor upon prolonged exposure. However, CP treatment can retort the activity of several enzymes (α-amylase, lipase, alkaline phosphatase, peroxidase, and lipoxygenase) that spoil seafood. Furthermore, CP improved the colour value of the seafood samples by increasing the L^* and b values through lipid oxidation and pigment production (Fig. 8).[161]

5.3. Meat and poultry

Salmonella spp., *E. coli* O157:H7, *S. aureus*, *L. monocytogenes*, and *Campylobacter jejuni* contaminate most meat and poultry products. These contaminants can be removed effectively using CP treatment. In addition, studies have shown the decontamination efficiency of cold plasma in many types of meat and poultry products (*i.e.*, pork, beef, poultry meat, and egg). The mechanism of action is similar to that discussed in the earlier sections. However, the quality characteristics vary based on the product's nature.[162]

At minimal exposure level, CP treatment does not induce any colour changes. However, at longer exposure times, the L^* (reduce), a (increase), and b (increase) values will change significantly. However, the treated sample partially recovered from the colour degradation during the storage period. Similarly, most of the plasma-treated meat and poultry samples observed a minimal effect on the off-odor and water content. However, it can be avoided by minimizing the treatment duration. When it comes to pH, inert gas CP treatment did not cause any considerable changes in meat or poultry products. However, excess nitrogen reactive species reportedly reduced the pH of the CP-treated samples. Nevertheless, the lipids in meat and poultry products also are oxidized due to the reactive plasma species. Further, the treatment also results in the degradation (oxidation) of proteins due to the acidic compounds (H_2O_2) produced by CP treatment.[162]

6. Sensory and consumer perception of plasma treated-food products

Though non-thermal technologies preserve the freshness of food products, some techniques impair the sensory qualities. For example, the oxidation of lipid compounds during plasma treatment results in the production of off-flavor-producing compounds. On the other hand, CP treatment also improved the sensory qualities of certain food products. For instance, cut cantaloupe exhibited better sensory characteristics after 40 kV plasma treatment (90 s). Whereas 15 kV CP treated dairy beverage did not cause any sensory attribute changes to the product. However, products like tender coconut had a negative impact (chemical odour) on the sensory quality due to CP (49.4 kJ kg^{-1}) treatment.[163] Therefore, understanding the CP effect on the sensory properties of different food products will be a breakthrough in plasma research. Nevertheless, consumer

perception of the plasma-treated products also needs to be counted for the success of plasma-treated food products. In this regard, consumers' perceptions of food products can be analyzed through the brain-computer interface method to obtain unbiased results from the consumers.[164] Therefore, Coutinho *et al.*[165] surveyed the perception of chocolate milk with 1085 participants. The study revealed that consumers are more concerned about the CP-treated product price and feel the plasma-treated product will be costlier than the conventionally processed products.

7. Other novel applications

7.1. Waterless (hydroponic) plant cultivation

Plasma activated water not only assists plant growth in stress (saline, drought, or heavy metal) conditions but also in soilless conditions. Generally, the nitrogen required for plant growth is supplied directly from the soil or from soil microbes. Hence, when the plants are grown in hydroponic conditions, substrates like coir peats, rice husk, *etc.*, are used to support the plant root and provide nutrients. However, PAW itself contains RNS that act as a nitrogen source for plants and eliminate the requirement of substrates. In addition, ROS species also produce H_2O_2 in PAW, which helps in controlling infections on the plant roots.[166] Nevertheless, the PAW effect on plants may not always be positive, as few studies mentioned a negative effect on plant growth (Lettuce); however, after PAW supply, the secondary metabolites (Epicatechin, rutin, quercetin, total phenolic) were found to be high in both roots and leaves.[167,168] However, a recent study utilized the plasma jet generated PAW solely for fulfilling the nitrogen requirement of corn and lettuce plants and assisted in seed germination and plant growth.[169,170]

7.2. Cold plasma as green fertilizer

The rapid climate change and increased population will have an impact on food shortage in the future. Therefore, increased crop production is needed, which is done with the utilization of chemical fertilizers for agricultural crops. Hence a sustainable technology with less energy consumption and reduced chemical fertilizer use are of interest to researchers and producers to meet the demands.[171] Cold plasma has the potential to be used as a green fertilizer in the future due to its increased efficiency and eco-friendly production. As the plasma treatment will lead to the production of reactive oxygen species and reactive nitrogen species in water, it acts as a fertilization liquid facilitating plant development. The H_2O_2 formed during the plasma treatment initiated the abscisic acid hormone and gibberellin, which is responsible for seed germination and dormancy. Similarly, the NO_3^- generated in PAW has a direct impact on the growth rate of the plant, as nitrate is a crucial element for plant growth. One of the major advantages of PAW as a green fertilizer is the presence of nutrients as ions rather than salts, which helps in easy absorption.[170] Matra *et al.*[172] have found that the PAW spray generated from the gliding arc plasma generator enhanced the amount of nitrogenous fertilizer in treated water. Similarly, Subramanian *et al.*[173] have reported that PAW generated from DBD has a higher specific energy of nitrogen, which is desirable for agricultural purposes. Stoleru *et al.*[168] have also concluded that the nitrites and nitrates from PAW worked as a fertilizer and enhanced the growth of plants. Though there are many studies on PAW as green fertilizer, the appropriate quantity of water used and concentration of nitrates could be a major breakthrough in this application.

7.3. Shape transformation

3D printing and sessile drop drying are the two commonly used additive manufacturing practices to produce shape-changing 2D food structures (xerogels). Both these techniques produce flat 2D food structures that can transform their existing structure into a defined 3D structure under external stimuli (water, oil, drying, or pH) contact.[174–177] However, to achieve the desired shape-shift, flat 2D structures need to be coated with food-grade constraint materials (*i.e.*, ethyl cellulose). These constraints act as a barrier between stimuli and food surfaces and limit the interaction in the coated areas. However, the uncoated areas interact with stimuli and induce stress gradients between coated and uncoated areas. As a result, the relative expansion increase causes the food structure to fold or bend in a specific pattern to produce a desirable 3D structure.[178–180] Nevertheless, surface wettability (*i.e.*, water absorption and oil absorption) and the binding nature of food surface with constraint material decide the success of these shape-transforming foods. Both these factors can be improved by treating these 2D foods in plasma. Plasma etching increases the surface area of food, thereby its binding behaviour and water/oil absorption.[30,180] Hence, to utilize the advantages of plasma treatment in shape transformation, Gupta *et al.*[181] treated wheat xerogels using glow discharge plasma (power: 7.32 W, duration: 5 min) and then coated them with ethyl cellulose in a defined pattern. Due to plasma treatment, the swelling gradient created between coated and uncoated areas of xerogels increased and resulted in better shape transformation when immersed in 90 °C hot water. Similar results were obtained in Stephen *et al.*[182] study on oil-triggered shape transformation, where the author treated corn xerogels in cold plasma (voltage: 1 kV, duration: 5 min) prior to cellulose acetate linear strip coating. As a result, the 2D structure curled into a spiral shape within 2 s in hot (220 °C) coconut oil due to the high relative extension and constraint material binding. Likewise, Cheeyattil *et al.*[183] obtained flower shape and samosa shape in the barley flour xerogel through oleomorphic shape shifting. However, same xerogel can be used to obtain water and oil-based shape transformation. Therefore, Jaspin *et al.*[179] tried obtaining complicated flower shapes from plasma-treated flat xerogels using hot water and oil stimuli and succeeded in both attempts.

8. Conclusion

Plasma treatment significantly affected the agri-food chain in terms of maintaining the quality and safety of products, increasing germination, extraction efficiency, plant growth, and removing hazardous contaminants from water, soil, and

agricultural produces. The interaction of plasma with food products, microbes, allergens, toxins, enzymes, insects, and other constituents varied depending on process variables such as gas composition, gas flow rate, power level, frequency, treatment time, and type of plasma chamber; product variables such as cultivar type, moisture, and other compositions; and other variables such as nature of pesticide, microbes, chemical contaminants, and their initial concentrations. Different mechanisms were involved in different plasma applications, such as microbial inactivation by surface etching and DNA modification, chemical removal by oxidation, allergen removal by protein and lipid functionality modification, germination by surface modification (wettability and surface etching), seed tolerance by heat shock protein production, disinfestation by nerve toxin effect, higher EO extraction by oil gland damages, browning retardation by changes in the secondary structure of proteins and modification of amino acid side chain, *etc.* However, many other reasons, such as species and cultivar-dependent efficiency change of treatment in microbes and agricultural commodities, extract quality improvement, uncertain quantity changes in food properties (*i.e.*, increase and decrease in TPC, colour changes, *etc.*), the effect of RS on consumption to human health and plant growth needs to be explained in further research studies. Also, plasma treatment's large-scale application in these areas is still not stated. Laboratory experiments were mostly done for a lesser quantity of samples. Cost, efficiency, safety, and productivity will be the concern when plasma treatments are used for large-scale operations. Understanding plasma treatment and RS mode of action can increase the chance of productive utilization of plasma treatment by avoiding deterioration during treatment. Some studies have mentioned the long-term effect of RS on product quality and safety.

Conflicts of Interest

The authors also declare that there are no conflicts of interest.

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References

1 S.-C. Ma, H.-B. Zhang, S.-T. Ma, R. Wang, G.-X. Wang, Y. Shao, *et al.*, Effects of mine wastewater irrigation on activities of soil enzymes and physiological properties, heavy metal uptake and grain yield in winter wheat, *Ecotoxicol. Environ. Saf.*, 2015, **113**, 483–490. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0147651314005867.

2 T. M. Salem, S. S. Ahmed, M. A. Hamed and G. H. Abd ElAziz, Risk assessment of hazardous impacts on urbanization and industrialization activities based upon toxic substances, *Global J. Environ. Sci. Manage.*, 2016, **2**(2), 163–176. Available from: https://www.gjesm.net/article_15789_44dbc7e25d290224656bad4969a53895.pdf.

3 R. Gothwal and T. Shashidhar, Antibiotic Pollution in the Environment: A Review, *Clean: Soil, Air, Water*, 2015, **43**(4), 479–489. Available from: https://onlinelibrary.wiley.com/doi/10.1002/clen.201300989.

4 L. Y. He, G. G. Ying, Y. S. Liu, H. C. Su, J. Chen, S. S. Liu, *et al.*, Discharge of swine wastes risks water quality and food safety: antibiotics and antibiotic resistance genes from swine sources to the receiving environments, *Environ. Int.*, 2016, **92–93**, 210–219. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0160412016301039.

