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Emerging technologies in food processing and preservation

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Abstract
The main objective of this study is to provide an overview of cutting-edge technology that has the potential to transform the food processing and preservation industries. Natural antimicrobials are used by nanotechnology to improve food safety, and photodynamic inactivation sterilises in an environmentally friendly way. Food Quality 4.0 uses omics and AI to provide real-time analysis while sonication enhances nutrition and reduces pesticide use. Derivatives of chitosan are susceptible to contamination; sun dryers with garages enhance drying. Utilising UV light and a pulsed electric field, microbes are controlled without compromising quality. While high hydrostatic pressure prolongs shelf life, cold plasma ensures safe surfaces. To effectively capitalise on those advancements within the food industry, further research is required.

Keywords: Nanotechnology, photodynamic inactivation, food safety 4.0, sonication, solar dryers with heat garage, chitosan, ultraviolet radiation, pulsed electric powered field

Introduction
In the food and beverage business, advances in food processing and maintenance technologies continue to grow. Producers are experimenting with new products in an effort to satisfy consumer demands for variety and comfort. This study looks at several emerging technologies for food safety and processing. Several elements have combined to make this era very green in terms of advancements in food production. It goes without saying that the need to ensure food safety has always pushed innovation (Aganovic *et al*., 2021) [1]. But with the advent of the revolutionary period, customer opportunities are playing a bigger role than before.

Consumers choice greater consolation, which lengthy-lasting merchandise offer. There is likewise a growing market for fitness and well-being items, which necessitates the improvement of food processing era to assist the protection of substances and using probiotics (Balakrishna *et al*., 2020) [2]. Perhaps maximum crucially, both producers and clients want extra meals produced more efficaciously that lets in you to feed the arena's ever-developing population. When you combine all of this with the want for stepped forward meals protection and a broader distribution range, it's no marvel that the whole sector is excitedly adopting new food processing technology. Many producers have already applied some of the progressive improvements highlighted on this paper (Bora *et al*., 2022) [3].

Nanotechnology
Food security is a critical topic these days because of the growing globalisation of the food industry, the increase in consumer demand for better-quality food, the volatility of the market, and the constant changing of regulations. Food manufacturers add chemical preservatives and antibiotics to their goods in an effort to address this issue and keep microbes at bay. However, using these preservatives incorrectly or excessively leads to an increase in bacterial resistance. People are turning more and more to herbal antibacterial compounds as they become more aware of the multiple negative effects of chemical preservatives and the emergence of antibiotic resistance (Cardello *et al*., 2007) [4].

Plant-derived substances such as essential oils, isothiocyanates, and polyphenols are examples of antimicrobial marketers that are unquestionably effective. Many of these naturally occurring antibacterial chemical compounds could change due to changes in manufacturing processes or garage accidents in the interim (Ekka and Kumar, 2023) [6]. Antimicrobial pills have additionally been verified to interact negatively with nutritional elements.

Antibacterial nanoparticles are being studied as potential antibacterial treatment options. Nanostructures feature as bioactive material transporters, enhancing their balance and effectiveness against pathogenic germs. These shielding houses may be visible throughout meals manufacturing and garage. The rate at which nanostructured antimicrobials are released affects their efficacy (Fraceto *et al*., 2016) [7].

Food products, whether they are processed or not, are composed of plants and animals that need to be treated in order to keep their quality while being stored. Plant goods preserved in different ways include unprocessed plant goods (fruits, salads, vegetables, etc.), processed plant goods (fruit juices and various fruit-derived commodities), animal tissues, dairy products, and bread items (Haris *et al*., 2023) [8]. All other food renovation technologies are outperformed by using nanoparticles. Nanoparticles can be used as preservatives in food packaging, or they'll be integrated into the meal itself. There are studies inside the literature on the maintenance of culmination, salads, meat, fish, dairy, and bread (Hassoun *et al*., 2023) [9].

