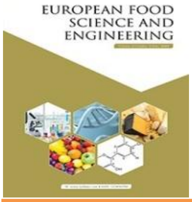

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Innovative approaches in the food industry: Microwave plasma technology and applicability in foods

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ABSTRACT

In this study, the advantages of microwave plasma technology with the microwave technique, which is increasingly used in the food sector, and the production of microwave plasma assembly in laboratory size are discussed. Plasma is an ionized gas known as the 4th state of matter. When a high electric field is applied to a low-pressure environment, the gas in the environment turns into plasma form. Inert gases are used in plasma formation, and low-level microwave energy is also utilized. Low-pressure plasma technology has emerged as a promising and innovative method for microbial inactivation on dry food surfaces. Therefore, microwave plasma system has a significant potential for use in many food systems such as spices, dried fruits, and vegetables. In this context, the microwave plasma setup was established by us in this study. In addition, it has been determined that the application time is very important for microwave plasma application in foods and that there is structural deterioration in foods within a certain period of time. As a result, it was understood that food poisoning can be prevented by using microwave plasma in foods and this will contribute to the extension of the shelf life of foods.

1. Introduction

Flat Microwave technology was discovered around the mid-20th century. The areas of application for this technology are widespread, primarily in the food sector but also in various other fields. Particularly, it is utilized in food processes such as thawing, boiling, and sterilization, as well as in the drying of industrial products like paper and wood, acceleration of chemical reactions, melting of industrial materials such as glass, rubber, and slurry, and in plasma generation has been proven in the literature (Konak et al., 2009). The food industry stands as one of the primary sectors where microwave technology finds extensive usage. This technology is employed in cooking, pasteurization, sterilization, baking, and heating processes (Oliveira & Franca, 2002). Plasma systems represent an alternative novel technology preferred for various purposes within the food industry. For instance, in the food industry, plasma systems are utilized for sterilizing packaging, thereby increasing the shelf life of food products and contributing to the production of safer foods (Laroussi, 2005).

Plasma; positive and negative, which are completely neutral and move in any direction. The negatively charged units are bulk material. Plasma content charged parts are independent of each other, when they move, the entire system is as if uncharged. Therefore, the quantity in the plasma is the movement collectively, not individually (Akan, 2006). This system is considered environmentally friendly since no pretreatment and chemicals are required, reducing problems such as the formation of chemical waste (Güleç, 2012).

Plasma systems are divided into high-temperature and low-temperature plasmas based on their temperature. Low-temperature plasmas are further divided into hot and cold plasmas (Albayrak & Kılıç, 2020). A hot plasma has a gas temperature of more than 1000 K and is typically between 104 and 105 K. It occurs in phenomena such as lightning, electric arcs and other high-energy environments. Cold plasma, on the other hand, has a gas temperature below 1000 K, usually between 300 and 400 K (Yangılar & Oğuzhan, 2013).

Microwave plasma technology is also a new technology that has been increasingly used in the food industry in recent years. In the last two decades, research on the applicability of microwave plasma in the field of food technology has gained intensity and interest (Baier et al., 2012). It is expected that the recognition of this technology, the increase in installation possibilities and its widespread use will have a positive impact

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on the food sector. In particular, it contributes positively to aspects such as the sterilization of products, the extension of shelf life and the prevention of yeast and mold formation (Kasar, 2022).

This study provides detailed information about the microwave plasma system, the materials used in the system, its structure, the basic principles, the areas of application in the food industry and its effects on human health. Based on the results of the literature review, the use and applicability of this novel technology in the food industry are summarized.

2. Microwave Plasma Setup

Microwaves are converted into electromagnetic radiation in magnetrons and klystrons in electron tubes. High-frequency waves can be generated between two electrodes using alternating currents. The energy generated by microwave generation systems is absorbed by the food and converted into internal energy (Uslu & Certel, 2006).

The essential materials for generating a microwave plasma include a vacuum pump, an argon gas tube, a control unit, a table, a voltage adjustment knob, a heat-resistant container, sealed plugs and others. Heat-resistant materials such as Pyrex glass and epoxy glass are used for the structure. Epoxy glass composites (DGEBA/DDS system) processed under 175 W microwave irradiation are also used (Kuşlu & Bayramoğlu, 2011). For precise control of the power setting, a microwave oven with an inverter is preferable. The vacuum table, which is responsible for generating the vacuum, is ideally made of a food-compatible aluminum-based material. The vacuum seals should also be made of food-compatible silicone material. A dry vacuum pump that is suitable for food and can work with oil should be used to generate the vacuum. If argon gas is to be used for plasma production, an argon gas tube is required (Kasar, 2022). Sealed plugs are used in the chamber to facilitate the drawing of the vacuum.