5 H. Nazir, H. N. Asghar, Z. A. Zahir, M. J. Akhtar and M. Saleem, Judicious use of kinetin to improve growth and yield of rice in nickel contaminated soil, *Int. J. Phytorem.*, 2016, **18**(7), 651–655. Available from: https://www.tandfonline.com/doi/full/10.1080/15226514.2015.1094444.

6 W. Gwenzi, N. Chaukura, C. Noubactep and F. N. D. Mukome, Biochar-based water treatment systems as a potential low-cost and sustainable technology for clean water provision, *J. Environ. Manage.*, 2017, **197**, 732–749. Available from: https://linkinghub.elsevier.com/retrieve/pii/S030147971730302X.

7 A. I. Mamedov, B. Bar-Yosef, I. Levkovich, R. Rosenberg, A. Silber, P. Fine, *et al.*, Amending Soil with Sludge, Manure, Humic Acid, Orthophosphate and Phytic Acid: Effects on Infiltration, Runoff and Sediment Loss, *Land Degradation and Development*, 2016, **27**(6), 1629–1639. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ldr.2474.

8 M. Ashraf and M. R. Foolad, Pre-Sowing Seed Treatment—A Shotgun Approach to Improve Germination, Plant Growth, and Crop Yield Under Saline and Non-Saline Conditions, *Adv. Agron.*, 2005, 223–271. Available from: https://linkinghub.elsevier.com/retrieve/pii/S006521130588006X.

9 L. Ling, L. Jiangang, S. Minchong, Z. Chunlei and D. Yuanhua, Cold plasma treatment enhances oilseed rape seed germination under drought stress, *Sci. Rep.*, 2015, **5**(1), 13033. Available from: https://www.nature.com/articles/srep13033.

10 F. Yeni, S. Yavaş, H. Alpas and Y. Soyer, Most Common Foodborne Pathogens and Mycotoxins on Fresh Produce: A Review of Recent Outbreaks, *Crit. Rev. Food Sci. Nutr.*, 2016, **56**(9), 1532–1544. Available from: https://www.tandfonline.com/doi/full/10.1080/10408398.2013.777021.

11 M. I. Gil, M. V. Selma, T. Suslow, L. Jacxsens, M. Uyttendaele and A. Allende, Pre- and Postharvest Preventive Measures and Intervention Strategies to Control Microbial Food Safety Hazards of Fresh Leafy Vegetables, *Crit. Rev. Food Sci. Nutr.*, 2015, **55**(4), 453–468. Available from: https://www.tandfonline.com/doi/abs/10.1080/10408398.2012.657808.

12 Q. Zhu, R. Gooneratne and M. A. Hussain, Listeria monocytogenes in fresh produce: outbreaks, prevalence

and contamination levels, *Foods*, 2017, **6**(3), 1–11. Available from: https://www.mdpi.com/2304-8158/6/3/21.

13 B. Singh, K. Suri, K. Shevkani, A. Kaur, A. Kaur and N. Singh, Enzymatic browning of fruit and vegetables: a review, in *Enzymes in Food Technology: Improvements and Innovations*, Springer Singapore, Singapore, 2018, p. 73–78, available from: https://link.springer.com/10.1007/978-981-13-1933-4_4.

14 F. Cheli, L. Pinotti, M. Novacco, M. Ottoboni, M. Tretola and V. Dell'Orto, Mycotoxins in Wheat and Mitigation Measures, in *Wheat Improvement, Management and Utilization*, InTech, 2017, p. 227, available from: https://www.intechopen.com/books/wheat-improvement-management-and-utilization/mycotoxins-in-wheat-and-mitigation-measures.

15 T. Bosona and G. Gebresenbet, Food traceability as an integral part of logistics management in food and agricultural supply chain, *Food Control*, 2013, **33**(1), 32–48. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713513000790.

16 D. Kumar and P. Kalita, Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries, *Foods*, 2017, **6**(1), 1–22. Available from: https://www.mdpi.com/2304-8158/6/1/8.

17 I. Chakraborty and A. Chattopadhyay, Advances in Postharvest Technologies of Vegetable Crops, in *Advances in Postharvest Technologies of Vegetable Crops*, ed. Singh B., Singh S. and Koley T. K., Apple Academic Press, Waretown, NJ, 2018, Series: Postharvest biology and technology, available from: https://www.taylorfrancis.com/books/9781351664165.

18 U. Tiwari and E. Cummins, Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and post-harvest food processing operations, *Food Res. Int.*, 2013, **50**(2), 497–506. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996911005370.

19 I. M. Caminiti, F. Noci, A. Muñoz, P. Whyte, D. J. Morgan, D. A. Cronin, *et al.*, Impact of selected combinations of non-thermal processing technologies on the quality of an apple and cranberry juice blend, *Food Chem.*, 2011, **124**(4), 1387–1392. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814610009647.

20 B. Boopathy, A. Rajan and M. Radhakrishnan, Ozone: An Alternative Fumigant in Controlling the Stored Product Insects and Pests: A Status Report, *Ozone: Sci. Eng.*, 2022, **44**(1), 79–95. Available from: https://www.tandfonline.com/doi/full/10.1080/01919512.2021.1933899.

21 A. Rajan and M. Radhakrishnan, Green Technologies for Sustainable Food Production and Preservation: An Overview of Ohmic Heating, Infrared Heating and UV Light Technology, in *Reference Module in Food Science*, Elsevier, 2023, available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128239605000664.

22 R. Mahendran, C. V. Kavitha Abirami and K. Alagusundaram, Cold plasma technology: an emerging non-thermal processing of foods—a review, in *Engineering Interventions in Agricultural Processing*, Apple Academic Press, Waretown, NJ, 2017, Series: Innovations in agricultural & biological engineering: Apple Academic Press, 2018, p. 33–55. available from: https://www.taylorfrancis.com/books/9781771885577/chapters/10.1201/9781315207377-2.

23 S. Potluri, K. Sangeetha, R. Santhosh, G. Nivas and R. Mahendran, Effect of low-pressure plasma on bamboo rice and its flour, *J. Food Process. Preserv.*, 2018, **42**(12), e13846. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/jfpp.13846.

24 R. Mahendran and K. Alagusundaram, Uniform discharge characteristics of non-thermal plasma for superficial decontamination of bread slices, in *International Journal of Agricultural Science and Research (IJASR)*, Transstellar Journal Publications and Research Consultancy Private Limited, 2015, p. 209–212, available from: https://www.academia.edu/download/45165821/25._Agri_Sci_-_IJASR___-Uniform_discharge_characteristics_of_non-thermal___-_Mahendran.pdf.

25 N. N. Misra, S. Kaur, B. K. Tiwari, A. Kaur, N. Singh and P. J. Cullen, Atmospheric pressure cold plasma (ACP) treatment of wheat flour, *Food Hydrocolloids*, 2015, **44**, 115–121. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0268005X14002951.

26 J. Jiang, X. He, L. Li, J. Li, H. Shao, Q. Xu, *et al.*, Effect of cold plasma treatment on seed germination and growth of wheat, *Plasma Sci. Technol.*, 2014, **16**(1), 54–58. Available from: https://iopscience.iop.org/article/10.1088/1009-0630/16/1/12.

27 G. J. Buonopane, C. Antonacci and J. L. Lopez, Effect of Cold Plasma Processing on Botanicals and Their Essential Oils, *Plasma Medical*, 2016, **6**(3–4), 315–324. Available from: https://www.dl.begellhouse.com/journals/5a5b4a3d419387fb,389e931927aa49bf,110e9426524acd52.html.

28 C. Hertwig, K. Reineke, J. Ehlbeck, D. Knorr and O. Schlüter, Decontamination of whole black pepper using different cold atmospheric pressure plasma applications, *Food Control*, 2015, **55**, 221–229. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713515001462.

29 K. Ratish Ramanan, R. Sarumathi and R. Mahendran, Influence of cold plasma on mortality rate of different life stages of Tribolium castaneum on refined wheat flour, *J. Stored Prod. Res.*, 2018, **77**, 126–134. Available from: https://www.researchgate.net/publication/311370163.

30 R. Anbarasan, S. Jaspin, B. Bhavadharini, A. Pare, R. Pandiselvam and R. Mahendran, Chlorpyrifos pesticide reduction in soybean using cold plasma and ozone treatments, *LWT–Food Sci. Technol.*, 2022, **159**, 113193. Available from: https://www.sciencedirect.com/science/article/pii/S0023643822001281.

31 E. Dolezalova and P. Lukes, Membrane damage and active but nonculturable state in liquid cultures of Escherichia coli treated with an atmospheric pressure plasma jet, *Bioelectrochemistry*, 2015, **103**, 7–14. Available from:

https://linkinghub.elsevier.com/retrieve/pii/S1567539414001340.

32 M. Yusupov, A. Bogaerts, S. Huygh, R. Snoeckx, A. C. T. van Duin and E. C. Neyts, Plasma-Induced Destruction of Bacterial Cell Wall Components: A Reactive Molecular Dynamics Simulation, *J. Phys. Chem. C*, 2013, **117**(11), 5993–5998. Available from: https://pubs.acs.org/doi/10.1021/jp3128516.

33 L. Mao, P. Mhaske, X. Zing, S. Kasapis, M. Majzoobi and A. Farahnaky, Cold plasma: microbial inactivation and effects on quality attributes of fresh and minimally processed fruits and Ready-To-Eat vegetables, *Trends Food Sci. Technol.*, 2021, **116**, 146–175. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0924224421004404.

34 J.-W. Lackmann, S. Schneider, E. Edengeiser, F. Jarzina, S. Brinckmann, E. Steinborn, *et al.*, Photons and particles emitted from cold atmospheric-pressure plasma inactivate bacteria and biomolecules independently and synergistically, *J. R. Soc., Interface*, 2013, **10**(89), 20130591. Available from: https://royalsocietypublishing.org/doi/10.1098/rsif.2013.0591.

35 E. Stoffels, Y. Sakiyama and D. B. Graves, Cold Atmospheric Plasma: Charged Species and Their Interactions With Cells and Tissues, *IEEE Trans. Plasma Sci.*, 2008, **36**(4), 1441–1457. Available from: https://ieeexplore.ieee.org/document/4598991/.

36 S. Ikawa, K. Kitano and S. Hamaguchi, Effects of pH on Bacterial Inactivation in Aqueous Solutions due to Low-Temperature Atmospheric Pressure Plasma Application, *Plasma Processes Polym.*, 2010, **7**(1), 33–42. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.200900090.

