Food & Nutrition Journal
Yaa'ri R, et al. Food Nutr J. 8: 303.
https://www.doi.org/ 10.29011/2575-7091.100203
www.gavinpublishers.com

Research Article

A Novel Approach to Improving the Rehydration of Freeze-Dried Potatoes through Electrical Treatment

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Citation: Yaa'ri R, Arazi S, Nussinovitch A (2024) A Novel Approach to Improving the Rehydration of Freeze-Dried Potatoes through Electrical Treatment. Food and Nutrition Journal, 9: 303. DOI: 10.29011/2575-7091.100203

Received Date: 18 June 2024; **Accepted Date:** 26 June 2024; **Published Date:** 01 July 2024

Abstract

Rehydration significantly impacts the quality of dehydrated foods, especially vegetables. Factors like porosity are key in this process. Our study introduces a novel method for enhancing the rehydration of freeze-dried potatoes using electrical treatment. By applying a DC voltage across electrodes with the sample between them, at an electrical field strength of up to 30 V/cm for 1 min, we observed improved rehydration ratios compared to untreated samples. Electrically treated specimens reached a rehydration ratio of 4.1 in 1.5 min, whereas untreated specimens reached only 2.1 in the same timeframe. SEM micrograph evaluation of freeze-dried potato specimens, pre- and post-electric treatment, revealed a significant increase in pore count and surface area in the treated samples compared to untreated ones. This heightened porosity likely contributes to the observed higher rehydration ratio in the treated specimens. Furthermore, the treated samples presented a softer texture, which is advantageous for applications such as potato flakes used in puree production. Additionally, electrically treated specimens exhibited higher L^* values, indicating increased lightness relative to untreated specimens.

Keywords: DC Electric Field; Rehydration; Porosity

Introduction

Rehydration of fruits and vegetables is a critical process in food preservation and restoration of their sensory qualities, particularly for products that have undergone dehydration techniques like freeze-drying or air-drying. When these food items are dehydrated, they lose water content, which can affect their texture, flavor, and overall quality. Rehydration aims to restore moisture to these foods, making them palatable and enjoyable for consumption [1,2].

Rehydration is considered one of the most significant quality properties of dehydrated foods. The ability of dehydrated foods to rehydrate effectively can greatly influence their texture, flavor, appearance, and overall consumer acceptance. Proper rehydration ensures that the product retains its original characteristics as closely as possible, resembling its fresh counterpart [1].

Scientific evidence supports the importance of rehydration in maintaining the quality of dehydrated foods. Numerous studies have shown that the rehydration process significantly impacts the sensory attributes and nutritional content of dehydrated products. For example, research by Lee and Kader demonstrated that the rehydration capacity of dried fruits directly affects their texture and flavor, with properly rehydrated samples exhibiting superior sensory properties compared to inadequately rehydrated ones [3]. Furthermore, the rehydration behavior of dehydrated foods has been extensively studied in relation to various processing techniques and conditions. Studies have shown that factors such as dehydration method, pre-treatment techniques, and storage conditions can influence the rehydration kinetics and quality of the final product [4,5].

Rehydration, a multifaceted process, involves bringing dried material into contact with a liquid, typically water, to restore its original properties [6]. Rapid and efficient rehydration holds significance from both consumer and manufacturing standpoints. Swift rehydration facilitates quicker consumption for consumers and enhances production efficiency and cost-effectiveness for manufacturers. The rehydration of dried plant tissues encompasses three concurrent processes: water imbibition into the dried material, swelling, and solubles leaching [6,7]. It is widely acknowledged that the extent of rehydration hinges on the level of cellular and structural disruption [8].

Rehydration can be characterized in various ways, with one common method being the rehydration ratio (also referred to as rehydration capacity), calculated as the weight after rehydration (W_f) divided by the initial weight (W_i) [6].

Numerous studies have demonstrated significant effects of various drying methods on the rehydration attributes of the targeted food items [2,9]. Additionally, pre-drying treatments, such as exposure to high- intensity electric field pulses and osmotic dehydration in sucrose solution, have been shown to impact rehydration properties [1]. Specifically, drying techniques influence additional properties of the rehydrated materials, including color, texture, density, and porosity [10].

