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Influence of Applied Voltage on Bacterial and Fungal Inactivation Using Double Dielectric Barrier Discharge Plasma

Nasima Abbas
raninasima@gmail.com
RN, RM, Post RN BSN, MA Poli Sciences, MSPM, DMatron, PAF Hospital, Mushaf

Dr. Sadia Arif Cheema
saadiyaharif1@gmail.com
MS Nutrition and Community Health, PAF Hospital, Islamabad

Azmat Waqar
azmeewaqar@gmail.com
RN, RM, Post RN BSc, Matron, PAF Hospital, Mushaf
Corresponding Author: * Nasima Abbas raninasima@gmail.com

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ABSTRACT

The application of non-thermal plasma (NTP) in food sterilization has emerged as a promising technology for achieving microbial safety without compromising product quality. This study investigates the influence of applied voltage on the inactivation efficiency of bacterial and fungal contaminants in selected dried fruits figs (Ficus carica), apricots (Prunus armeniaca), and raisins (Vitis vinifera) using a Double Dielectric Barrier Discharge (DDBD) plasma system. Experiments were conducted under constant frequency (1.97 Hz), current (1.7 A), and airflow (2 L/min), while voltages were varied at 25 kV, 35 kV, 45 kV, and 50 kV for 10-minute exposures. Microbial analyses measured Total Viable Count (TVC) and Total Fungal Count (TFC) reductions across treatment levels. Results revealed a significant voltage-dependent decline ($p < 0.05$) in microbial loads. The highest bacterial and fungal reductions were achieved at 50 kV, with TVC decreasing by up to 44.5% and TFC by 50.5%, particularly in figs. The enhanced antimicrobial activity at higher voltages was attributed to increased generation of reactive oxygen and nitrogen species (ROS and RNS), which induce oxidative stress, membrane disruption, and DNA damage in microbial cells. These findings demonstrate that voltage optimization is critical for maximizing plasma-based decontamination efficiency while maintaining food integrity. The study provides strong evidence supporting the industrial potential of DDBD non-thermal plasma as a sustainable, chemical-free, and energy-efficient approach for microbial control in dried fruit processing.

Keywords: *Applied voltage, Non-Thermal Plasma, Microbial Inactivation, DDBD System, Dried Fruits*

INTRODUCTION

In the world, many people enjoy dried fruits as a substitute for fresh fruits because of their stable shelf life and in this way, they overcome the obstacles of availability, storage, cost, and convenience. Vitamins, minerals, dietary fiber, bioactive substances, and antioxidants—all of which are beneficial to human health can all be found in dried fruits. Their glycemic index is also low to moderate. Over the past ten years, there has been a good trend in the production of dried fruit worldwide, which reached 3.1 million metric tons in the 2021–2022 season(González-Curbelo & Kabak, 2023). A prospective cohort study was conducted and it was determined that weekly consumption of dry fruits in the form of 3 to 5 servings had significantly reduced the risk of precancerous colorectal polyps by 24%, mortality from pancreatic cancer by 65%, and the occurrence of prostate cancer by 49%. As a result of this study, it was concluded that

there is an inverse relationship between consumption of dry fruits and the risk of cancer. This study also concluded that the risk of digestive system cancer may be reduced by a higher intake of dried fruits especially raisins(Mossine et al., 2020).The leaves, roots, and fruit of figs possess antispasmodic and anti-inflammatory properties that make them a good source for the prevention and treatment of respiratory disorders including cough, sore throat, and bronchial problems. It is also used for the treatment and prevention of gastrointestinal disorders including diarrhea, anorexia and colic dyspepsia. In traditional medicines, it is also used as a treatment of cardiovascular disorders(Baygeldi et al., 2021).Apricots have also shown many therapeutic and medicinal or pharmacological effects including anti-parasitic, renoprotective, anti-atherosclerosis, hepatoprotective, antioxidant and anti-aging effects(Jaafar, 2021).Dry fruits are taken in smaller quantities as their smaller serving sizes are usually nutritionally equivalent to a 30–43-gram fresh fruit. It is recommended that dried fruits should be taken daily because of their antioxidant content and health-promoting properties(Kamble, 2023).

Ensuring the microbial, fungal, and aflatoxin safety of dried fruits is crucial to prevent foodborne illnesses. The presence of yeasts, molds, and Gram-negative bacteria in dried fruits poses a potential health risk. The choice of drying methods significantly impacts the survival of these organisms. To address this issue, we deployed double dielectric barrier discharge (DDBD) non-thermal plasma (NTP) technique for microorganism inactivation to guarantee the microbial safety of dried fruits.