37 T. K. Ranjitha Gracy, V. Gupta and R. Mahendran, Influence of low-pressure nonthermal dielectric barrier discharge plasma on chlorpyrifos reduction in tomatoes, *J. Food Process Eng.*, 2019, **42**(6), e13242. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/jfpe.13242.

38 N. N. Misra, O. Schlüter and P. J. Cullen, *Cold Plasma in Food and Agriculture: Fundamentals and Applications*, Academic Press, 2016, p. 1–368, available from: https://www.sciencedirect.com/book/9780128013656/cold-plasma-in-food-and-agriculture.

39 S. Kumar, J. Park, E. Kim, J. Na, Y. S. Chun, H. Kwon, *et al.*, Oxidative stress induced by chlorine dioxide as an insecticidal factor to the Indian meal moth, Plodia interpunctella, *Pestic. Biochem. Physiol.*, 2015, **124**, 48–59. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0048357515000814.

40 L. Ten Bosch, R. Köhler, R. Ortmann, S. Wieneke and W. Viöl, Insecticidal effects of plasma treatedwater, *Int. J. Environ. Res. Public Health*, 2017, **14**(12), 1460. Available from: https://www.mdpi.com/1660-4601/14/12/1460.

41 K. V. Donohue, B. L. Bures, M. A. Bourham and R. M. Roe, Mode of Action of a Novel Nonchemical Method of Insect Control: Atmospheric Pressure Plasma Discharge, *J. Econ. Entomol.*, 2006, **99**(1), 38–47. Available from: https://academic.oup.com/jee/article-lookup/doi/10.1093/jee/99.1.38.

42 L. Sivachandiran and A. Khacef, Enhanced seed germination and plant growth by atmospheric pressure cold air plasma: combined effect of seed and water treatment, *RSC Adv.*, 2017, **7**(4), 1822–1832. Available from: https://xlink.rsc.org/?DOI=C6RA24762H.

43 B. Será, V. Stranák, M. Serý, M. Tichý and P. Spatenka, Germination of Chenopodium Album in Response to Microwave Plasma Treatment, *Plasma Sci. Technol.*, 2008, **10**(4), 506–511. Available from: https://iopscience.iop.org/article/10.1088/1009-0630/10/4/22.

44 H. M. Kalaji and A. Rastogi, Pharmaceutical compounds: an emerging pollutant (a review on plant-pharmaceuticals interaction), *Chiang Mai J. Sci.*, 2017, **44**(2), 287–297. Available from: https://www.thaiscience.info/Journals/Article/CMJS/10985613.pdf.

45 M. Magureanu, N. B. Mandache and V. I. Parvulescu, Degradation of pharmaceutical compounds in water by non-thermal plasma treatment, *Water Res.*, 2015, **81**(11), 124–136. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0043135415300208.

46 N. J. Rowan, S. Espie, J. Harrower, J. G. Anderson, L. Marsili and S. J. Macgregor, Pulsed-Plasma Gas-Discharge Inactivation of Microbial Pathogens in Chilled Poultry Wash Water, *J. Food Prot.*, 2007, **70**(12), 2805–2810. Available from: https://meridian.allenpress.com/jfp/article/70/12/2805/171258/PulsedPlasma-GasDischarge-Inactivation-of.

47 C. Bradu, M. Magureanu and V. I. Parvulescu, Degradation of the chlorophenoxyacetic herbicide 2,4-D by plasma-ozonation system, *J. Hazard. Mater.*, 2017, **336**, 52–56. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389417302996.

48 G. Kamgang-Youbi, J.-M. Herry, T. Meylheuc, J.-L. Brisset, M.-N. Bellon-Fontaine, A. Doubla, *et al.*, Microbial inactivation using plasma-activated water obtained by gliding electric discharges, *Lett. Appl. Microbiol.*, 2009, **48**(1), 13–18. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1472-765X.2008.02476.x.

49 R. Thirumdas, A. Kothakota, U. Annapure, K. Siliveru, R. Blundell, R. Gatt, *et al.*, Plasma activated water (PAW): chemistry, physico-chemical properties, applications in food and agriculture, *Trends Food Sci. Technol.*, 2018, **77**, 21–31. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0924224417305873.

50 J. Feng, Z. Zheng, J. Luan, K. Li, L. Wang and J. Feng, Gas–liquid hybrid discharge-induced degradation of diuron in aqueous solution, *J. Hazard. Mater.*, 2009, **164**(2–3), 838–846. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389408012958.

51 Y. Hu, Y. Bai, X. Li and J. Chen, Application of dielectric barrier discharge plasma for degradation and pathways of dimethoate in aqueous solution, *Sep. Purif. Technol.*, 2013, **120**, 191–197. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1383586613005893.

52 R. Zhou, T. Zhang, R. Zhou, A. Mai-Prochnow, S. B. Ponraj, Z. Fang, *et al.*, Underwater microplasma bubbles for efficient and simultaneous degradation of mixed dye pollutants, *Sci. Total Environ.*, 2021, **750**, 142295, DOI: 10.1016/j.scitotenv.2020.142295.

53 G. Iervolino, V. Vaiano and V. Palma, Enhanced removal of water pollutants by dielectric barrier discharge non-thermal plasma reactor, *Sep. Purif. Technol.*, 2019, **215**, 155–162. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1383586618337432.

54 F. Tampieri, A. Giardina, F. J. Bosi, A. Pavanello, E. Marotta, B. Zaniol, *et al.*, Removal of persistent organic pollutants from water using a newly developed atmospheric plasma reactor, *Plasma Processes Polym.*, 2018, **15**(6), 1700207. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.201700207.

55 C. Sarangapani, N. N. Misra, V. Milosavljevic, P. Bourke, F. O'Regan and P. J. Cullen, Pesticide degradation in water using atmospheric air cold plasma, *J. Water Process. Eng.*, 2016, **9**, 225–232. Available from: https://linkinghub.elsevier.com/retrieve/pii/S221471441630006X.

56 M. J. Pavlovich, H.-W. Chang, Y. Sakiyama, D. S. Clark and D. B. Graves, Ozone correlates with antibacterial effects from indirect air dielectric barrier discharge treatment of water, *J. Phys. D: Appl. Phys.*, 2013, **46**(14), 145202. Available from: https://iopscience.iop.org/article/10.1088/0022-3727/46/14/145202.

57 M. Hijosa-Valsero, R. Molina, H. Schikora, M. Müller and J. M. Bayona, Removal of priority pollutants from water by means of dielectric barrier discharge atmospheric plasma, *J. Hazard. Mater.*, 2013, **262**, 664–673. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389413006663.

58 S. Jung, H. J. Kim, S. Park, H. In Yong, J. H. Choe, H.-J. Jeon, *et al.*, The use of atmospheric pressure plasma-treated water as a source of nitrite for emulsion-type sausage, *Meat Sci.*, 2015, **108**, 132–137. Available from: https://linkinghub.elsevier.com/retrieve/pii/S030917401530036X.

59 M. J. Traylor, M. J. Pavlovich, S. Karim, P. Hait, Y. Sakiyama, D. S. Clark, *et al.*, Long-term antibacterial efficacy of air plasma-activated water, *J. Phys. D: Appl. Phys.*, 2011, **44**(47), 472001. Available from: https://iopscience.iop.org/article/10.1088/0022-3727/44/47/472001.

60 M. Naïtali, G. Kamgang-Youbi, J.-M. Herry, M.-N. Bellon-Fontaine and J.-L. Brisset, Combined Effects of Long-Living Chemical Species during Microbial Inactivation Using Atmospheric Plasma-Treated Water, *Appl. Environ. Microbiol.*, 2010, **76**(22), 7662–7664. Available from: https://journals.asm.org/doi/10.1128/AEM.01615-10.

61 M. Chen, P. Xu, G. Zeng, C. Yang, D. Huang and J. Zhang, Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: applications, microbes and future research needs, *Biotechnol. Adv.*, 2015, **33**(6), 745–755. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0734975015300021.

62 H. D. Stryczewska, K. Ebihara, M. Takayama, Y. Gyoutoku and M. Tachibana, Non-thermal plasma-based technology for soil treatment, *Plasma Processes Polym.*, 2005, **2**(3), 238–245. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.200400061.

63 M. Hatzisymeon, D. Tataraki, C. Tsakiroglou, G. Rassias and C. A. Aggelopoulos, Highly energy-efficient degradation of antibiotics in soil: extensive cold plasma discharges generation in soil pores driven by high voltage nanopulses, *Sci. Total Environ.*, 2021, **786**, 147420. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0048969721024918.

64 J. Zhan, Y. Liu, W. Cheng, A. Zhang, R. Li, X. Li, *et al.*, Remediation of soil contaminated by fluorene using needle-plate pulsed corona discharge plasma, *Chem. Eng. J.*, 2018, **334**, 2124–2133. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894717320156.

65 C. A. Aggelopoulos, C. D. Tsakiroglou, S. Ognier and S. Cavadias, Non-aqueous phase liquid-contaminated soil remediation by ex situ dielectric barrier discharge plasma, *Int. J. Environ. Sci. Technol.*, 2015, **12**(3), 1011–1020. Available from: https://link.springer.com/10.1007/s13762-013-0489-4.

66 N. Lu, J. Lou, C. H. Wang, J. Li and Y. Wu, Evaluating the Effects of Silent Discharge Plasma on Remediation of Acid Scarlet GR-Contaminated Soil, *Water, Air, Soil Pollut.*, 2014, **225**(6), 1991. Available from: https://link.springer.com/10.1007/s11270-014-1991-0.

67 J. Lou, N. Lu, J. Li, T. Wang and Y. Wu, Remediation of chloramphenicol-contaminated soil by atmospheric pressure dielectric barrier discharge, *Chem. Eng. J.*, 2012, **180**, 99–105. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894711013921.

68 T. C. Wang, N. Lu, J. Li and Y. Wu, Plasma-TiO2 catalytic method for high-efficiency remediation of p-nitrophenol contaminated soil in pulsed discharge, *Environ. Sci. Technol.*, 2011, **45**(21), 9301–9307. Available from: https://pubs.acs.org/doi/10.1021/es2014314.

69 T. C. Wang, N. Lu, J. Li and Y. Wu, Degradation of pentachlorophenol in soil by pulsed corona discharge plasma, *J. Hazard. Mater.*, 2010, **180**(1–3), 436–441. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389410004954.

70 T. C. Wang, G. Qu, J. Li, D. Liang and S. Hu, Depth dependence of p-nitrophenol removal in soil by pulsed discharge plasma, *Chem. Eng. J.*, 2014, **239**, 178–184. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894713014599.