Figure 1 shows the installation schematic of the low-pressure microwave plasma system designed by us (Kasar, 2022). The essential components required for the setup are depicted in Figure 2 (Kasar, 2022).

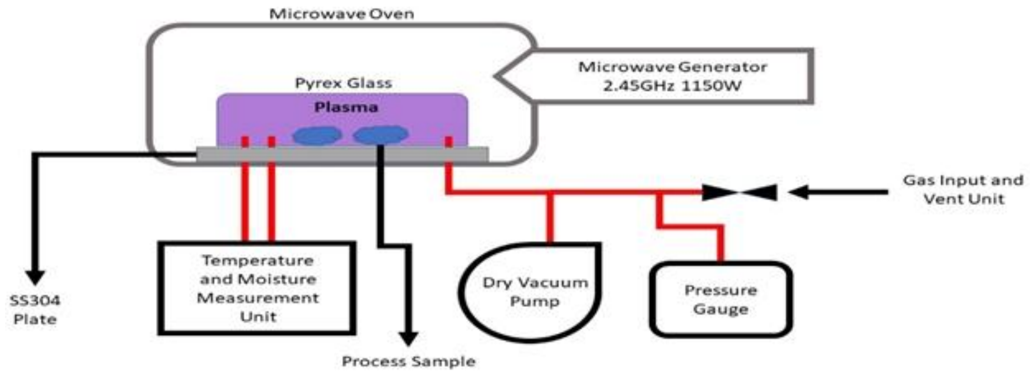

Figure 1. Experimental setup.

Figure 2. Microwave plasma setup/system used in the study (a: vacuum pump, b: argon gas tube, c: control device, d) system internal structure, e) heat-resistant chamber, f: voltage control unit, g: sealed plugs)

3. Utilization of Microwave Plasma Technology in the Food Industry

Nowadays, factors such as the increasing diversity of food consumption, the balance between supply and demand in product preferences and product quality make the application of alternative technologies in the food industry essential (Thirumdas et al., 2015). The consumption of food without any thermal processing forms the basis for minimizing microbial contamination. It has been found that existing technologies are not sufficient to ensure fresh, safe and high-quality food without adverse effects. In addition, the need to explore alternative technologies arises from the need to minimize changes in food processes, limit microbial load in accordance with government regulations, etc. (Albayrak & Kılıç, 2020).

Plasma techniques, especially cold plasma, as well as processes such as hot plasma and microwave plasma are used in the food sector. These processes are preferred due to their positive effects such as no thermal treatment, avoidance of adverse conditions on the outer surface of food, low energy consumption and minimal physical and chemical losses. In addition, the system is effective in minimizing microbial formation. The positive benefits of plasma in the food industry are expected to increase its preference (Kasar et al., 2021).

Microwave energy has been used for pasteurization or sterilization of food at lower temperatures and shorter time than conventional heating (Shın & Pyun, 1997). Further plasma sterilization can be achieved either in the discharge itself or in its afterglow (Moisan et al., 2002).

Research into the use of microwave plasma in the food sector is ongoing. These studies are being carried out in various sub-sectors of the food industry, such as milk and dairy products, fruit and vegetables, red meat, poultry, etc.

In a study on fruit and vegetables, the effect of plasma on rosehip fruit was investigated. In this study, the ascorbic acid content of untreated rosehip fruits was measured, and then the fruits were treated with plasma at a controlled frequency and gas concentration. It was found that the vitamin C content was lower after plasma treatment compared to other solutions (Bozkurt, 2014).

Kim et al. (2013) investigated the applicability of atmospheric pressure plasma generated by radiofrequency using argon gas on chicken ham to inactivate *Campylobacter jejuni*. The study was conducted with an inoculation level of 106 CFU. It was found that *C. jejuni* NCTC11168 and ATCC49943 decreased by up to 3 log CFU and 1.5 log CFU after 6 and 10 min of treatment, respectively

In his study, Kasar (2022) examined the physicochemical, microbiological, sensory, and shelf-life extension parameters of ravioli using microwave plasma technology. Stuffed pasta (mantı) were dried using traditional and microwave drying methods, reducing the moisture content to 12%. After drying, mantı were subjected to four different gas parameters in the microwave plasma environment. As a result, it was found that excessive use of argon gas in plasma discharge could have a burning effect on mantı. Additionally, it was concluded that besides traditional mantı drying methods, microwave drying, and four different plasma applications could be alternatives in terms of drying time. No mold formation was observed in samples treated with plasma. The higher sensory acceptability of ravioli produced with microwave-drying plasma application also indicates consumer satisfaction.

In addition to microwave plasma systems used in the food industry, cold gas plasmas and atmospheric plasmas are also used. In a study investigating the effectiveness of the gas plasma method on *Listeria innocua* bacteria on chicken skin for sterilization, positive results of the gas plasma method were observed, indicating its potential for development and use in the food sector (Yangılar & Oğuzhan, 2013).