Nanoparticles are used in agriculture because of their awesome physiochemical traits. Soil satisfactory and plant boom may be determined by means of the interplay among nanomaterials and soil additives (Jadhav *et al*., 2023) [8]. This technology is used to improve the first-class and decrease put up-harvest losses of agricultural merchandise. Nanotechnology is also used as a nano fertiliser in agriculture for high productiveness and higher plant growth. It is a crucial source of balanced nutrients for the crop, seed germination, and first-class enrichment. It may be significantly useful to reduce down on food waste and infection (Liu *et al*., 2023) [12].

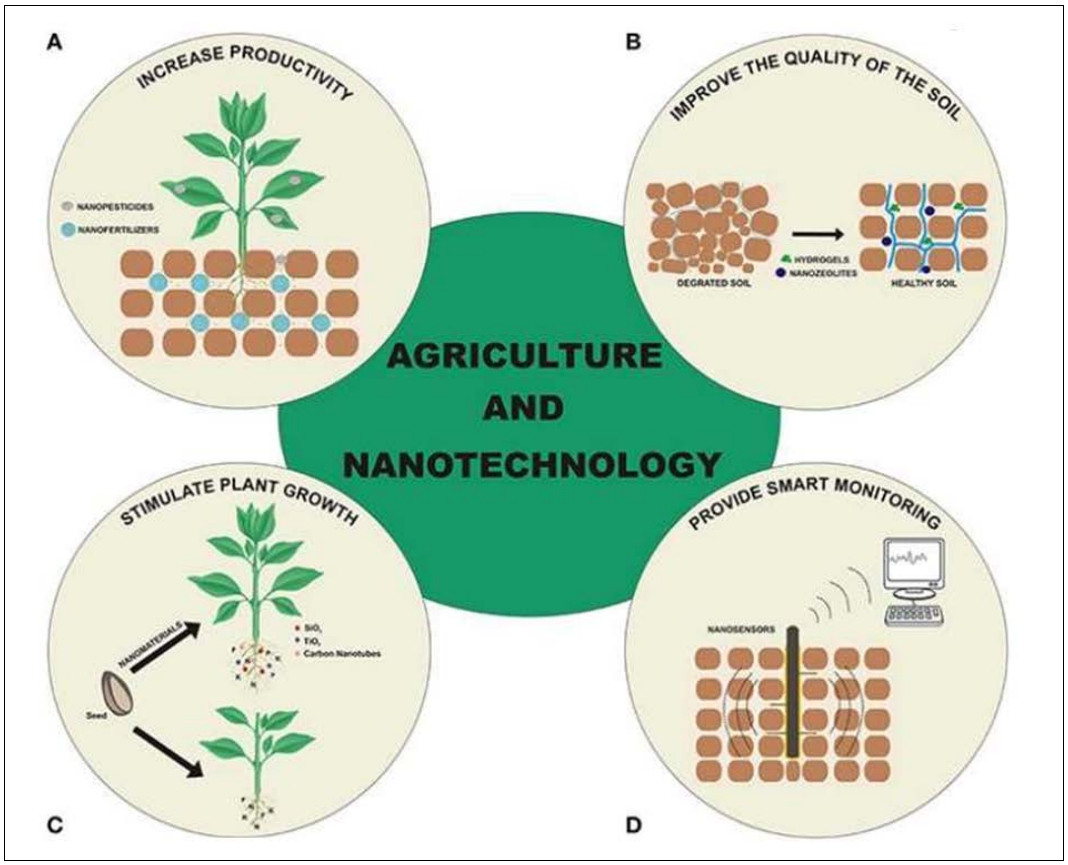

Fig 1: Potential applications of Nanotechnology in Agriculture

Photodynamic inactivation and it's software in food maintenance

Photodynamic inactivation is a brand-new progressive sterilization generation that has gained interest because of its gigantic sterilization effect, environmental friendliness, protection, and price-effectiveness (Manzoor *et al*., 2023) [13]. The PDI gadget is carried out to meals renovation, with the primary emphasis on herbal photosensitizers and their software to inactivate *in vitro* and *in vivo* microorganisms in meals matrixes which includes sparkling veggies, culmination, seafood, and rooster (Mohamed *et al*., 2022) [14].