71 T. C. Wang, N. Lu, J. Li and Y. Wu, Evaluation of the Potential of Pentachlorophenol Degradation in Soil by Pulsed Corona Discharge Plasma from Soil Characteristics, *Environ. Sci. Technol.*, 2010, **44**(8), 3105–3110. Available from: https://pubs.acs.org/doi/10.1021/es903527w.

72 H. D. Stryczewska, J. Pawłat and K. Ebihara, Non-Thermal Plasma Aided Soil Decontamination, *J. Adv. Oxid. Technol.*, 2013, **16**(1), 23–30. Available from: https://

www.degruyter.com/document/doi/10.1515/jaots-2013-0103/html.

73 E. J. Rifna, K. Ratish Ramanan and R. Mahendran, Emerging technology applications for improving seed germination, *Trends Food Sci. Technol.*, 2019, **86**, 95–108. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0924224417307975.

74 Y. Li, T. Wang, Y. Meng, G. Qu, Q. Sun, D. Liang, *et al.*, Air Atmospheric Dielectric Barrier Discharge Plasma Induced Germination and Growth Enhancement of Wheat Seed, *Plasma Chem. Plasma Process.*, 2017, **37**(6), 1621–1634. Available from: https://link.springer.com/10.1007/s11090-017-9835-5.

75 J.-W. Kim, P. Puligundla and C. Mok, Effect of corona discharge plasma jet on surface-borne microorganisms and sprouting of broccoli seeds, *J. Sci. Food Agric.*, 2017, **97**(1), 128–134. Available from: https://onlinelibrary.wiley.com/doi/10.1002/jsfa.7698.

76 A. Zahoranová, M. Henselová, D. Hudecová, B. Kaliňáková, D. Kováčik, V. Medvecká, *et al.*, Effect of Cold Atmospheric Pressure Plasma on the Wheat Seedlings Vigor and on the Inactivation of Microorganisms on the Seeds Surface, *Plasma Chem. Plasma Process.*, 2016, **36**(2), 397–414. Available from: https://link.springer.com/10.1007/s11090-015-9684-z.

77 D. Dobrin, M. Magureanu, N. B. Mandache and M.-D. Ionita, The effect of non-thermal plasma treatment on wheat germination and early growth, *Innovative Food Sci. Emerging Technol.*, 2015, **29**, 255–260. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856415000429.

78 L. Li, J. Li, M. Shen, J. Hou, H. Shao, Y. Dong, *et al.*, Improving Seed Germination and Peanut Yields by Cold Plasma Treatment, *Plasma Sci. Technol.*, 2016, **18**(10), 1027–1033. Available from: https://iopscience.iop.org/article/10.1088/1009-0630/18/10/10.

79 M. Darmanin, A. Fröhling, S. Bußler, J. Durek, S. Neugart, M. Schreiner, *et al.*, Aqueous and gaseous plasma applications for the treatment of mung bean seeds, *Sci. Rep.*, 2021, **11**(1), 19681. Available from: https://www.nature.com/articles/s41598-021-97823-1.

80 J. Jiang, Y. Lu, J. Li, L. Li, X. He, H. Shao, *et al.*, Effect of Seed Treatment by Cold Plasma on the Resistance of Tomato to Ralstonia solanacearum (Bacterial Wilt). Yousfi M, editor, *PLoS One*, 2014, **9**(5), e97753. Available from: https://dx.plos.org/10.1371/journal.pone.0097753.

81 L. Ling, J. Jiafeng, L. Jiangang, S. Minchong, H. Xin, S. Hanliang, *et al.*, Effects of cold plasma treatment on seed germination and seedling growth of soybean, *Sci. Rep.*, 2015, **4**(1), 5859. Available from: https://www.nature.com/articles/srep05859.

82 S. Bußler, W. B. Herppich, S. Neugart, M. Schreiner, J. Ehlbeck, S. Rohn, *et al.*, Impact of cold atmospheric pressure plasma on physiology and flavonol glycoside profile of peas (Pisum sativum 'Salamanca'), *Food Res. Int.*, 2015, **76**(P1), 132–141. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996915001507.

83 M. Henselová, Ľ. Slováková, M. Martinka and A. Zahoranová, Growth, anatomy and enzyme activity changes in maize roots induced by treatment of seeds with low-temperature plasma, *Biologia*, 2012, **67**(3), 490–497. Available from: https://link.springer.com/10.2478/s11756-012-0046-5.

84 T. Stolárik, M. Henselová, M. Martinka, O. Novák, A. Zahoranová and M. Černák, Effect of Low-Temperature Plasma on the Structure of Seeds, Growth and Metabolism of Endogenous Phytohormones in Pea (Pisum sativum L.), *Plasma Chem. Plasma Process.*, 2015, **35**(4), 659–676. Available from: https://link.springer.com/10.1007/s11090-015-9627-8.

85 E. Bormashenko, Y. Shapira, R. Grynyov, G. Whyman, Y. Bormashenko and E. Drori, Interaction of cold radiofrequency plasma with seeds of beans (Phaseolus vulgaris), *J. Exp. Bot.*, 2015, **66**(13), 4013–4021. Available from: https://academic.oup.com/jxb/article-lookup/doi/10.1093/jxb/erv206.

86 P. Puligundla, J.-W. Kim and C. Mok, Effects of Nonthermal Plasma Treatment on Decontamination and Sprouting of Radish (Raphanus sativus L.) Seeds, *Food Bioprocess Technol.*, 2017, **10**(6), 1093–1102. Available from: https://link.springer.com/10.1007/s11947-017-1886-3.

87 P. Sookwong, S. Yodpitak, J. Doungkaew, J. Jurithayo, D. Boonyawan and S. Mahatheeranont, Application of Oxygen-argon Plasma as a Potential Approach of Improving the Nutrition Value of Pre-germinated Brown Rice, *J. Food Nutr. Res.*, 2014, **2**(12), 946–951. Available from: https://pubs.sciepub.com/jfnr/2/12/14/index.html.

88 S. Živković, N. Puač, Z. Giba, D. Grubišić and Z. L. Petrović, The stimulatory effect of non-equilibrium (low temperature) air plasma pretreatment on light-induced germination of Paulownia tomentosa seeds, *Seed Sci. Technol.*, 2004, **32**(3), 693–701. Available from: https://www.ingentaconnect.com/content/ista/sst/2004/00000032/00000003/art00005.

89 B. Šerá, I. Gajdová, M. Šerý and P. Špatenka, New Physicochemical Treatment Method of Poppy Seeds for Agriculture and Food Industries, *Plasma Sci. Technol.*, 2013, **15**(9), 935–938. Available from: https://iopscience.iop.org/article/10.1088/1009-0630/15/9/19.

90 S. Kyzek, Ľ. Holubová, V. Medvecká, J. Tomeková, E. Gálová and A. Zahoranová, Cold Atmospheric Pressure Plasma Can Induce Adaptive Response in Pea Seeds, *Plasma Chem. Plasma Process.*, 2019, **39**(2), 475–486. Available from: https://link.springer.com/10.1007/s11090-018-9951-x.

91 A. Iranbakhsh, N. O. Ardebili, Z. O. Ardebili, M. Shafaati and M. Ghoranneviss, Non-thermal Plasma Induced Expression of Heat Shock Factor A4A and Improved Wheat (Triticum aestivum L.) Growth and Resistance Against Salt Stress, *Plasma Chem. Plasma Process.*, 2018, **38**(1), 29–44. Available from: https://link.springer.com/10.1007/s11090-017-9861-3.

92 Q. Guo, Y. Wang, H. Zhang, G. Qu, T. Wang, Q. Sun, *et al.*, Alleviation of adverse effects of drought stress on wheat seed germination using atmospheric dielectric barrier

discharge plasma treatment, *Sci. Rep.*, 2017, **7**(1), 16680. Available from: https://www.nature.com/articles/s41598-017-16944-8.

93 D. Bermúdez-Aguirre, E. Wemlinger, P. Pedrow, G. Barbosa-Cánovas and M. Garcia-Perez, Effect of atmospheric pressure cold plasma (APCP) on the inactivation of Escherichia coli in fresh produce, *Food Control*, 2013, **34**(1), 149–157. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713513002065.

94 F. Pasquali, A. C. Stratakos, A. Koidis, A. Berardinelli, C. Cevoli, L. Ragni, *et al.*, Atmospheric cold plasma process for vegetable leaf decontamination: a feasibility study on radicchio (red chicory, Cichorium intybus L.), *Food Control*, 2016, **60**, 552–559. Available from: https://linkinghub.elsevier.com/retrieve/pii/S095671351530178X.

95 M. Amini and M. Ghoranneviss, Black and green tea decontamination by cold plasma, *Res. J. Microbiol.*, 2016, **11**(1), 42–46. Available from: https://scialert.net/abstract/?doi=jm.2016.42.46.

96 J. Durek, A. Fröhling, S. Bußler, A. Hase, J. Ehlbeck and O. K. Schlüter, Pilot-scale generation of plasma processed air and its influence on microbial count, microbial diversity, and selected quality parameters of dried herbs, *Innovative Food Sci. Emerging Technol.*, 2022, **75**, 102890. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856421002915.

97 M. Baier, J. Foerster, U. Schnabel, D. Knorr, J. Ehlbeck, W. B. Herppich, *et al.*, Direct non-thermal plasma treatment for the sanitation of fresh corn salad leaves: evaluation of physical and physiological effects and antimicrobial efficacy, *Postharvest Biol. Technol.*, 2013, **84**, 81–87. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0925521413001063.

98 F. Grzegorzewski, J. Ehlbeck, O. Schlüter, L. W. Kroh and S. Rohn, Treating lamb's lettuce with a cold plasma – influence of atmospheric pressure Ar plasma immanent species on the phenolic profile of valerianella locusta, *LWT–Food Sci. Technol.*, 2011, **44**(10), 2285–2289. Available from: https://linkinghub.elsevier.com/retrieve/pii/S002364381100140X.

99 F. Grzegorzewski, S. Rohn, L. W. Kroh, M. Geyer and O. Schlüter, Surface morphology and chemical composition of lamb's lettuce (Valerianella locusta) after exposure to a low-pressure oxygen plasma, *Food Chem.*, 2010, **122**(4), 1145–1152. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814610003985.

100 N. N. Misra, T. Moiseev, S. Patil, S. K. Pankaj, P. Bourke, J. P. Mosnier, *et al.*, Cold Plasma in Modified Atmospheres for Post-harvest Treatment of Strawberries, *Food Bioprocess Technol.*, 2014, **7**(10), 3045–3054. Available from: https://link.springer.com/10.1007/s11947-014-1356-0.