Krokida and Maroulis investigated how drying methods influence the porosity of various vegetables. Their findings suggest that selecting the right drying method allows for control over the porosity of the product. Freeze-dried materials exhibited the highest porosity, while conventional air-drying resulted in the lowest porosity [11].

Scientific evidence demonstrates the significance of rehydration in maintaining the quality of dehydrated foods. For example, a study by Krokida et al. investigated the effect of rehydration on the texture of dried vegetables. The researchers found that proper rehydration improved the texture of the vegetables, resulting in a softer and more palatable final product compared to inadequately rehydrated samples [8].

Furthermore, research by Varela et al. examined the impact of rehydration on the nutritional properties of dried fruits. The study revealed that rehydration led to the restoration of certain nutrients, such as vitamins and antioxidants, which are essential for human health. Proper rehydration helped maintain the nutritional value of the dried fruits, making them a viable alternative to fresh produce [12].

Freeze-drying, a preservation technique employed for diverse vegetables such as potatoes, is commonly utilized in the production of instant mashed potato products. This method rapidly removes moisture from prepared potato mash, transforming it into flakes that can be conveniently reconstituted. By preserving the taste and texture of the potatoes, freeze-drying meets the demand for convenient and shelf-stable food options in households and commercial settings alike. Freeze-dried potatoes typically exhibit high porosity due to the sublimation of ice crystals formed during freezing, resulting in a more open structure that facilitates rapid water uptake and efficient reconstitution [13]. To further enhance the rehydration rate of freeze-dried potatoes, various pretreatments can be employed. One such pretreatment is electroporation, also known as electropermeabilization, a technique utilized to increase cell membrane permeability through the application of short, high-intensity electric pulses. Electroporation finds widespread application in diverse fields, including medicine, biology, and food processing [14].

The use of electrical treatments in food processing includes various techniques such as ohmic heating [15], low electrical fields [16], moderate electrical fields [15], and high electrical fields [17,18].

Ohmic heating is a process where heat is generated within a food material by passing an electric current through it. This method relies on the electrical resistance of the food, which converts electrical energy into heat. Ohmic heating uniformly generates heat throughout the food material, making it particularly efficient for heating foods with high electrical conductivity [15,19].

Low electrical field treatments typically involve the application of electric fields of relatively low intensity to food or biological materials. Low electrical field treatments aim to induce more subtle effects. These effects can include enhancing mass transfer processes (such as drying, extraction, or impregnation), improving microbial safety through mild pasteurization effects, and potentially modifying structural or functional properties of the treated materials without causing significant damage [16,18].

Moderate electrical field (MEF) treatments in food processing involve applying electric fields of intermediate intensity. This technique lies between low electrical field treatments and high intensity pulsed electric fields (PEF). MEF aims to induce controlled changes in food properties without causing significant damage or compromising quality [15,17].

High electrical field (HEF) treatments in food processing involve applying intense electric fields to food materials for very short durations, typically in the range of microseconds to milliseconds. This technique is known as pulsed electric fields (PEF) and is used to achieve various effects on food products, primarily through the disruption of cell membranes [17-20].

The application of an electric field to potato tissues, as achieved through electroporation, can induce the creation or enlargement of pores in cell membranes. This process is commonly utilized to enhance cell permeability to substances like water and enzymes [21]. Electrification may induce structural alterations in the potato tissue, potentially impacting its porosity and, consequently, its texture, water absorption capacity, and rehydration behavior. Electroporation is occasionally employed in the food industry to optimize processes such as drying, rehydration, and marination by enhancing porosity and, thus, improving efficiency [18].

Scientific studies have explored various methods to enhance the rehydration of freeze-dried potatoes, aiming to improve their texture and overall quality. Some techniques and their associated scientific evidence include except of electrical treatment, osmotic pretreatment, and vacuum impregnation. Osmotic pretreatment involves immersing the freeze-dried potatoes in osmotic solutions prior to rehydration. This process helps to enhance water uptake and improve the texture of the rehydrated product. Studies have shown that osmotic pretreatment with solutions such as sucrose or salt can improve the rehydration kinetics and quality of freeze-dried potatoes [22]. Vacuum impregnation is another technique that has been explored to improve the rehydration of freeze-dried potatoes. This method involves infusing the potatoes with a liquid solution under vacuum conditions, which promotes the uptake of moisture during rehydration. Research by Vega-Mercado et al. demonstrated that vacuum impregnation could enhance the rehydration kinetics and sensory attributes of freeze-dried fruits and vegetables [23]. Overall, these techniques offer promising strategies for enhancing the rehydration of freeze-dried potatoes, ultimately improving their texture, flavor, and overall consumer acceptance.