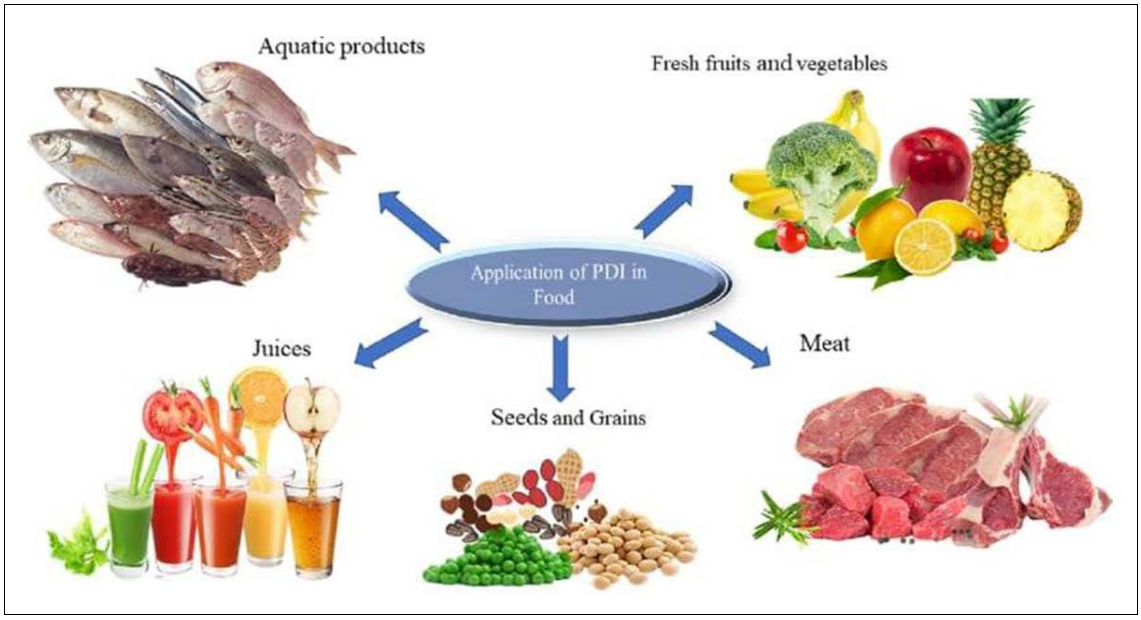

Fig 2: Potential applications of PDI in different food substrates

Food quality 4.0

Food Quality 4.0 is a new concept of Industry 4.0 technologies for food analysis to achieve rapid, dependable, and goal assessment of food exceptional. It is characterized through growing digitalization and automation of meals analysis the use of superior technology (Pal, 2017) [16].

Fig 3: Food quality 4.0: From traditional approaches to digitalized automated analysis

Food Quality 4.0 consisting of non-detrimental fingerprinting technologies, omics technology, and `bioinformatics equipment, AI and massive statistics have fantastic capability to revolutionize meals fine, but many of those technologies are underneath development (Shahbaz *et al*., 2023) [17].

Sonication

Sustainable rising sonication era is used for fungicide discount and tomato juice processing. Sonicated treatments have been carried out at forty kHz, 480 W, and 30±2 °C one of a kind time durations in an ultrasonic bath cleaner. Results indicated that the treatments extensively reduced the anilazine fungicide awareness. It stepped forward the colloidal stability of juice with the aid of decreasing particle size, apparent viscosity, and sedimentation index (Teixeira *et al*., 2021) [18]. In the destiny, sonication processing may be used industrially to beautify fruit juice's dietary residences and shelf life and decrease pesticides and other natural residues.