101 A. Limnaios, N. Pathak, G. Grossi Bovi, A. Fröhling, V. P. Valdramidis, P. S. Taoukis, *et al.*, Effect of cold atmospheric pressure plasma processing on quality and shelf life of red currants, *LWT–Food Sci. Technol.*, 2021, **151**, 112213. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643821013669.

102 G. G. Bovi, A. Fröhling, N. Pathak, V. P. Valdramidis and O. Schlüter, Safety control of whole berries by cold atmospheric pressure plasma processing: a review, *J. Food Prot.*, 2019, **82**(7), 1233–1243. Available from: https://meridian.allenpress.com/jfp/article/82/7/1233/421004/Safety-Control-of-Whole-Berries-by-Cold.

103 M. Baier, J. Ehlbeck, D. Knorr, W. B. Herppich and O. Schlüter, Impact of plasma processed air (PPA) on quality parameters of fresh produce, *Postharvest Biol. Technol.*, 2015, **100**, 120–126. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0925521414002609.

104 C. Sarangapani, G. O'Toole, P. J. Cullen and P. Bourke, Atmospheric cold plasma dissipation efficiency of agrochemicals on blueberries, *Innovative Food Sci. Emerging Technol.*, 2017, **44**, 235–241. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856416305586.

105 M. Ali, J.-H. Cheng and D.-W. Sun, Effect of plasma activated water and buffer solution on fungicide degradation from tomato (Solanum lycopersicum) fruit, *Food Chem.*, 2021, **350**, 129195. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814621001990.

106 A. Soni, J. Choi and G. Brightwell, Plasma-Activated Water (PAW) as a Disinfection Technology for Bacterial Inactivation with a Focus on Fruit and Vegetables, *Foods*, 2021, **10**(1), 166. Available from: https://www.mdpi.com/2304-8158/10/1/166.

107 C. Hertwig, A. Leslie, N. Meneses, K. Reineke, C. Rauh and O. Schlüter, Inactivation of Salmonella Enteritidis PT30 on the surface of unpeeled almonds by cold plasma, *Innovative Food Sci. Emerging Technol.*, 2017, **44**, 242–248. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856416306737.

108 B. G. Dasan, I. H. Boyaci and M. Mutlu, Nonthermal plasma treatment of Aspergillus spp. spores on hazelnuts in an atmospheric pressure fluidized bed plasma system: Impact of process parameters and surveillance of the residual viability of spores, *J. Food Eng.*, 2017, **196**, 139–149. Available from: https://linkinghub.elsevier.com/retrieve/pii/S026087741630351X.

109 M. Amini and M. Ghoranneviss, Effects of cold plasma treatment on antioxidants activity, phenolic contents and shelf life of fresh and dried walnut (Juglans regia L.) cultivars during storage, *LWT–Food Sci. Technol.*, 2016, **73**, 178–184. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643816303462.

110 B. G. Dasan, M. Mutlu and I. H. Boyaci, Decontamination of Aspergillus flavus and Aspergillus parasiticus spores on hazelnuts via atmospheric pressure fluidized bed plasma reactor, *Int. J. Food Microbiol.*, 2016, **216**, 250–259. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0168160515301197.

111 B. A. Niemira, Cold Plasma Reduction of Salmonella and Escherichia coli O157:H7 on Almonds Using Ambient Pressure Gases, *J. Food Sci.*, 2012, **77**(3), M171–M175.

Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1750-3841.2011.02594.x.

112 S. Deng, R. Ruan, C. K. Mok, G. Huang, X. Lin and P. Chen, Inactivation of Escherichia coli on Almonds Using Nonthermal Plasma, *J. Food Sci.*, 2007, **72**(2), M62–M66. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1750-3841.2007.00275.x.

113 P. Basaran, N. Basaran-Akgul and L. Oksuz, Elimination of Aspergillus parasiticus from nut surface with low pressure cold plasma (LPCP) treatment, *Food Microbiol.*, 2008, **25**(4), 626–632. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0740002008000063.

114 G. G. Gebremical, S. A. Emire and T. Berhanu, Effects of Multihollow Surface Dielectric Barrier Discharge Plasma on Chemical and Antioxidant Properties of Peanut, *J. Food Qual.*, 2019, **2019**, 1–10. Available from: https://www.hindawi.com/journals/jfq/2019/3702649/.

115 H. Venkataratnam, C. Sarangapani, O. Cahill and C. B. Ryan, Effect of cold plasma treatment on the antigenicity of peanut allergen Ara h 1, *Innovative Food Sci. Emerging Technol.*, 2019, **52**, 368–375. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856418312128.

116 I. Siciliano, D. Spadaro, A. Prelle, D. Vallauri, M. Cavallero, A. Garibaldi, *et al.*, Use of Cold Atmospheric Plasma to Detoxify Hazelnuts from Aflatoxins, *Toxins*, 2016, **8**(5), 125. Available from: https://www.mdpi.com/2072-6651/8/5/125.

117 S. Mošovská, V. Medvecká, N. Halászová, P. Ďurina, Ľ. Valík, A. Mikulajová, *et al.*, Cold atmospheric pressure ambient air plasma inhibition of pathogenic bacteria on the surface of black pepper, *Food Res. Int.*, 2018, **106**, 862–869. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996918300747.

118 M. Amini, M. Ghoranneviss and S. Abdijadid, Effect of cold plasma on crocin esters and volatile compounds of saffron, *Food Chem.*, 2017, **235**, 290–293. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814617308580.

119 J. E. Kim, H.-S. Choi, D.-U. Lee and S. C. Min, Effects of processing parameters on the inactivation of Bacillus cereus spores on red pepper (Capsicum annum L.) flakes by microwave-combined cold plasma treatment, *Int. J. Food Microbiol.*, 2017, **263**, 61–66. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0168160517304026.

120 J. E. Kim, Y. J. Oh, M. Y. Won, K.-S. Lee and S. C. Min, Microbial decontamination of onion powder using microwave-powered cold plasma treatments, *Food Microbiol.*, 2017, **62**, 112–123. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0740002015301908.

121 M. Y. Won, H. Y. Choi, K. S. Lee and S. C. Min, Helium dielectric barrier discharge-cold plasma treatment for microbiological safety and preservation of onion powder, *Korean J. Food Sci. Technol.*, 2016, **48**(5), 486–491. Available from: https://koreascience.or.kr/journal/view.jsp?kj=SPGHB5&py=2016&vnc=v48n5&sp=486.

122 Y. Takemura, S. Umeji, K. Ito, S. Furuya and M. Furuta, Inactivation Treatment of Bacterial Spores Contaminated Spices by Atmospheric Plasma Jet, *Plasma Medical*, 2014, **4**(1–4), 89–100. Available from: https://www.dl.begellhouse.com/journals/5a5b4a3d419387fb,700f28e67d84b510,6ebdef2642136c8d.html.

123 S. Sun, N. M. Anderson and S. Keller, Atmospheric Pressure Plasma Treatment of Black Peppercorns Inoculated with Salmonella and Held Under Controlled Storage, *J. Food Sci.*, 2014, **79**(12), E2441–E2446. Available from: https://onlinelibrary.wiley.com/doi/10.1111/1750-3841.12696.

124 M. Grabowski, A. Strzelczak and W. Dąbrowski, Low Pressure Cold Plasma as an Alternative Method for Black Pepper Sterilization, *J. Life Sci.*, 2014, **8**, 931–939. Available from: https://www.academia.edu/download/46561076/Journal_of_Life_Sciences_2014.12.pdf#page=11.

125 J. E. Kim, D.-U. Lee and S. C. Min, Microbial decontamination of red pepper powder by cold plasma, *Food Microbiol.*, 2014, **38**, 128–136. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0740002013001810.

126 L. G. Carpen, C. Chireceanu, M. Teodorescu, A. Chiriloaie, A. Teodoru and G. Dinescu, The effect of argon/oxygen and argon/nitrogen atmospheric plasma jet on stored products pests, *Rom. J. Phys.*, 2019, **64**(503), 1–11. Available from: https://rjp.nipne.ro/2019_64_3-4/RomJPhys.64.503.pdf.

127 A. Los, D. Ziuzina, S. Akkermans, D. Boehm, P. J. Cullen, J. Van Impe, *et al.*, Improving microbiological safety and quality characteristics of wheat and barley by high voltage atmospheric cold plasma closed processing, *Food Res. Int.*, 2018, **106**, 509–521. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996918300097.

128 J. Durek, O. Schlüter, A. Roscher, P. Durek and A. Fröhling, Inhibition or Stimulation of Ochratoxin A Synthesis on Inoculated Barley Triggered by Diffuse Coplanar Surface Barrier Discharge Plasma, *Front Microbiol*, 2018, **9**, 1–9. Available from: https://www.frontiersin.org/article/10.3389/fmicb.2018.02782/full.

129 H. Tolouie, M. A. Mohammadifar, H. Ghomi and M. Hashemi, Cold atmospheric plasma manipulation of proteins in food systems, *Crit. Rev. Food Sci. Nutr.*, 2018, **58**(15), 2583–2597. Available from: https://www.tandfonline.com/doi/full/10.1080/10408398.2017.1335689.

130 D. Butscher, D. Zimmermann, M. Schuppler and P. Rudolf von Rohr, Plasma inactivation of bacterial endospores on wheat grains and polymeric model substrates in a dielectric barrier discharge, *Food Control*, 2016, **60**, 636–645. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713515301821.

131 L. Kordas, W. Pusz, T. Czapka and R. Kacprzyk, The effect of low-temperature plasma on fungus colonization of winter wheat grain and seed quality, *Pol. J. Environ. Stud.*, 2015, **24**(1), 433–438. Available from: https://www.pjoes.com/The-Effect-of-Low-Temperature-Plasma-r-non-Fungus-Colonization-of-Winter-Wheat-r,89435,0,2.html.

132 D. Butscher, T. Schlup, C. Roth, N. Müller-Fischer, C. Gantenbein-Demarchi and P. Rudolf von Rohr, Inactivation of microorganisms on granular materials: reduction of Bacillus amyloliquefaciens endospores on

wheat grains in a low pressure plasma circulating fluidized bed reactor, *J. Food Eng.*, 2015, **159**, 48–56. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0260877415001004.

133 M. Selcuk, L. Oksuz and P. Basaran, Decontamination of grains and legumes infected with Aspergillus spp. and Penicillum spp. by cold plasma treatment, *Bioresour. Technol.*, 2008, **99**(11), 5104–5109. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0960852407007894.