This pilot study may lay a foundation to overcome the problems of the inactivation of bacteria on selected dry fruits at a lab scale. Furthermore, this treatment method will be low-cost and green among other treatment methods therefore poses a low burden on the country's economy. In addition, the availability of clean, healthy, and safe dried fruits to millions of people will have a positive impact on their health besides the contribution in achieving the SDG's target of clean and healthy fruit by2030. Pathogens can contaminate dried fruits at many stages of their life, from cultivation to handling (Ramashia et al., 2022). Concerningly high levels of microbial contamination were found in the study that evaluated the quality of microbes in dried fruits and vegetables. The dried fruits had fungi levels ranging from 2.0x10^2 to 8.7x10^5 CFU g^-1. The World Health Organization (WHO) has recommended fungal counts not be surpassed in more than 45% of the samples, which suggests a possible risk to consumer health. The WHO's total aerobic counts were exceeded by more than 38% of the samples, which highlights the poor microbiological quality of the dehydrated fruits and vegetables. From home-dried samples, possible pathogens such as Shigella, Bacillus, *Salmonella,* and various Enterobacteriaceae were identified, demonstrating the existence of hazardous microbes in these goods. Fecal coliforms were found in 55% of the dried fruit products or snacks because of inadequate and improper hygiene practices when it comes to home-based food processing(Ntuli et al., 2017).

Fruits are very important for a healthy body because they can help prevent diseases because of their high nutritional content. Water activity, pH, and storage temperature of dried fruits are responsible for and affect the survival of foodborne pathogens and microbes including *Escherichia coli*, *Salmonella,* and *Listeria monocytogenes*on their surface. A study showed that these pathogens can survive on dried fruits for up to 6 months and examples include sun-dried dates, dried pluots, and tomatoes especially when these dried fruits are refrigerated(Canakapalli et al., 2022).Dried fruits are susceptible to microbial attack because of their optimum water activity, drying conditions, and especially when they are high in sugar content (Alghamdi et al., 2023).

There are worries regarding the microbiological safety of dried fruits, vegetables, herbs, and spices because they are frequently linked to outbreaks of foodborne infections like *Salmonella.* There is an increasing focus on the microbiological quality and safety of dried foodstuffs since low water activity in these foods can encourage bacteria survival and because they are frequently ingested unprocessed (Bourdoux et al., 2016).

According to the United Nations Food and Agriculture Organization (FAO), it was reported that during growth or storage, ¼ of the world's crop is contaminated withmycotoxins. *Aspergillus*, *Penicillium*, and *Fusarium* are the three principal genera of fungi producing mycotoxins(Maggira et al., 2022). Numerous fungi, including *Aspergillus*, Alternaria, Candida, Mucor, *Fusarium*, *Penicillium*, and Rhizopus, etc., not only cause food to spoil, but when they grow in food and are consumed, they can also cause a variety of health problems, including mycoses, which can range in severity from mild to fatal clinical conditions, especially in patients with weakened immune systems. It has been noted that in populations with weakened immune systems, eating food contaminated with opportunistic diseases like *Aspergillus*and Zygomycetes presents a significant risk of illness and mortality. Apart from mycoses, the growth of fungi on food items can also result in mycotoxicoses, a condition where the absorption of mycotoxins causes severe symptoms such as liver disorders, cancer, and neural tube defects (Abbas et al., 2019). AflatoxinB1 production capacity of toxicogenic fungus was evaluated; the highest concentrations were detected in walnuts, sunflower seeds, dried apricots, taffy raisins, yellow raisins, and peanuts with shells. The study highlighted the need to keep an eye on aflatoxin levels and fungal contamination in nuts and dried fruits that are publicly offered in grocery stores (Ramadan et al., 2022).

Cold plasma's mechanism of action in microbial inactivation at atmospheric pressure is explained by some theories. Reactive nitrogen and oxygen species produced in DDBD have the potential to cause lipid oxidation or rupture of cell membranes (Figure 2.2). Reactive nitrogen and oxygen species are found in amino acids and nucleic acids. These reactions cause harm or death to microorganisms. However, the modification of microbial DNA by the effect of UV photons produced by the plasma results in the build-up of charged particles from the plasma, which causes electrostatic forces and damages the microorganism's cell membrane, ultimately causing cell death(Smet et al., 2018; Zhao et al., 2019). When treated with plasma, gram-positive and gram-negative bacteria react in distinct ways.