Solar dryers with heat storage systems

Open solar drying is particularly practiced for the drying of agricultural merchandise. It is reasonably-priced but has barriers. Solar power has emerged as a substitute for lots thermal programs. The use of sun dryers for drying packages removes the diverse problems associated with open solar drying and business drying. The downside of solar drying is its intermittent nature which can be conquer by means of integrating a thermal garage machine with the sun dyer. A very high temperature processing damages the product and is some other quandary of solar dryers at the same time as the very low temperature takes longer period ensuing in attack by microorganisms. The dryer is mixed

with a storage machine to acquire the desired temperature and power will be stored for the duration of the peak hours of solar radiation and retrieved at some point of the off-sunshine hours. The look at performed with the aid of Kumar *et al*. In 2022 targeted at the performance analysis of a dryer for the paddy drying procedure. They used latent thermal storage (PCM) to save the thermal strength in the drying chamber and observed uniform heating of the product. Another observe performed by Kumar *et al*. In 2020 & 2021 became on the overall performance analysis of natural convection dryers with realistic thermal storage. They focused at the evaluation of variant in non-dimensional numbers (Wang *et al*., 2023) [19].

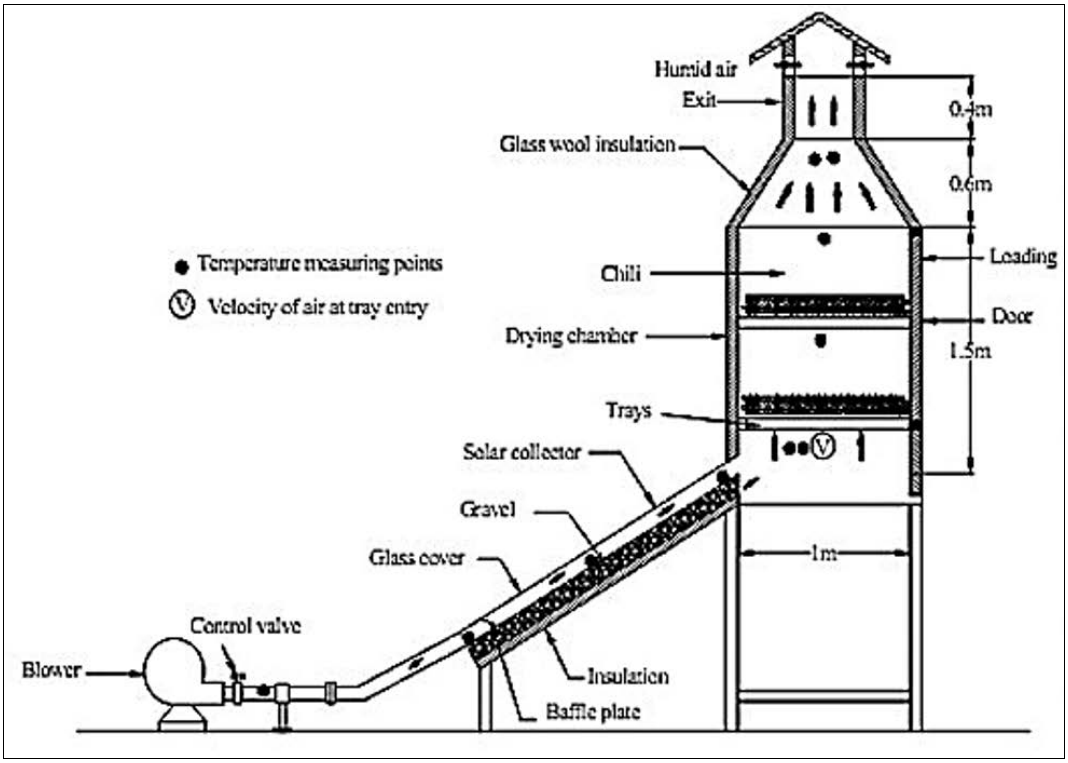

Fig 4: Thermal energy storage based solar drying systems

Thermal power storage medium beautifies the overall performance of the dryer by way of reducing the energy losses from the drying chamber. Behnaz *et al*. (2016) [21] designed practical warmness storage executed the thermodynamic evaluation and determined that the boom in input electricity flowrate and a decrease in outlet strength float charge increases the charging temperature of the electricity storage machine. Check out the effectiveness of an oblique sun dryer in drying monodical charantia they compare 3 instances and numerous experiments conducted to assess temperature drying kinetics and power analysis. Analyze the drying method of Ganoderma using a mixed-mode greenhouse solar dryer.

Thermal garage improves dryer overall performance but excellent drying of agricultural merchandise remains an undertaking.

Chitosan