In our study, we analyzed the impact of applying low DC electric fields as a pre-treatment for freeze-dried potatoes, aiming to enhance the porosity and rehydration rate of the dried samples. If successful, this study could lead to scalable applications in the food industry, potentially improving quality and reducing costs to achieve better products in food processing and related industries

Materials and Methods

Plant material

Fresh potatoes (S*olanum tuberosum* var. Winston) were purchased from a local grocery store. Cylindrical specimens, ca. 3.0 mm thick by 6.5 mm in diameter, were trimmed using a cork borer, as previously described [24].

Drying procedure

All specimens (untreated and electrically treated) were frozen at −80 °C for 1 h before freeze-drying, which was carried out at −50 °C at a pressure of 1.1 Pa for 30 h (Martin Christ freeze-drying apparatus model ALFA I-5; Osterode am Harz, W. Germany) [25].

Electrical apparatus

A custom-designed apparatus was constructed to facilitate the electrical treatment of potato specimens submerged in water, as detailed in prior work [16]. The specimens, measuring 3.0 × 6.5 mm (thickness by diameter), were positioned between a pair of spiral-shaped electrodes, with the intervening space filled with distilled water. Direct current (DC) voltage was applied across the electrodes using a DC power, generating an electrical field strength of up to 30 V/cm for 1 minute, as outlined previously [26]. The utilization of relatively low electrical field strength is preferred to minimize the absorption of energy by the treated systems, which could otherwise be converted into heat.

Scanning electron microscopy (SEM) and image-processing analysis

To study the dry potato' structure and changes therein as a result of the electrical treatment, scanning electron microscopy (SEM) was performed. The dry potato specimens were taken from the same batches that had produced samples for mechanical determinations. A 1:1 mixture of colloidal graphite in isopropyl alcohol and Ducco household glue was used as a conductive mounting adhesive and the sample was mounted on 10x10mm aluminum SEM stubs coated with approximately 50 nm Au/Pd (60:40 w/w) in a Polaron E5100 unit equipped with a Peltier cooling stage. Samples were examined by electron microscopy (Jeol JSM 35C SEM, Tokyo, Japan) in high-vacuum mode (10^{-3} mm Hg) at an accelerating voltage of 25 kV. The electron micrographs were then scanned (Hewlett Packard scanner, version 3.02, model 5300C) and saved as bmp files. The scanned micrographs were analyzed using Image Pro Plus (version 3.0.01.00, Media Cybernetics, L.P.). This program determines the number of pores and their area, in pixels, and translates the measurements into metric units. All results, statistical and otherwise, were calculated and plotted with the Excel software package (Microsoft Corporation, Soft Art Inc.)

Mechanical tests

Compression tests

Freeze-dried potato specimens (untreated and electrically treated) were compressed between parallel lubricated plates to reduce friction and ensure smooth operation during testing at a deformation rate of 10 mm/min in an Instron Universal Testing Machine (UTM), model 5544 (Instron Co., Canton, MA).

The UTM was interfaced with an IBM-compatible computer using a card. 'Merlin' software (Instron Co.) performed data acquisition and conversion of the UTM's continuous voltage vs. time output into digitized force vs. deformation relationships. The cross-sectional area of the compressed freeze-dried electrically treated and untreated potato tissue specimens typically undergoes minimal expansion, as observed in other cellular solids [27].

Elasticity

Potato specimens, both untreated and following electrical field application, underwent a uniaxial compression-decompression cycle between two lubricated plates, as outlined previously [28]. The integral of the compression curve represents the total work per unit volume, while the integral of the decompression curve denotes the recoverable work per unit volume. The crosshead speed was maintained at 10 mm/min. The direction of crosshead movement was reversed upon reaching 20% deformation of the specimen's original height [26].