134 M. Radhakrishnan, K. R. Ramanan, R. Sargunam and R. Sarumathi, Effect of cold plasma on mortality of Tribolium castaneum on refined wheat flour, *Proc 10th Int Conf Control Atmos Fumigation Stored Prod (CAF 2016)*, 2016, pp. 7–11, available from: https://www.researchgate.net/publication/311370163.

135 R. Mahendran, K. Ratish Ramanan, R. Sargunam and R. Sarumathi, Effect of Cold Plasma on Mortality of Tribolium Castaneum on Maida Flour, *Agric. Eng.*, 2016, 37–44. Available from: https://arhiva.nara.ac.rs/handle/123456789/2038.

136 S. Bußler, B. A. Rumpold, A. Fröhling, E. Jander, H. M. Rawel and O. K. Schlüter, Cold atmospheric pressure plasma processing of insect flour from Tenebrio molitor: impact on microbial load and quality attributes in comparison to dry heat treatment, *Innovative Food Sci. Emerging Technol.*, 2016, **36**, 277–286. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856416301345.

137 S. Held, C. E. Tyl and G. A. Annor, Effect of Radio Frequency Cold Plasma Treatment on Intermediate Wheatgrass (Thinopyrum intermedium) Flour and Dough Properties in Comparison to Hard and Soft Wheat (Triticum aestivum L.), *J. Food Qual.*, 2019, 1–8. Available from: https://www.hindawi.com/journals/jfq/2019/1085172/.

138 R. Thirumdas, A. Trimukhe, R. R. Deshmukh and U. S. Annapure, Functional and rheological properties of cold plasma treated rice starch, *Carbohydr. Polym.*, 2017, **157**, 1723–1731. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0144861716313248.

139 N. Bahrami, D. Bayliss, G. Chope, S. Penson, T. Perehinec and I. D. Fisk, Cold plasma: a new technology to modify wheat flour functionality, *Food Chem.*, 2016, **202**, 247–253. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814616301224.

140 P. Pal, P. Kaur, N. Singh, A. Kaur, N. N. Misra, B. K. Tiwari, *et al.*, Effect of nonthermal plasma on physico-chemical, amino acid composition, pasting and protein characteristics of short and long grain rice flour, *Food Res. Int.*, 2016, **81**, 50–57. Available from: https://linkinghub.elsevier.com/retrieve/pii/S096399691530291X.

141 S. Bußler, V. Steins, J. Ehlbeck and O. Schlüter, Impact of thermal treatment versus cold atmospheric plasma processing on the techno-functional protein properties from Pisum sativum 'Salamanca, *J. Food Eng.*, 2015, **167**, 166–174. Available from: https://linkinghub.elsevier.com/retrieve/pii/S026087741500254X.

142 M. Menkovska, M. Mangova and K. Dimitrov, Effect of cold plasma on wheat flour and bread making quality, *Macedonian Journal of Animal Science*, 2014, **4**(1), 27–30. Available from: https://www.mjas.ukim.edu.mk/files/MJAS-04-1-_2014_-183-Mangova.pdf.

143 S. Tappi, L. Ragni, U. Tylewicz, S. Romani, I. Ramazzina and P. Rocculi, Browning response of fresh-cut apples of different cultivars to cold gas plasma treatment, *Innovative Food Sci. Emerging Technol.*, 2019, **53**, 56–62. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856417306045.

144 S. Tappi, A. Berardinelli, L. Ragni, M. Dalla Rosa, A. Guarnieri and P. Rocculi, Atmospheric gas plasma treatment of fresh-cut apples, *Innovative Food Sci. Emerging Technol.*, 2014, **21**, 114–122. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856413001501.

145 I. Ramazzina, S. Tappi, P. Rocculi, G. Sacchetti, A. Berardinelli, A. Marseglia, *et al.*, Effect of Cold Plasma Treatment on the Functional Properties of Fresh-Cut Apples, *J. Agric. Food Chem.*, 2016, **64**(42), 8010–80118. Available from: https://pubs.acs.org/doi/10.1021/acs.jafc.6b02730.

146 X. Liao, J. Li, A. I. Muhammad, Y. Suo, S. Chen, X. Ye, *et al.*, Application of a Dielectric Barrier Discharge Atmospheric Cold Plasma (Dbd-Acp) for Eshcerichia Coli Inactivation in Apple Juice, *J. Food Sci.*, 2018, **83**(2), 401–408. Available from: https://onlinelibrary.wiley.com/doi/10.1111/1750-3841.14045.

147 B. Surowsky, A. Fröhling, N. Gottschalk, O. Schlüter and D. Knorr, Impact of cold plasma on Citrobacter freundii in apple juice: Inactivation kinetics and mechanisms, *Int. J. Food Microbiol.*, 2014, **174**, 63–71. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0168160514000026.

148 B. G. Dasan and I. H. Boyaci, Effect of Cold Atmospheric Plasma on Inactivation of Escherichia coli and Physicochemical Properties of Apple, Orange, Tomato Juices, and Sour Cherry Nectar, *Food Bioprocess Technol.*, 2018, **11**(2), 334–343. Available from: https://link.springer.com/10.1007/s11947-017-2014-0.

149 S. K. Pankaj, Z. Wan, W. Colonna and K. M. Keener, Effect of high voltage atmospheric cold plasma on white grape juice quality, *J. Sci. Food Agric.*, 2017, **97**(12), 4016–4021. Available from: https://onlinelibrary.wiley.com/doi/10.1002/jsfa.8268.

150 T.-Y. Wu, N.-N. Sun and C.-F. Chau, Application of corona electrical discharge plasma on modifying the physicochemical properties of banana starch indigenous to Taiwan, *J. Food Drug Anal.*, 2018, **26**(1), 244–251. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1021949817300807.

151 N. Matan, M. Nisoa, N. Matan and T. Aewsiri, Effect of cold atmospheric plasma on antifungal activities of clove oil and eugenol against molds on areca palm (Areca catechu) leaf sheath, *Int. Biodeterior. Biodegrad.*, 2014, **86**, 196–201.

Available from: https://linkinghub.elsevier.com/retrieve/pii/S0964830513003417.

152 C. H. Pragna, T. K. Ranjitha Gracy, R. Mahendran and C. Anandharamakrishnan, Effects of Microwave and Cold Plasma Assisted Hydrodistillation on Lemon Peel Oil Extraction, *Int. J. Food Eng.*, 2019, **15**(10), 1–10. Available from: https://www.degruyter.com/document/doi/10.1515/ijfe-2019-0093/html.

153 M. Ebadi, S. Abbasi, A. Harouni and F. Sefidkon, Effect of cold plasma on essential oil content and composition of lemon verbena, *Food Sci. Nutr.*, 2019, **7**(4), 1166–1171. Available from: https://onlinelibrary.wiley.com/doi/10.1002/fsn3.876.

154 S. Kodama, B. Thawatchaipracha and H. Sekiguchi, Enhancement of Essential Oil Extraction for Steam Distillation by DBD Surface Treatment, *Plasma Processes Polym.*, 2014, **11**(2), 126–132. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.201300047.

155 V. Hemmati, F. Garavand, M. Goudarzi, Z. Sarlak, I. Cacciotti and B. K. Tiwari, Cold atmospheric-pressure plasma treatment of turmeric powder: microbial load, essential oil profile, bioactivity and microstructure analyses, *Int. J. Food Sci. Technol.*, 2021, **56**(5), 2224–2232. Available from: https://onlinelibrary.wiley.com/doi/10.1111/ijfs.14838.

156 N. B. Rathod, S. P. Kahar, R. C. Ranveer and U. S. Annapure, Cold plasma an emerging nonthermal technology for milk and milk products: a review, *Int. J. Dairy Technol.*, 2021, **74**(4), 615–626. Available from: https://onlinelibrary.wiley.com/doi/10.1111/1471-0307.12771.

157 D. Manoharan, J. Stephen and M. Radhakrishnan, Study on low-pressure plasma system for continuous decontamination of milk and its quality evaluation, *J. Food Process. Preserv.*, 2021, **45**(2), e15138. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15138.

158 S. B. Ponraj, J. Sharp, J. R. Kanwar, A. J. Sinclair, L. Kviz, K. R. Nicholas, *et al.*, Sterilization of cow's milk using liquid plasma, *22nd Int. Symp. Plasma Chem*, 2015, pp. 5–7. available from: https://www.ispc-conference.org/ispcproc/ispc22/P-III-10-25.pdf.

159 X. Wu, Y. Luo, F. Zhao, M. Safian Murad and G. Mu, Influence of dielectric barrier discharge cold plasma on physicochemical property of milk for sterilization, *Plasma Processes Polym.*, 2021, **18**(1), 1900219. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.201900219.

160 D. Manoharan, J. Stephen and M. Radhakrishnan, Study on the effect of atmospheric and low-pressure plasma and its combination on the microbial reduction and quality of milk, *J. Food Saf.*, 2022, e13018; Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfs.13018.

161 N. B. Rathod, R. C. Ranveer, P. K. Bhagwat, F. Ozogul, S. Benjakul, S. Pillai, *et al.*, Cold plasma for the preservation of aquatic food products: an overview, *Compr. Rev. Food Sci. Food Saf.*, 2021, **20**(5), 4407–4425. Available from: https://onlinelibrary.wiley.com/doi/10.1111/1541-4337.12815.

162 S. Wei, R. Chelliah, D. Oh and S. Liu, Applications of Cold Plasma, ed. Ding T., Cullen P. J. and Yan W., in *Applications of Cold Plasma in Food Safety*, Singapore, Springer Singapore, 2022, available from: https://link.springer.com/10.1007/978-981-16-1827-7.

163 C. dos Santos Rocha, M. Magnani, G. L. de Paiva Anciens Ramos, F. F. Bezerril, M. Q. Freitas, A. G. Cruz, *et al.*, Emerging technologies in food processing: impacts on sensory characteristics and consumer perception, *Curr. Opin. Food Sci.*, 2022, **47**, 100892. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2214799322000947.

164 R. Anbarasan, D. Gomez Carmona and R. Mahendran, Human Taste-Perception: Brain Computer Interface (BCI) and Its Application as an Engineering Tool for Taste-Driven Sensory Studies, *Food Eng. Rev.*, 2022, 408–434. Available from: https://link.springer.com/10.1007/s12393-022-09308-0.