4. Advantages and Disadvantages of the System in the Food Industry

The use of plasma technology in the food industry offers numerous advantages. The system includes cold, atmospheric, microwave plasmas and similar applications. Cold plasma technology is a novel green process that offers an alternative solution for food packaging. It is particularly preferred for the surface decontamination of food packaging materials. The cold plasma system is also used for sterilization in the food industry. It is a chemical-free, fast and safe system that can be applied to various packaging materials without leaving any residue (Pankaja, et al., 2014). It has been demonstrated that antibacterial coatings can be produced using atmospheric pressure plasma technology without visibly changing the color of the samples produced (Sarghini et al., 2011). Plasma technology is also used in polymerized coatings and offers advantages in processing and device performance compared to conventional polymer coatings, while being environmentally friendly (Kumar, et al., 2011). The microwave plasma system has been shown to provide effective etching compared to other systems, contains no toxic substances and minimizes negative effects on food structure and sensory analysis parameters (Kasar, 2022). In microwave systems, pretreatment leads to increased mass changes, which shortens the drying time and thus saves energy (Vladic et al., 2021).

However, the use of plasma systems in the food industry is also associated with disadvantages. These include high installation and application costs, requirements for special equipment, the formation of undesirable residues and long processing times (Yun, et al., 2010).

5. Microwave Plasma and People Health

The terms microwave, plasma, and radiation are often perceived negatively or evoke negative associations. However, these applications have minimal adverse effects on health or safety (Kasar, 2022).

There are concerns about the potential health effects of microwave technology. The tissues and organs in the human body that have a high-water content absorb microwave energy, resulting in an increase in their temperature. In addition, organs that are sensitive to an increase in temperature, such as the eyes, which have a slow blood supply, may be adversely affected. Microwave radiation can cause thermal denaturation of lens proteins, leading to cataracts (Konak et al., 2009). Microwave technology, which emits electromagnetic waves, is thought to cause circulatory and digestive system disorders as well as conditions such as hypertension, DNA synthesis disorders, headaches and depression (Yakıncı, 2016).

In order to curb the potentially harmful effects of microwave technology on human health, legal regulations have been issued for the use of microwave ovens. According to these regulations, the amount of leakage from the oven surface should not exceed 1 mW/cm^2 at a distance of 5 cm from the factory oven, 5 mW/cm^2 for a consumer microwave oven used for the first time at home and should not exceed 10 mW/cm^2 throughout the lifetime of the oven (Konak et al., 2009).

It was found that the lack of anticancer effect of non-microwaved, microwave-treated garlic is related to the inactivation of alliinase (Cavagnaro et al., 2007).

The use of non-thermal technologies can be promoted due to their advantages, such as low cost, temperature control, no environmental pollution and retention of quality characteristics, without posing health risks (Aydın et al., 2023). To this end, it is necessary to increase the number of studies examining the effects of microwave systems on human health.

6. Conclusion and Recommendations

The world is experiencing continuous acceleration. Factors such as population growth, destruction of agricultural lands, and inadequate water resources are leading consumers to demand organic, reliable, and accessible raw or minimally processed foods. Plasma technology is being investigated to ensure microbial quality in foods and stabilize the physical, chemical, and sensory changes occurring in products. Although this technology has been widely used in sectors like pharmaceuticals and cosmetics, its application in the food industry has been extensively explored in recent years. Studies have shown positive results of plasma systems in processes such as sterilization, microbial load reduction, extending the shelf life of food, and being environmentally friendly. Positive outcomes have also been achieved in quality, physicochemical analyses, and sensory parameters of different food groups in plasma applications. However, the complex nature of plasma technology, the need for specialized equipment during the process, and the high initial investment cost can hinder its widespread adoption. While plasma systems have been studied for reactions in some foods, it is essential to fill the gaps in the literature by applying plasma systems to various foods.

Plasma technology, in light of current technological advancements, offers an alternative approach to preserving natural resources, providing new resources, and ensuring the production of safe products. This study has discussed the application of plasma technology in the food industry, focusing primarily on microwave plasma, along with the schematic structure of the system, its advantages, disadvantages, and its impact on human health, as well as some past research endeavors. Continuing research efforts to apply this novel technology in the food industry, develop the system, and increase the number of facilities will result in significant gains for the food industry.

In this study, the setup, operating parameters, and applications of microwave plasma in foods were investigated. As an alternative to heat treatments, microwave plasma applications in the food processing were used, to maintain microbial quality, to reduce microbial load, to provide low cost and minimum changes in the food and food products. According to the results obtained, it was concluded that a strong vacuum application and the use of Argon gas are necessary in microwave plasma formation and the application time is very important for microwave plasma applications.

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