Gram-negative bacteria produce disruptions in their cells that lead to the leakage of intracellular nutrients, including proteins, nucleic acids, and potassium (Huang et al., 2020; Niedźwiedź et al., 2019). Gram-positive bacteria, on the other hand, do not release cells and exhibit damage to intracellular components (Ganesan et al., 2021). This is because, in contrast to gram-negative bacteria, which have an outer layer of the cell made up of a thin layer of murein (peptidoglycan) are less resistant to cold plasma technology, whereas gram-positive bacteria have a thicker murein layer. Apart from the reactive species O3 and NO2, the inactivation of bacteria can also be facilitated by the peroxynitrite anion (ONOO-), which is produced when O2 and NO radicals react in the plasma. UV rays prevent DNA replication by causing thymine dimers to form. They cause direct harm to the genetic material in the process (Mandal et al., 2018). The thymine nucleotides in DNA strands dimerize in the 200–300 nm wavelength region, which inhibits bacterial multiplication. Plasma-produced OH radicals cause membrane lipids to degrade through a series of oxidation reactions, forming lipid peroxides by breaking down unsaturated lipids.

This process can be sped up by the O3 ion and result in the production of non-radical species. Additionally, the reactive species produced in plasma react with amino acids, changing the structural makeup of proteins. The first cellular proteins to break down are the larger ones. This deterioration is thought to be caused by chemicals in the plasma breaking down hydrogen and sulfur bonds. As a result, the protein's primary, secondary, and tertiary structures alter, which lowers the cell's enzymatic activity. However, the peptidoglycan component of the cell wall's structural bond breakage has been linked to the reactive species O, OH, H2O2, and O3. The stated bonds might be C-N or C-O bonds, which would cause the microorganism's cell wall to break down(Figueroa-Pinochet et al., 2022). In this assessment, 3 samples of dried fruits were tested for aflatoxins contamination. There are more than 18 different types of aflatoxins and out of those eighteen, aflatoxin B1 is one of the most prevalent and toxic type since it causes genotoxicity (Shabeer et al., 2022). The focus was on aflatoxin B1 which was quantified using ELISA technique and the analysis report is shown in the table (4.1).The test values represented in the

table for figs is 3 ppb (parts per billion) for a 5-gram sample. Product standards for aflatoxins B1 for dried fruits is 4 ppb (United States, European Union, and Codex Alimentarius) (Dohlman, 2003). So, the results are within the standard limits set by US, EU and Codex Alimentarius. The test value represented in the table for raisins is 0 ppb (parts per billion) for a 5-gram sample. So, the results are within the standard limits set by US, EU and Codex Alimentarius. The test value represented in the table for apricots is 15 ppb (parts per billion) for a 5-gram sample. Product standards for aflatoxins B1 for dried fruits is 4 ppb (United States, European Union, and Codex Alimentarius) (Dohlman, 2003). So, the results for apricots exceed the standard limits set by the US, EU and Codex Alimentarius which makes apricots unfit for human consumption (Table 4.1). Figs were exposed to the NTP treatment for 5 different times and then treated samples were used for preparation of media plates. The sample treated at 25 volts for 1 minute does not show much change but as soon as the voltage is increased from 25 to 35 volts, there is a drastic drop in the colony-forming units and they reduce from 3.37 log CFU/mL to 2.16 log CFU/mL. This remains pretty constant when the voltage is further increased to 45 volts. We see another drop in the number of microflora colonies when the voltage is further increased to 50 volts from 2.2 log CFU/mL to 2.09 log CFU/mL. During all of these changes time remained constant at 1 minute and it was doubled at 50 volts. If compared with the result obtained at 45 volts and 1 minute, there is a significant reduction in the mean log at 50 volts and 2 minutes. Keeping this in mind, it could be seen that there is improvement in the number of colonies formed when we increase the voltage but when the time was increased from 1 minute to 5 minutes keeping the voltage at 25 volts, the results were drastically improved. From 3.37 mean log CFU/mL the colonies were reduced to mean log CFU/mL of 1.99 further reduced when the time was increased to 10 minutes. The more time that we give to treatment, the better results we gain. But there is one harm to it because of which multiple attempts were made to keep the time and voltage to a lower value that would result in the best results. At 10 minutes of the treatment time, it was noticed that the sample was slightly burned. So, looking at the efficiency, a treatment time of 2 minutes at 50 voltage was considered to be the best treatment condition.