165 N. M. Coutinho, M. R. Silveira, J. T. Guimarães, L. M. Fernandes, T. C. Pimentel, M. C. Silva, *et al.*, Are consumers willing to pay for a product processed by emerging technologies? The case of chocolate milk drink processed by cold plasma, *LWT–Food Sci. Technol.*, 2021, **138**, 110772. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643820317618.

166 J. Ferrell, T.-C. Tsai, S. Kalghatgi, J. S. Louis and R. L. Gray, Plasma Activated Water for an enhanced soil-free horticulture, WO2017/049263Al, 2017, https://patents.google.com/patent/WO2017049263A1/en.

167 S. W. Noh, J. S. Park, S. J. Kim, D.-W. Kim and W. S. Kang, Effect of Plasma-activated Water Process on the Growth and Functional Substance Content of Lettuce during the Cultivation Period in a Deep Flow Technique System, *Protected horticulture and Plant Factory*, 2020, **29**(4), 464–472. Available from: https://www.ksbec.org/articles/doi/10.12791/KSBEC.2020.29.4.464.

168 V. Stoleru, R. Burlica, G. Mihalache, D. Dirlau, S. Padureanu, G.-C. Teliban, *et al.*, Plant growth promotion effect of plasma activated water on Lactuca sativa L. cultivated in two different volumes of substrate, *Sci. Rep.*, 2020, **10**(1), 20920. Available from: https://www.nature.com/articles/s41598-020-77355-w.

169 P. Lamichhane, M. Veerana, J. S. Lim, S. Mumtaz, B. Shrestha, N. K. Kaushik, *et al.*, Low-Temperature Plasma-Assisted Nitrogen Fixation for Corn Plant Growth and Development, *Int. J. Mol. Sci.*, 2021, **22**(10), 5360. Available from: https://www.mdpi.com/1422-0067/22/10/5360.

170 T.-C. Wang, S.-Y. Hsu, Y.-T. Lai and J.-G. Duh, Improving the Growth Rate of Lettuce Sativa Young Plants via Plasma-Activated Water Generated by Multitubular Dielectric Barrier Discharge Cold Plasma System, *IEEE Trans. Plasma Sci.*, 2022, **50**(7), 2104–2109. Available from: https://ieeexplore.ieee.org/document/9797287/.

171 D. Pańka, M. Jeske, A. Łukanowski, A. Baturo-Cieśniewska, P. Prus, M. Maitah, *et al.*, Can Cold Plasma Be Used for Boosting Plant Growth and Plant Protection in Sustainable Plant Production?, *Agronomy*, 2022, **12**(4),

841. Available from: https://www.mdpi.com/2073-4395/12/4/841.

172 K. Matra, Y. Tanakaran, V. Luang-In and S. Theepharaksapan, Enhancement of Lettuce Growth by PAW Spray Gliding Arc Plasma Generator, *IEEE Trans. Plasma Sci.*, 2022, **50**(6), 1430–1439. Available from: https://ieeexplore.ieee.org/document/9524451/.

173 P. S. G. Subramanian, J. Ananthanarasimhan, P. Leelesh, H. Rao, A. M. Shivapuji, P.-L. Girard-Lauriault, *et al.*, Plasma-activated water from DBD as a source of nitrogen for agriculture: specific energy and stability studies, *J. Appl. Phys.*, 2021, **129**(9), 093303. Available from: https://aip.scitation.org/doi/10.1063/5.0039253.

174 K. Ratish Ramanan and R. Mahendran, Morphogenesis and characterization of wheat xerogel structure and insights into its 4D transformation, *Food Struct.*, 2021, **28**, 100170. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2213329120300344.

175 B. Boopathy, A. Rajan, J. Stephen and M. Radhakrishnan, Development and characterisation of structurally reforming engineered flat-rice xerogel for hot water cooking, *Int. J. Food Sci. Technol.*, 2022; Available from:https://onlinelibrary.wiley.com/doi/10.1111/ijfs.16128.

176 B. Boopathy, J. Stephen, A. Rajan and M. Radhakrishnan, Evaluation of temperature and concentration on the development of rice hydrogel and 2D xerogel, *J. Food Process. Preserv.*, 2021, **45**(10), e15853. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15853.

177 J. Stephen, D. Manoharan, B. Boopathy, A. Rajan and M. Radhakrishnan, Investigation of hydrogel temperature and concentration on tapioca xerogel formation, *J. Food Process Eng.*, 2021, **44**(11), e13833. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpe.13833.

178 F. Momeni and J. Ni, Laws of 4D Printing, *Engineering*, 2020, **6**(9), 1035–1055. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2095809920302101.

179 S. Jaspin, R. Anbarasan, M. Dharini and R. Mahendran, Structural analysis of tapioca xerogel and its water and oil triggered shape change, *Food Struct.*, 2021, **30**, 100226. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2213329121000502.

180 S. Jaspin, R. Anbarasan, M. Dharini and R. Mahendran, Morphological analysis of corn xerogel and its shape shifting in water, *J. Food Eng.*, 2022, **330**, 111107. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0260877422001613.

181 V. Gupta, T. K. Ranjitha Gracy, J. Stephen and M. Radhakrishnan, Cold plasma-assisted shape-shifting of a flat two-dimensional wheat xerogel and its morphological behavior, *J. Food Process Eng.*, 2020, **43**(9), e13456. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpe.13456.

182 J. Stephen, D. Manoharan and M. Radhakrishnan, Corn morphlour hydrogel to xerogel formation and its oleomorphic shape-shifting, *J. Food Eng.*, 2021, **292**, 110360. Available from: https://doi.org/10.1016/j.jfoodeng.2020.110360.

183 S. Cheeyattil, A. Rajan, J. Stephen and M. Radhakrishnan, Study on the optimization of barley flour xerogel and its programed oleomorphic 3D shape-shifting, *J. Food Process Eng.*, 2022, e14197; https://onlinelibrary.wiley.com/doi/10.1111/jfpe.14197.

184 K. Ulucan-Altuntas, M. Saleem, G. Tomei, E. Marotta and C. Paradisi, Atmospheric plasma-based approaches for the degradation of dimethyl phthalate (DMP) in water, *J. Environ. Manage.*, 2022, **301**, 113885. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479721019472.

185 C. Sarangapani, N. N. Misra, V. Milosavljevic, P. Bourke, F. O'Regan and P. J. Cullen, Pesticide degradation in water using atmospheric air cold plasma, *J. Water Process. Eng.*, 2016, **9**, 225–232. Available from: https://linkinghub.elsevier.com/retrieve/pii/S221471441630006X.

186 M. Magureanu, D. Piroi, F. Gherendi, N. B. Mandache and V. Parvulescu, Decomposition of Methylene Blue in Water by Corona Discharges, *Plasma Chem. Plasma Process.*, 2008, **28**(6), 677–688. Available from: https://link.springer.com/10.1007/s11090-008-9155-x.

187 N. Jiang, Y. Qu, Z. Yu, B. Peng, J. Li, K. Shang, *et al.*, p-Nitrophenol contaminated soil remediation in a spray-type coaxial cylindrical dielectric barrier discharge plasma system, *Environ. Sci. Pollut. Res.*, 2022, **29**(38), 58110–58120. Available from: https://link.springer.com/10.1007/s11356-022-19912-6.

188 M. Redolfi, C. Makhloufi, S. Ognier and S. Cavadias, Short communication: oxidation of kerosene components in a soil matrix by a dielectric barrier discharge reactor, *Process Saf. Environ. Prot.*, 2010, **88**(3), 207–212. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0957582010000091.

189 H. Hashizume, H. Kitano, H. Mizuno, A. Abe, G. Yuasa, S. Tohno, *et al.*, Improvement of yield and grain quality by periodic cold plasma treatment with rice plants in a paddy field, *Plasma Processes Polym.*, 2021, **18**(1), 2000181. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ppap.202000181.

190 Ľ. Holubová, R. Švubová, Ľ. Slováková, B. Bokor, V. Chobotová Kročková, J. Renčko, *et al.*, Cold Atmospheric Pressure Plasma Treatment of Maize Grains—Induction of Growth, Enzyme Activities and Heat Shock Proteins, *Int. J. Mol. Sci.*, 2021, **22**(16), 8509. Available from: https://www.mdpi.com/1422-0067/22/16/8509.

191 J. Mravlje, M. Regvar, P. Starič, M. Mozetič and K. Vogel-Mikuš, Cold Plasma Affects Germination and Fungal Community Structure of Buckwheat Seeds, *Plants*, 2021, **10**(5), 851. Available from: https://www.mdpi.com/2223-7747/10/5/851.

192 R. P. Guragain, H. B. Baniya, S. P. Pradhan, S. Dhungana, G. K. Chhetri, B. Sedhai, *et al.*, Impact of non-thermal plasma treatment on the seed germination and seedling development of carrot (Daucus carota sativus L.), *J. Phys.*

Commun., 2021, **5**(12), 125011. Available from: https://iopscience.iop.org/article/10.1088/2399-6528/ac4081.

193 A. Sudarsan and K. Keener, Inactivation of spoilage organisms on baby spinach leaves using high voltage atmospheric cold plasma (HVACP) and assessment of quality, *Innovative Food Sci. Emerging Technol.*, 2022, **79**, 103023. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856422001084.

194 N. Dawood, Surface modification of date palm leaves by cold plasma treatment, *J. King Saud Univ., Sci.*, 2021, **33**(5), 101465. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1018364721001269.

195 M. Keshavarzi, G. Najafi, H. Ahmadi Gavlighi, P. Seyfi and H. Ghomi, Enhancement of polyphenolic content extraction rate with maximal antioxidant activity from green tea leaves by cold plasma, *J. Food Sci.*, 2020, **85**(10), 3415–3422. Available from: https://onlinelibrary.wiley.com/doi/10.1111/1750-3841.15448.

196 M. Ahmadnia, M. Sadeghi, R. Abbaszadeh and H. R. Ghomi Marzdashti, Decontamination of whole strawberry via dielectric barrier discharge cold plasma and effects on quality attributes, *J. Food Process. Preserv.*, 2021, **45**(1), e15019. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15019.

197 Y. Wang, Z. Ye, J. Li, Y. Zhang, Y. Guo and J.-H. Cheng, Effects of dielectric barrier discharge cold plasma on the activity, structure and conformation of horseradish peroxidase (HRP) and on the activity of litchi peroxidase (POD), *LWT–Food Sci. Technol.*, 2021, **141**, 111078. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643821002310.