Degree of Elasticity: The degree of elasticity can be quantified as the ratio of recoverable work to total work, often expressed as a percentage. It indicates how much of the deformation energy the potato can recover, reflecting its resilience or ability to return to its original state after deformation. Measuring elasticity by calculating recoverable work divided by total work is a valid approach in certain contexts, especially when dealing with viscoelastic materials. The degree of elasticity, in this case, represents the ability of a material to recover its original shape after deformation.

Relaxation tests

Potato specimens, both untreated and following electrical field application, were compressed by an Instron UTM model TM and allowed to relax as previously described [29,30].

Color

Potato specimens (untreated and subjected to an electrical field intensity of 30 V/cm for 1 min) were analyzed and monitored using a Minolta Chroma Meter CR-100 (Minolta Camera Co., Ltd., Osaka, Japan). The chromameter was first calibrated with a white standard tile and checked for recalibration between measurements, although no adjustments were necessary. Readings are reported in the L^*, a^*, b^* system, where L^* corresponds to lightness, a^* to the red/green scale, and b^* to the yellow/blue scale. The extent of browning in potato samples was measured by the changes in these parameters after 21 h [31].

Rehydration

The freeze-dried potato mass-to-water ratio was 1:50. The water used for rehydration was at room temperature. Rehydration took place over a period of 1.5 minutes with stirring. Prior to any subsequent measurements, the rehydrated material was gently blotted with tissue paper.

Statistical analysis

In general, all statistical analyses were conducted with JMP software (SAS Institute, Cary, NC), including ANOVA and the Tukey–Kramer Honestly Significant Difference method for comparisons of means. $P \leq 0.05$ was considered significant.

Results and Discussion

Potatoes can undergo dehydration using a variety of methods, such as hot air drying, microwave drying, heat pump drying, infrared radiation drying, and freeze-drying. Freeze-dried food preserves the majority of its nutrients during the process and once rehydrated, closely matches the nutritional content of fresh produce. Compared to alternative drying methods, freeze-drying offers superior preservation of color, appearance, texture, and flavor akin to fresh samples, while also minimizing nutrient loss [32-34]. Moreover, freeze-dried potatoes exhibit a high rehydration capacity, resulting in a spongy and porous interior [35]. As previously noted, a crucial aspect of assessing the quality of dehydrated foods lies in their capacity to rehydrate when immersed in a liquid medium. Figure 1 illustrates the outcomes of rehydration trials conducted on freeze-dried potato samples in water, both untreated and electrically treated.

ISSN: 2575-7091

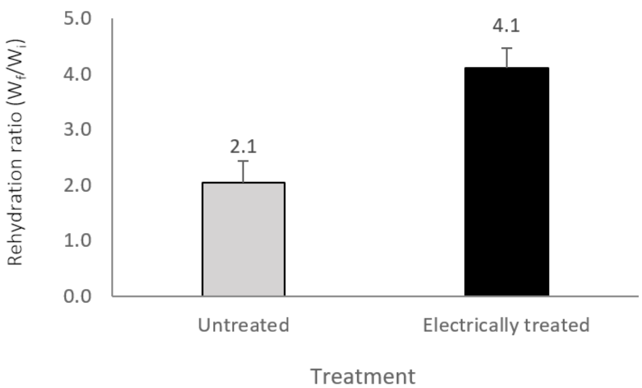

Figure 1: Rehydration ratio of potato specimens (untreated and electrically treated).

The rehydration process of the electrically treated specimens occurred at a quicker pace compared to the untreated specimens. Electrically treated specimens reached a rehydration ratio of 4.1 in 1.5 min, whereas untreated specimens reached only 2.1 in the same timeframe. This variation in rehydration rates has been linked to discrepancies in the porosity of the structures formed post-drying, as evidenced by various studies [36,37].

In our prior investigations involving freeze-dried potato specimens treated with electricity, we demonstrated that the treated samples did not exhibit significantly higher porosity compared to untreated freeze-dried tissue. This finding was rationalized by the fact that the pores induced by electrical permeabilization were on the nanometer scale, rendering them negligible in comparison to the micron-scale pores formed during freeze-drying. In the current study, we employed spiral wire-shaped electrodes, a method previously shown to augment surface porosity in freeze-dried alginate gels [38].