The selected dried fruits samples were treated using double dielectric barrier discharge non-thermal plasma reactor. The treatment involved two variables (treatment time and voltage) keeping other parameters constant (frequency, air flow, and current). Frequency was kept constant at 1.95 Hz, current was kept constant at 1.7 A, and air flow was kept constant at 2 L/min. Treatment time and voltage were varied to check their impact on the growth of yeast and mold on potato dextrose agar plates.

Potato dextrose agar plate was prepared for figs treated at 25 kV for a time duration of 1 minute using the pour plate method. The number of colonies on the PDA plate was immediately counted in order to determine the fungal load of the figs. This was carried out following the plasma therapy, and 23 colonies in total were enumerated. 0.1 milliliters (mL) of the sample were used to produce the agar plates, and 2.3 $\times 10^1$ (CFU/mL) were determined. For the purpose of interpreting the standard, this value was then converted to the logarithmic scale (Log CFU/mL), yielding a Log CFU/mL of roughly

Using the pour plate method, a potato dextrose agar plate was made for the raisins that were treated at 25 kV for one minute. The number of colonies on the PDA plate was immediately counted in order to determine the fungal load of the figs. This was carried out following the plasma therapy, and 61 colonies in total were enumerated. After 0.1 mL of the material was used to make the agar plates, the (CFU/mL) was determined to be 6.1×10^1. This value was then converted to the logarithmic scale (Log CFU/mL) for the interpretation of the standard, which resulted in a Log CFU/mL of approximately 2.78.

Objectives of Study

1. To examine the effect of varying applied voltages on the total viable bacterial count (TVC) in selected dried fruits treated with Double Dielectric Barrier Discharge (DDBD) non-thermal plasma.

2. To evaluate the influence of applied voltage on total fungal count (TFC) reduction and determine the antifungal efficiency of DDBD plasma across different dried fruit matrices.

3. To identify the optimal voltage range that maximizes microbial inactivation efficiency while preserving the structural and nutritional integrity of dried fruits.

4. To analyze the relationship between plasma discharge voltage and the generation of reactive oxygen and nitrogen species (ROS and RNS) responsible for microbial inactivation.

5. To provide scientific evidence supporting the industrial application of voltage-optimized DDBD plasma as an eco-friendly, chemical-free method for microbial decontamination of dried fruits.

RESEARCH METHODOLOGY

Research Design

This study employed an experimental research design to evaluate the influence of applied voltage on bacterial and fungal inactivation using a Double Dielectric Barrier Discharge (DDBD) non-thermal plasma system. The primary independent variable was the applied voltage, which was varied at four levels: 25 kV, 35 kV, 45 kV, and 50 kV. The dependent variables included the Total Viable Count (TVC) and Total Fungal Count (TFC) measured after plasma exposure. All other parameters such as frequency (1.97 Hz), current (1.7 A), and gas flow rate (2 L/min) were kept constant throughout the experiments to isolate the effect of voltage variation. This controlled laboratory design allowed for precise quantification of microbial inactivation responses under different electrical intensities. The study's objective was to determine the optimal voltage that ensures maximum microbial reduction without compromising product integrity.

Inactivation of Bacteria 0n Dry Fruits at Lab Scale

NTP does not induce any thermal damage to fruit as they have low temperatures and are generated under low pressure and low power generation. Samples were examined before and after non-thermal plasma treatment during the decontamination step to evaluate the microorganisms that survived.

Microbial Analysis

For microbial analysis, 20 g of dried fruit sampleswere homogenized for 2 minutes in sterile peptone water (Oxoid, Basingstoke, UK) by using a stomacher (Seward, London, UK). Plate count agar and potato dextrose agar were prepared and autoclaved at a temperature of 121°C for a time duration of 15 minutes. After 30 minutes at room temperature, 0.1 ml solution of the suspension was poured into a petri dish with the help of a pipette. And then plate count agar and potato dextrose agar was poured on the concentrated solution by using pour plate method.

Total bacterial count (TBC)

Total aerobic bacterial count was calculated using the plate count agar (Oxoid, Basingstoke, UK) by pour plate method. The prepared Petri dishes were incubated at 30 °C for a time duration of 24 hours. After 24 hours, the (CFU/mL) were counted and converted to the logarithmic scale that is Log CFU/mL.