Chitin is considered one of Earth's maximum considerable biopolymers and its deacetylation ends in chitosan. Chitosan is beneficial for the synthesis and improvement of bioactive cloth with its incompatible nature and practical properties, consisting of biodegradability, biocompatibility, nontoxicity, movie- forming, and gelling houses, encapsulation potential, chelating, antioxidant, anticoagulant, and antimicrobial characteristics. Its derivatives have sizable capability inside the meals industry because of meals product contamination. Chitosan has high antimicrobial pastime to pathogenic and spoilage microorganisms which have garnered severe interest in meals processing and packaging era (Zhu *et al*., 2021) [20].

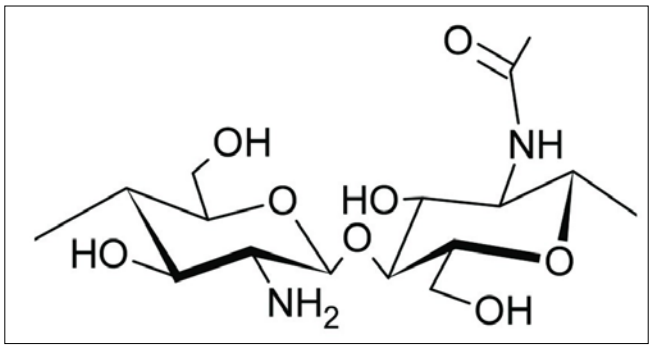

Fig 5: Chemical structure of chitosan

Ultraviolet-radiation Technology

UV treatment is famous for its effective sterilization and decontamination residences. The formation of pyrimidine dimers is the primary inactivation mechanism of UV treatment. The remedy has been utilized in water treatment for sterilization, and fruit or vegetable for a prolonged shelf-lifestyles. UV turned into accredited as a cold sterilization era to lower microorganisms in meals, however the use of UV mild for microbial inactivation of meat and meat products became incredibly restrained because of the consideration of its deteriorative effect on meat excellent. As little impact on the sensory excellent of meals products,

UV is used to deal with meat and meat products, blended with pulses and mild-emitting diode (LED) lamps, which result in higher sterilization (Delorme *et al*., 2020) [5].

Pulsed Electric Field Processing

The pulsed electric powered discipline is taken into consideration superior to conventional heat remedy as it significantly minimizes the negative adjustments inside the bodily and sensory residences of food. It is suitable for the decontamination of heat-touchy ingredients and has no environmental threat or toxicity. Two mechanisms are proposed for the mode of motion of pulsed electric powered discipline action at the microbial membrane of the organism, they're electroporation and electric powered breakdown. A pulsed electric powered area suggests deadly effects on vegetative bacteria, molds, and yeasts. This era is effective in inactivating Bacillus subtilis in pea soup, Listeria innocua and L. Monocytogenese in milk, Staphylococcus aureus in skim milk, Escherichia coli in liquid egg, Lactobacillus brevis in yogurt and Saccharomyces cerevisiae in apple juice. The inactivation of enzymes calls for more potent electric conditions than microbial inactivation. This era also influences the extension of shelf existence, retention of nutrients, development in nice and flavor, and excessive degree of meals safety (Jeyamkondan *et al*., 1999) [11].