Figure 2 presents SEM micrographs of untreated and electrically treated freeze-dried specimens.

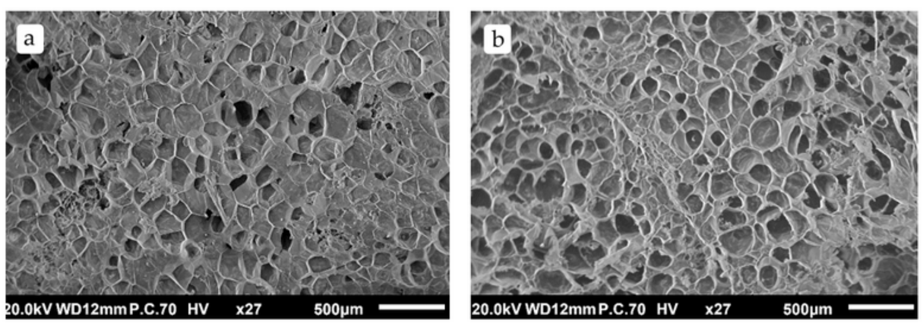

Figure 2: SEM micrographs of freeze-dried potato specimens; a and b: untreated and electrically treated tissues, respectively.

These micrographs were utilized to determine the quantity and distribution of the pores formed, as depicted in Figure 3.

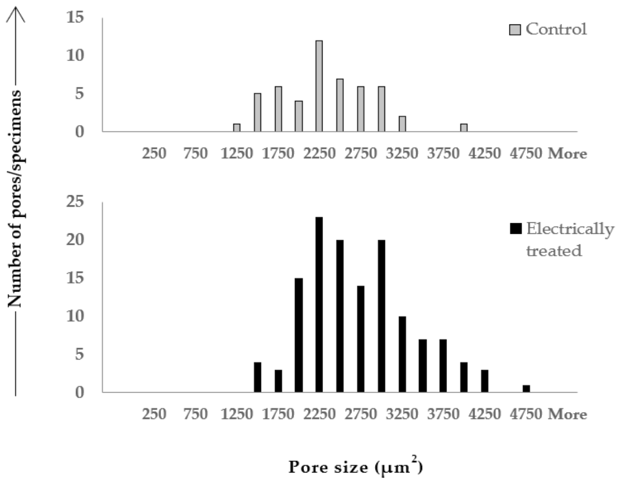

Figure 3: Number of pores/specimen vs. pore size (μm^2) as derived by image analysis for potato freeze-dried specimens before and after electrical treatment.

The number of pores per specimen versus pore size (μm^2), as determined through image analysis, was compared for freeze-dried potato specimens before and after electrical treatment.

It is evident from Figure 3 that the electrically treated specimen exhibits a significantly greater number of pores compared to the untreated specimen, along with the presence of pores with larger surface areas. This increased porosity in the electrically treated specimens may account for the higher rehydration ratio observed compared to the untreated specimens.

The higher rehydration ratios of the electrically treated specimens in comparison to the untreated ones, can be explained by the differences in their mechanical properties.

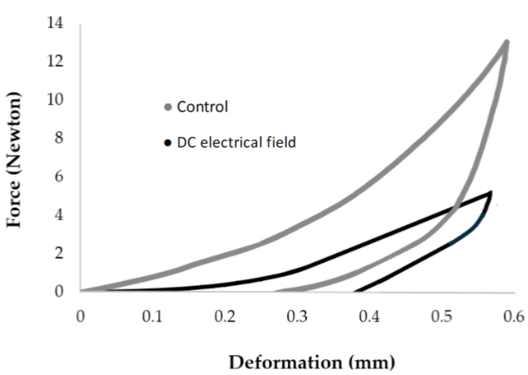

Figure 4: Degree of elasticity curves of potato specimens, before and after electrical treatment.

Figure 4 demonstrates degree of elasticity curves (i.e. compression-decompression curves) applied to potato specimens.

The degree of elasticity of the electrically treated samples was smaller than for the untreated samples (28% and 36%, respectively).