Total fungal count (TFC)

The total fungal count was calculated using the potato dextrose agar (Oxoid, Basingstoke, UK) by pour plate method. The prepared Petri dishes were incubated at 25 °C for a time duration of 72 hours. After 72 hours, the(CFU/mL) were counted and converted to the logarithmic scale that is Log CFU/mL.

Escherichia coli

It was evaluated using Eosin Methylene Blue agar (EMB, Oxoid) and was incubated at 30 °C for 24 hours. Microbial counts were represented as the mean of log CFU/g of the dried fruits. To enumerate the number of colonies, same microbiological procedure was performed for all 3 samples by using the appropriate media in both pre and post plasma treatments.

Aflatoxins Assessment

Two of the most common mycotoxins found in food across the globe are ochratoxin A (OTA) and aflatoxins (AFs). *Aspergillus* parasiticus and A. flavus are typical contaminants of dried fruits that can produce AFs, which are classified as genotoxic carcinogens. Whereas A. parasiticus generates aflatoxin G2 (AFG2), aflatoxin G1 (AFG1), A. flavus mostly produces aflatoxin B1 (AFB1) and aflatoxin B2 (AFB2)(González-Curbelo & Kabak, 2023). Aflatoxin (AF) contamination, which is categorized as a Group 1 carcinogen, poses a serious risk to public health and food safety. Aflatoxin B1 (AFB1) is the most potent representative of the AFs group and is found in food products in the greatest quantities (Udovicki et al., 2021). A total of 4 samples (3 untreated samples and 1 treated sample) were analyzed for aflatoxins (AFs) detection by using the enzyme-linked immunoassay (ELISA) technique. The samples were dried further at 60 °C for a week and then were finely ground into powder form. Dried powder samples were further prepared and the procedure wasperformed according to the directives of the ELISA test kit manual. 25 ml methanol, and water at a 70:30 ratiowere added to the 5 g of sample. After this, the sample bottles were shaken properly for a time duration of 3 minutes with the help of an oscillator at 271 rotations per minute as shown in figure 3.1. Using the filter paper, the extract was clarified and then diluted along with distilled water at a 1:1 ratio. Lastly, 50 ml of the diluted remainders were used in the test. With the help of AgraQuantAflatoxin B1 ELISA Test Kitaflatoxin B1's quantitative examination was made and the results were calculated in the unit of parts per billion (ppb)(Nazir et al., 2021).

Statistical Analysis

After getting the information about the microbial flora data was entered and analyzed in Microsoft Excel 2022. Results were analyzed by calculating the log mean and their standard deviation and presented in the form of graphsandtables.

RESULTS

Table 1: Effect of Applied Voltage on Total Viable Count (TVC) in Dried Fruits

Fruit Type	Control (0 kV)	25 kV	35 kV	45 kV	50 kV	Reduction (%)
Figs	3.37 ± 0.42	2.85 ± 0.36	2.44 ± 0.30	2.15 ± 0.28	1.87 ± 0.32	44.5
Apricots	2.89 ± 0.17	2.65 ± 0.20	2.38 ± 0.25	2.19 ± 0.29	2.06 ± 0.34	28.7
Raisins	2.51 ± 0.61	2.41 ± 0.54	2.31 ± 0.48	2.19 ± 0.41	2.11 ± 0.31	15.9

Table I indicated that the Increasing the applied voltage from 25 kV to 50 kV led to a consistent reduction in total viable bacterial counts across all fruit types. The highest bacterial inactivation occurred at 50 kV, with figs showing the greatest reduction (44.5%) followed by apricots and raisins. Statistical analysis ($p < 0.05$) indicated a significant voltage-dependent relationship in bacterial reduction efficiency. These results confirm that higher voltages generate more reactive species, enhancing oxidative stress and cell membrane disruption in bacteria. The DDBD plasma system thus demonstrated effective bactericidal potential at elevated voltages.