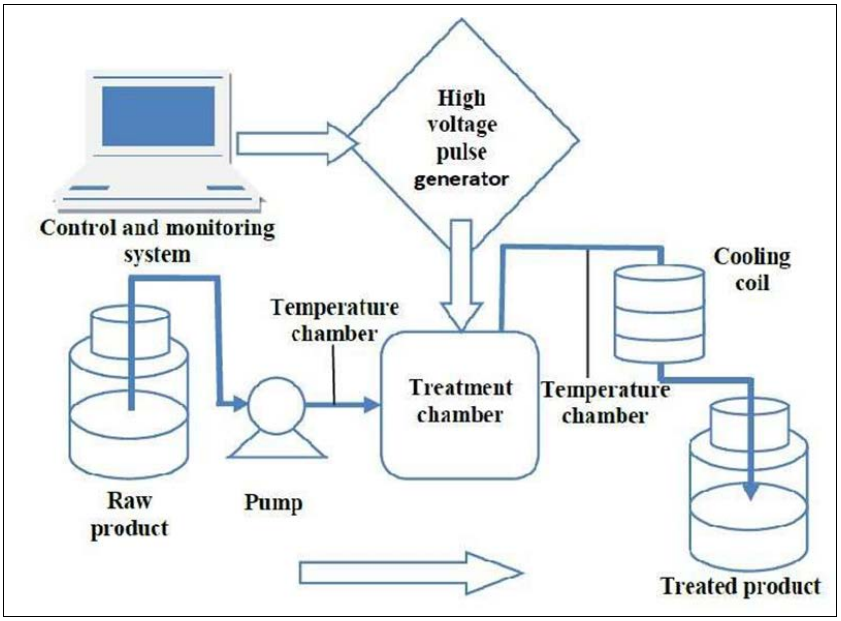

Fig 6: Flow chart of a PEF food processing system with basic component

The software of pulsed electric subject is gaining reputation as a non-thermal generation to keep the original high-quality of meals as regards texture, coloration, taste, appearance except nutritive values.

It is likewise used to pasteurize a variety of liquid and semisolid ingredients. This technology can be coupled with other processing methods, used as a non-stop technique, and could be very appropriate for warmth-sensitive foods. It is a singular, non-thermal method of meals renovation and is associated with the electromechanical instability of mobile membranes.

High hydrostatic pressure

High pressure or High hydrostatic pressure or High pressure processing, is a technology that immerses a product beneath water and exposes it to a hydrostatic stress of several hundred megapascal in an HP vessel. The product is packed in a high-strain suitable packaging and decompression before being held below strain for a positive time. HPP has the potential for food maintenance and shelf-like extension even as retaining sure high-quality attributes of dealt with food. It can also mixed with high temperatures for the inactivation of spores.