A smaller degree of elasticity in freeze-dried samples typically indicates that the material has undergone significant structural changes during the freeze-drying process, resulting in a loss of its original elasticity. This could be due to factors such as collapse of the porous structure, changes in molecular arrangement, or loss of moisture. In food science, a decrease in elasticity may affect the texture and mouthfeel of the product [39]. Additional information on the properties of the treated samples versus the untreated ones was obtained by analyzing the stress relaxation properties of the samples. Stress relaxation is a phenomenon observed in viscoelastic materials whereby, after an initial deformation, the stress in the material decreases over time while maintaining a constant strain. This behavior occurs due to the internal rearrangement of molecular chains or structures within the material. Essentially, stress relaxation reflects how a material gradually "relaxes" under a constant strain, reducing the applied stress over time [37].

Stress relaxation tests are performed to characterize the viscoelastic properties of materials, particularly polymers and biological tissues, and to understand their behavior under prolonged loading conditions. This information is crucial in various fields such as materials science, biomechanics, and food science. For example, in food science, stress relaxation tests can help assess the mechanical properties of food materials during processing, storage, and consumption, providing insights into their texture, shelf stability, and sensory attributes. M. Peleg has contributed significantly to the field of food science and engineering, particularly in the area of mathematical modeling and analysis [37, 40].

Peleg's method is a mathematical approach used to linearize stress-relaxation curves, particularly in food science and engineering. Stress-relaxation curves represent the behavior of viscoelastic materials, such as food products, when subjected to a constant deformation or stress over time. Peleg's method involves transforming the non-linear stress-relaxation data into linear form by plotting specific functions of time and relaxation modulus against each other. According to this method the experimental force relaxation curves are first normalized and then linearized [40]. Peleg equation is commonly used to linearize stress-relaxation curves and is expressed as follows:

1) $$\frac{t}{Y(t)} = \frac{F_0 \cdot t}{F_0 - F_t} = k_1 + k_2 t$$

where F_0 is the initial force, F_t is the decaying force after time t and k_1 and k_2 are constants. According to this equation the reciprocal of k_1 depicts the initial decay rate, and the reciprocal of k_2 is the representative of a hypothetical asymptotic level of the normalized relaxation parameter $[(F_0 - F_t)/F_0]$. Since the latter is expressed as a dimensionless ratio it has the same value if expressed in terms of stresses or moduli [41].

k_1 is the constant related to the initial rate of relaxation or the slope of the linearized curve. It reflects the material's viscoelasticity and how quickly it responds to the applied stress. Higher values of k_1, suggests a more elastic behavior of the material. Lower values of k_1, on the other hand, indicate a more viscous behavior. k_2 of eq. 1 is the representative of the degree of solidity and it varies between the value of l for a material that is truly a liquid (i.e. all the stress relaxes) to a value of ∞ for an ideal elastic solid where the stress does not relax at all [40]. Figure 5 summarizes the stress relaxation tests for the electrically treated potato samples versus the untreated ones.

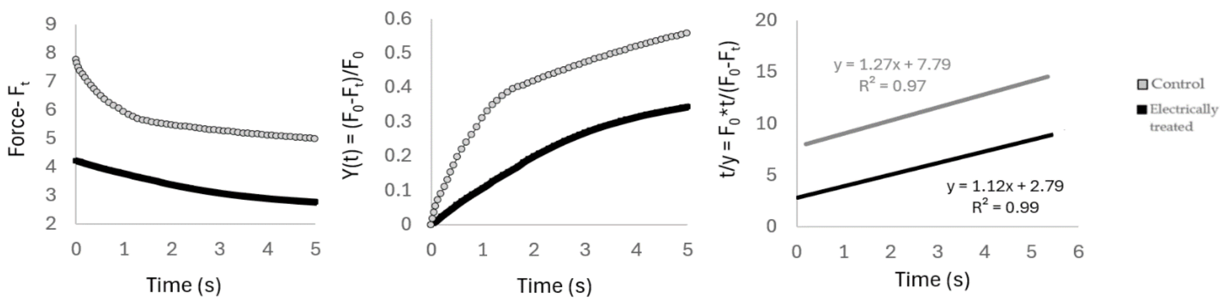

Figure 5: Stress-relaxation curves of potato specimens, before and after electrical treatment.

The constants k_1 and k_2 were higher for the control specimens (1.27 and 7.79, respectively) compared to the electrically treated ones (1.12 and 2.79, respectively), indicating a more elastic behavior in the control specimens. These findings are consistent with the results shown in Figure 4, which illustrate an elasticity of 36% for the control specimens versus 28% for the electrically treated specimens.