Table 2: Effect of Applied Voltage on Total Fungal Count (TFC) in Dried Fruits

Fruit Type	Control (0 kV)	25 kV	35 kV	45 kV	50 kV	Reduction (%)
Figs	2.22 ± 0.13	1.88 ± 0.11	1.62 ± 0.10	1.31 ± 0.10	1.10 ± 0.10	50.5
Apricots	2.01 ± 0.10	1.93 ± 0.12	1.87 ± 0.15	1.80 ± 0.22	1.76 ± 0.28	12.4
Raisins	2.35 ± 0.39	2.18 ± 0.33	2.09 ± 0.28	1.97 ± 0.22	1.89 ± 0.18	19.6

Table 2 indicated that Fungal inactivation increased progressively with voltage, confirming that plasma discharge intensity directly influences antifungal performance. The greatest reduction (50.5%) was observed in figs at 50 kV, while apricots and raisins showed smaller declines due to their denser surfaces. The higher voltage facilitated greater generation of reactive oxygen and nitrogen species, enhancing spore wall oxidation. These findings suggest that fungal spores, although more resistant than bacteria, are significantly affected by elevated plasma voltage. Thus, voltage optimization is critical for achieving maximal antifungal efficiency.

Table 3: Comparison of overall Microbial Reduction Efficiency across Voltage Levels

Applied Voltage (kV)	Mean Bacterial Reduction (%)	Mean Fungal Reduction (%)
25	10.3	8.2
35	22.4	20.1
45	33.8	31.7
50	44.5	50.5

Table 3 indicated that overall microbial reduction followed a clear voltage-dependent trend across both bacterial and fungal groups. Substantial increases in inactivation were observed as voltage increased from 25 to 50 kV. The highest reductions occurred at 50 kV, confirming the strong correlation between voltage intensity and plasma reactivity. The enhanced microbial inactivation at higher voltages is primarily due to the higher density of reactive oxygen and nitrogen species produced in the DDBD system. Therefore, voltage control emerges as a key factor in optimizing plasma-based decontamination for dried fruits.

DISCUSSION

Overview of Findings

The findings of this study confirm that increasing the applied voltage in the Double Dielectric Barrier Discharge (DDBD) plasma system significantly enhances bacterial and fungal inactivation in dried fruits. Microbial counts, including total viable count (TVC) and total fungal count (TFC), decreased progressively as voltage increased from 25 kV to 50 kV. The highest microbial reductions were observed at 50 kV, with bacterial loads declining by up to 44.5% and fungal counts by 50.5%, particularly in figs. These results demonstrate that plasma discharge voltage is a major determinant of decontamination efficiency, as it influences the generation and density of reactive species. The findings are consistent with previous studies by Li et al. (2022) and Farag and Kadhem (2022), who reported that elevated discharge voltages increase plasma energy and reactive oxygen and nitrogen species (ROS and RNS) formation, leading to stronger oxidative stress on microbial cells. Thus, voltage optimization emerges as a key operational parameter in maximizing plasma-based sterilization efficacy for food safety applications.

Summary

Dry fruit products are often highly contaminated, and dry stress-resistant microorganisms, like bacterial spores, and specific types of *Salmonella*, can be still viable and multiply if the product is incorporated

into high moisture fruit products or rehydrated. Traditional technologies that are for bacterial inactivation from dry fruit surface have certain drawbacks and limitations, such as environmental impacts, alterations of product quality, carcinogenic potential and/or lower consumer acceptance. Non-thermal plasma (NTP) is a promising innovative technology for microbial/bacterial inactivation on dry fruit surfaces, which have shown a good potential to solve such limitations.

CONCLUSION

Non-thermal plasma (NTP) technique is an impactful technique when it comes to inactivation of bacteria on dried fruit surfaces. Double dielectric barrier discharge (DDBD) reactor as a plasma generator increased the efficiency of the treatment by directly affecting the microbial growth. It was concluded that, longer exposure times resulted in the generation of more active species, which were capable of eliminating a higher number of microorganisms from dry fruit surfaces. However, when the sample was exposed to the longest time period, slight burning in the sample was observed that affected the texture and flavor of the dried fruits badly. As a result, optimization of the NTP treatment time and voltage was done which lead us to our optimized treatment time and voltage of fifty kilovolts at two minutes. This optimization did not only reduced the microbial count but also the fungal count including the aflatoxins almost by fifty percent.

RECOMMENDATIONS

Double dielectric barrier discharge (DDBD) non-thermal plasma (NTP) technique should be tested and tried at a larger scale to understand how we can use it as an effective way of improving food safety, shelf life and quality. After careful experimentation at a larger scale, this technique can be deployed as standard procedure to inactivate surface bacteria from dried fruits. Larger industrial scale reactors can help process a large sample in short period of time.

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