198 Y. Ji, W. Hu, J. Liao, A. Jiang, Z. Xiu, S. Gaowa, *et al.*, Effect of atmospheric cold plasma treatment on antioxidant activities and reactive oxygen species production in postharvest blueberries during storage, *J. Sci. Food Agric.*, 2020, **100**(15), 5586–5595. Available from: https://onlinelibrary.wiley.com/doi/10.1002/jsfa.10611.

199 T. Sandanuwan, D. Attygalle, S. Amarasinghe, S. C. Weragoda, B. Ranaweera, K. Rathnayake, *et al.*, Shelf Life Extension of Cavendish Banana Fruit Using Cold Plasma Treatment, in *2020 Moratuwa Engineering Research Conference (MERCon)*, IEEE, 2020, p. 182–186, available from: https://ieeexplore.ieee.org/document/9185237/.

200 C.-M. Lin, A. K. Patel, Y.-C. Chiu, C.-Y. Hou, C.-H. Kuo, C.-D. Dong, *et al.*, The application of novel rotary plasma jets to inhibit the aflatoxin-producing Aspergillus flavus and the spoilage fungus, Aspergillus niger on peanuts, *Innovative Food Sci. Emerging Technol.*, 2022, **78**, 102994. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856422000790.

201 M. Makari, M. Hojjati, S. Shahbazi and H. Askari, Elimination of Aspergillus flavus from Pistachio Nuts with Dielectric Barrier Discharge (DBD) Cold Plasma and Its Impacts on Biochemical Indices, *J. Food Qual.*, 2021, 1–12. Available from: https://www.hindawi.com/journals/jfq/2021/9968711/.

202 Z. Esmaeili, B. Hosseinzadeh Samani, A. Nemati, F. Nazari and S. Rostami, Development of novel green pesticide system by using cold plasma to control Plodia interpunctella in pistachio, *J. Food Process. Preserv.*, 2021, **45**(7), e15621. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15621.

203 M. Ahangari, Y. Ramezan and M. R. Khani, Effect of low pressure cold plasma treatment on microbial decontamination and physicochemical properties of dried walnut kernels (Juglans regia L.), *J. Food Process Eng.*, 2021, **44**(1), e13593. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpe.13593.

204 E. G. Alves Filho, L. M. A. Silva, F. Oiram Filho, S. Rodrigues, F. A. N. Fernandes, M. I. Gallão, *et al.*, Cold plasma processing effect on cashew nuts composition and allergenicity, *Food Res. Int.*, 2019, **125**, 108621. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996919304995.

205 K. Shirani, F. Shahidi and S. A. Mortazavi, Investigation of decontamination effect of argon cold plasma on physicochemical and sensory properties of almond slices, *Int. J. Food Microbiol.*, 2020, **335**, 108892. Available from: https://linkinghub.elsevier.com/retrieve/pii/S016816052030386X.

206 A. I. Muhammad, Y. Li, X. Liao, D. Liu, X. Ye, S. Chen, *et al.*, Effect of dielectric barrier discharge plasma on background microflora and physicochemical properties of tiger nut milk, *Food Control*, 2019, **96**, 119–127. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713518304638.

207 H. Darvish, Y. Ramezan, M. R. Khani and A. Kamkari, Effect of low-pressure cold plasma processing on decontamination and quality attributes of Saffron (Crocus sativus L.), *Food Sci. Nutr.*, 2022, **10**(6), 2082–2090. Available from: https://onlinelibrary.wiley.com/doi/10.1002/fsn3.2824.

208 G. De Silva, S. Amarasena, N. Amunugoda, S. Gunawardena and A. De Alwis, Effect of Low-Pressure Cold Plasma Treatment on Microbiological and Physicochemical Properties of Black Peppercorns, in *2021 From Innovation To Impact (FITI)*, IEEE, 2021, p. 1–6, available from: https://ieeexplore.ieee.org/document/9833050/.

209 X. Chen, Y. Qiu, J. Zhang, Y. Guo, Y. Ding and F. Lyu, Degradation efficiency and products of deoxynivalenol treated by cold plasma and its application in wheat, *Food Control*, 2022, **136**, 108874. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0956713522000676.

210 F. L. Pathan, R. R. Deshmukh and U. S. Annapure, Potential of cold plasma to control Callosobruchus chinensis (Chrysomelidae:Bruchinae) in chickpea cultivars during four year storage, *Sci. Rep.*, 2021, **11**(1), 13425. Available from: https://www.nature.com/articles/s41598-021-92792-x.

211 E. Feizollahi and M. S. Roopesh, Degradation of Zearalenone by Atmospheric Cold Plasma: Effect of Selected Process and Product Factors, *Food Bioprocess Technol.*, 2021, **14**(11), 2107–2119. Available from: https://link.springer.com/10.1007/s11947-021-02692-1.

212 E. Feizollahi, B. Iqdiam, T. Vasanthan, M. S. Thilakarathna and M. S. Roopesh, Effects of Atmospheric-Pressure Cold Plasma Treatment on Deoxynivalenol Degradation, Quality Parameters, and Germination of Barley Grains, *Appl. Sci.*, 2020, **10**(10), 3530. Available from: https://www.mdpi.com/2076-3417/10/10/3530.

213 S. A. Sutar, R. Thirumdas, B. B. Chaudhari, R. R. Deshmukh and U. S. Annapure, Effect of cold plasma on insect infestation and keeping quality of stored wheat flour, *J. Stored Prod. Res.*, 2021, **92**, 101774. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0022474X21000138.

214 L. Zare, N. Mollakhalili-Meybodi, H. Fallahzadeh and M. Arab, Effect of atmospheric pressure cold plasma (ACP) treatment on the technological characteristics of quinoa flour, *LWT–Food Sci. Technol.*, 2022, **155**, 112898. Available from: https://linkinghub.elsevier.com/retrieve/pii/S002364382102051X.

215 J. K Joy, R. G. T. Kalaivendan, G. Eazhumalai, S. P. Kahar and U. S. Annapure, Effect of pin-to-plate atmospheric cold plasma on jackfruit seed flour functionality modification, *Innovative Food Sci. Emerging Technol.*, 2022, **78**, 103009. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856422000947.

216 S. Jaddu, R. C. Pradhan and M. Dwivedi, Effect of multipin atmospheric cold plasma discharge on functional properties of little millet (Panicum miliare) flour, *Innovative Food Sci. Emerging Technol.*, 2022, **77**, 102957. Available from: https://linkinghub.elsevier.com/retrieve/pii/S146685642200042X.

217 D. Zhou, T. Li, K. Cong, A. Suo and C. Wu, Influence of cold plasma on quality attributes and aroma compounds in fresh-cut cantaloupe during low temperature storage, *LWT–Food Sci. Technol.*, 2022, **154**, 112893. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643821020466.

218 A. Khoshkalam Pour, S. Khorram, A. Ehsani, A. Ostadrahimi and Z. Ghasempour, Atmospheric cold plasma effect on quality attributes of banana slices: Its potential use in blanching process, *Innovative Food Sci. Emerging Technol.*, 2022, **76**, 102945. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466856422000303.

219 N. Kumar Mahnot, L.-P. Siyu, Z. Wan, K. M. Keener and N. N. Misra, In-package cold plasma decontamination of fresh-cut carrots: microbial and quality aspects, *J. Phys. D: Appl. Phys.*, 2020, **53**(15), 154002. Available from: https://iopscience.iop.org/article/10.1088/1361-6463/ab6cd3.

220 X. Li, M. Li, N. Ji, P. Jin, J. Zhang, Y. Zheng, *et al.*, Cold plasma treatment induces phenolic accumulation and enhances antioxidant activity in fresh-cut pitaya (Hylocereus undatus) fruit, *LWT–Food Sci. Technol.*, 2019, **115**, 108447. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0023643819307893.

221 C. Chen, C. Liu, A. Jiang, Q. Guan, X. Sun, S. Liu, *et al.*, The Effects of Cold Plasma-Activated Water Treatment on the Microbial Growth and Antioxidant Properties of Fresh-Cut Pears, *Food Bioprocess Technol.*, 2019, **12**(11), 1842–1851. Available from: https://link.springer.com/10.1007/s11947-019-02331-w.

222 T. R. B. Farias, S. Rodrigues and F. A. N. Fernandes, Comparative study of two cold plasma technologies on apple juice antioxidant capacity, phenolic contents, and enzymatic activity, *J. Food Process. Preserv.*, 2022, **46**(10), e16871. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpp.16871.

223 K. F. Leite, T. V. Fonteles, B. A. R. Miguel, G. Silvestre da Silva, E. Sousa de Brito, E. G. Alves Filho, *et al.*, Atmospheric cold plasma frequency imparts changes on cashew apple juice composition and improves vitamin C bioaccessibility, *Food Res. Int.*, 2021, **147**, 110479. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996921003781.

224 D. R. G. de Castro, J. M. Mar, L. S. da Silva, K. A. da Silva, E. A. Sanches, J. de Araújo Bezerra, *et al.*, Dielectric barrier atmospheric cold plasma applied on camu-camu juice processing: effect of the excitation frequency, *Food Res. Int.*, 2020, **131**, 109044. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963996920300697.

225 Z. Liu, W. Zhao, Q. Zhang, G. Gao and Y. Meng, Effect of cold plasma treatment on sterilizing rate and quality of kiwi turbid juice, *J. Food Process Eng.*, 2021, **44**(6), e13711. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpe.13711.

226 L. M. N. Paixão, T. V. Fonteles, V. S. Oliveira, F. A. N. Fernandes and S. Rodrigues, Cold Plasma Effects on Functional Compounds of Siriguela Juice, *Food Bioprocess Technol.*, 2019, **12**(1), 110–121. Available from: https://link.springer.com/10.1007/s11947-018-2197-z.

227 Y. Hou, R. Wang, Z. Gan, T. Shao, X. Zhang, M. He, *et al.*, Effect of cold plasma on blueberry juice quality, *Food Chem.*, 2019, **290**, 79–86. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308814619306065.

228 F. Jangi, M.-T. Ebadi and M. Ayyari, Qualitative changes in hyssop (Hyssopus officinalis L.) as affected by cold plasma, packaging method and storage duration, *J. Appl. Res. Med. Aromat. Plants*, 2021, **22**, 100289. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2214786120300504.

229 S. Rezaei, M.-T. Ebadi, B. Ghobadian and H. Ghomi, Optimization of DBD-Plasma assisted hydro-distillation for essential oil extraction of fennel (Foeniculum vulgare Mill.) seed and spearmint (Mentha spicata L.) leaf, *J. Appl. Res. Med. Aromat. Plants*, 2021, **24**, 100300. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2214786121000097.