Finally, we examined the effect of the electrical treatment on the color of the potato specimens. Color is a crucial quality attribute in potato products, influencing consumer perception, acceptability, and purchase decisions. The visual appearance of potato products, including their color, significantly impacts consumer perception of freshness, quality, and palatability [42-44]. Vibrant and appetizing colors are often associated with freshness and superior quality, while dull or discolored products may be perceived as less desirable. Color can serve as a distinguishing factor among various potato products in the market. Unique and attractive colors can help products stand out on store shelves and attract consumers' attention, facilitating brand recognition and loyalty [42]. The color of potato products can also indicate their cooking quality and suitability for different culinary applications. For example, consumers often prefer potato products with a golden-brown color when frying or roasting, as it signifies crispiness and flavor development during cooking. Color is often associated with nutritional value in food products. Bright and vibrant colors in potatoes, such as deep yellow or purple hues, may be perceived as indicative of higher nutritional content, including antioxidants and phytonutrients [43]. Monitoring and maintaining color consistency during processing and storage are essential for ensuring product quality and shelf stability. Changes in color, such as browning or discoloration, may indicate enzymatic or non-enzymatic reactions, oxidation, or microbial spoilage, which can affect the safety and sensory properties of potato products [45].

As previously noted, color is a key quality parameter for potato products. Measures, such as preservation methods, are undertaken to uphold an attractive and consistent color throughout the product's shelf life. Browning is a particular concern to be addressed. Therefore, it was imperative to assess the impact of electrical treatment on the specimen's color. Quantitative results of color determinations are shown in Figure 6.

Specimens which were electrically treated prior to freeze-drying were brighter relative to the untreated specimens (i.e. higher $L*$ values), as previously described [16].

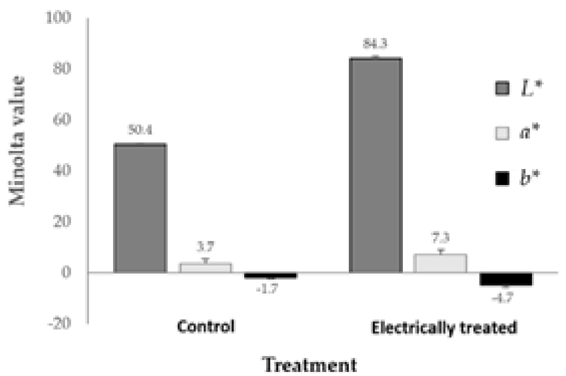

Figure 6: Color parameters of potato specimens (untreated and electrically treated). *L** corresponds to lightness, *a** to the red/green scale, and *b** to the yellow/blue scale.

This result is attributed to the pH changes leading to inactivation of enzymes responsible for browning [26,24]. In addition to the *L** values, a slight difference in *b** values were observed between the untreated and the electrically treated specimens. The higher values of *b** in the untreated specimens in comparison to the treated ones reflects a higher tendency towards yellow and thus there is some yellowish contribution to the browning of the non-electrified specimens.

Conclusions

The straightforward application of low DC electrical fields effectively boosted the rehydration ratio of freeze-dried potato specimens. Such treatment holds promising utility across diverse applications, including enhancing the rehydration of fruit or vegetable pieces destined for cereals or soups, as well as facilitating quick preparation in instant meals where time is of the essence.