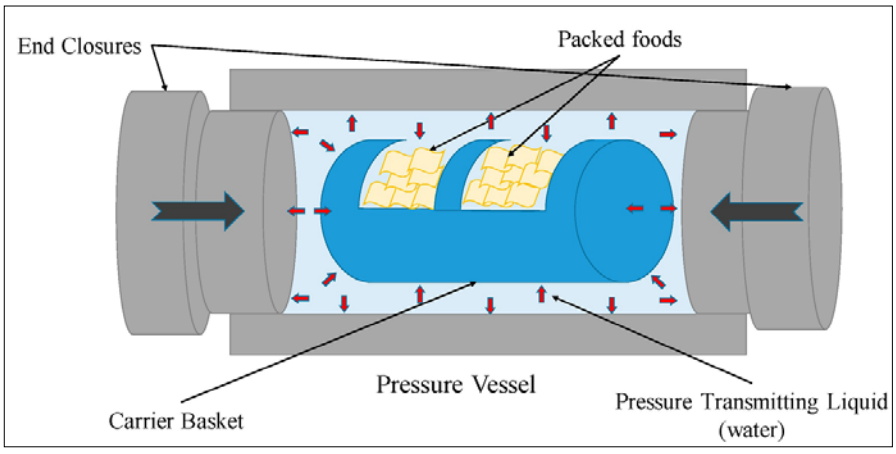

Fig 7: Schematic representation of a high pressure processing (HPP) vessel

Today HPP is used to treat meat products, fruits and vegetables products aquatic products, and liquids and is suitable for most foods which have enough water content material and no air voids. HPP is and steeply- priced technology and is used for super meals to preserve their clean and dietary individual. HP is used with the desires of inactivating microorganisms, shelf life extension, and physical and chemical change of the food matrix.

Although it's far recognized as a era with the ability to provide secure foods with excessive satisfactory, there's nevertheless sure dilemma related to the utility of generation depending at the processing parameter that includes survival of pathogenic microorganisms and first-class-related microorganisms (spoilage organisms), Undesired (bio-) chemical reactions and outcomes on growing allergenicity.

Cold Plasma

Plasma technology is a non-thermal method used for meals processing. This technology gives fundamental blessings to heat-sensitive products by using having minimum deteriorative consequences on first-class. Retaining dietary properties, purposeful cost, and sensory houses as a result ensuring a fresh look or traits are the foremost applications of this method and are used for structural changes of meals and even packaging substances.

The cold Plasma technique is one of the simplest methods of disinfection in comparison to cleaning with water or chemical compounds. It can also be applied for floor sterilization of packaging cloth putting off microbes and their spores. It is a fuel that could without problems deal with irregularly formed applications and bottles and now not simplest does it control the microbial infection of meals or food merchandise however additionally able to improve or preserve the satisfactory of raw/processed foods.

It is used to deal with cereals, dairy merchandise, meat, and meat merchandise, eggs and rooster products, nuts and seeds, greens and fruits, spices and herbs, and fish and fishery products. While it holds promise for various applications, similarly research is needed to refine remedy conditions, check long-term outcomes, and make certain that handled meals meet safety and great standards. The impact of bloodless plasma on allergens and anti-dietary elements remains much less acknowledged and is an area of extremely good hobby for similarly exploration (Niemira, 2012) [15].

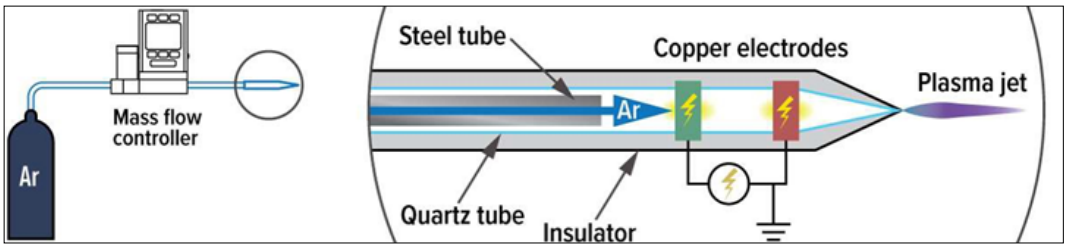

Fig 8: Regulating cold plasma flow and pressure

Conclusion

The developing attitude of meals processing and preservation technology gives a promising direction closer to greater food security, shelf life extension, and first-rate. The zone is being reshaped with the aid of nanotechnology, photodynamic inactivation, and novel methods like as Food Quality 4.0. Sonication, sun drying, and cold plasma are all strategies that make contributions to sustainability and protection. These breakthroughs have great ability to revolutionize food production and address extreme issues in the supply chain that provide food global.

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