References

1. Górnicki K, Choińska A, Kaleta A (2020) Effect of Variety on Rehydration Characteristics of Dried Apples. Processes 8: 1454.
2. Zhou C, Feng Y, Zhang LY, Abu E, Wahia H, et al. (2021) Rehydration characteristics of vacuum freeze- and hot air-dried garlic slices. LWT - Food Science and Technology, 143, 111158.
3. Lee SK, Kader AA (2000) Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, 20: 207-220.
4. Li H, Yuan Q, Deng Q, Gao D, Dai J (2013) Effect of different dehydration methods on the product quality and rehydration property of longan (*Dimocarpus longan Lour.*). International Journal of Food Science & Technology, 48: 1032-1038.
5. Chakraborty S, Shukla AC, Mishra HN, Sarkar PK (2015) Quality of dehydrated green chili (*Capsicum annuum L.*) powder as affected by different drying methods and pretreatments. Journal of Food Science and Technology, 52: 5862-5872.
6. Lewicki PP (1998) Some Remarks on Rehydration of Dried Foods. Journal of Food Engineering, 36: 81-87.
7. McMinn WA, Magee TR (1997) Quality and physical structure of a dehydrated starch-based system. Drying Technology, 15: 1961-1971.
8. Krokida MK, Marinos-Kouris D, Maroulis ZB (2003) Rehydration kinetics of dehydrated products. Journal of Food Engineering, 49: 33-42.
9. Zielinska M, Markowski M (2015) The influence of microwave-assisted drying techniques on the rehydration behavior of blueberries (*Vaccinium corymbosum L.*). Food Chemistry, 196: 1188-96.
10. Lewicki PP, Lukaszuk A (2007) Changes pf rheological properties of apple tissue undergoing convective drying. Drying Technology, 18: 707-722.
11. Krokida MK, Maroulis ZB (1997) Effect of drying method on shrinkage and porosity. Drying Technology, 15: 2441–2458.
12. Varela P, Fiszman S, Santacatalina JV (2013) Nutritional improvements of rehydrated dried fruits: An opportunity to increase the intake of health-promoting compounds. Journal of Food Engineering, 117: 436-443.
13. Harnkarnsujarit N, Kawai K, Watanabe M, Suzuki T (2016) Effects of freezing on microstructure and rehydration properties of freeze-dried soybean curd, Journal of Food Engineering, 184: 10-20.
14. Garner AL (2019) Pulsed electric field inactivation of microorganisms: from fundamental biophysics to synergistic treatments. Applied microbiology and biotechnology, 103: 7917-7929.
15. Sastry S (2008) Ohmic Heating and Moderate Electric Field Processing. Food Science and Technology International, 14: 419-422.
16. Zvitov-Yaa'ri R, Nussinovitch A (2014) Browning prevention in rehydrated freeze-dried non-blanched potato slices by electrical treatment. LWT - Food Science and Technology, 56: 194-199.
17. Nowosad K, Sujka M, Pankiewicz U, Kowalski R (2021) The application of PEF technology in food processing and human nutrition. Journal of food science and technology, 58: 397–411.
18. Vorobiev E, Lebovka NI (2019) Pulsed electric field in green processing and preservation of food products. Green Food Processing Techniques.
19. Zhang HW, Mohamed A, Breikin T, Howarth M (2021) Modelling and Simulation of an Ohmic Heating Process. Open Journal of Modelling and Simulation, 9: 26-42.
20. Raso J, Heinz V, Álvarez I, Toepfl S (2022) Pulsed Electric Fields Technology for the Food Industry Fundamentals and Applications: Fundamentals and Applications.
21. Kranjc M, Bajd F, Serša I, Mark de Boevere DM (2016) Electric field distribution in relation to cell membrane electroporation in potato tuber tissue studied by magnetic resonance techniques, Innovative Food Science & Emerging Technologies, 37: 384- 390.
22. Tao Y, Zhang M,Adhikari B (2012) Effect of osmotic precolortreatment on freeze-drying characteristics and quality of potato. Drying Technology, 30: 407-414.

23. Vega-Mercado H, Góngora-Nieto MM, Barbosa-Cánova, GV, Swanson BG, Góngora-Nieto M (2001) Pulsed electric fields for food preservation: basics and applications. Food Engineering Series, 5: 139-166.

24. Zvitov, R, Nussinovitch A (2005) Low DC electrification of gel-plant tissue 'sandwiches' facilitates extraction and separation of substances from beta vulgaris Beetroots. Food Hydrocolloids, 19: 997-1004.

25. Tal Y, van Rijn J, Nussinovitch A (1999) Improvement of mechanical and biological properties of freeze-dried denitrifying alginate beads by using starch as a filler and carbon source. Applied Microbiology and Biotechnology, 51: 773–779.

26. Zvitov R, Nussinovitch A (2001) Physico-chemical properties and structural changes in vegetative tissues as affected by direct current (DC) electrical field. Biotechnology Progress, 17: 1099-1106.

27. Gibson LJ, Ashby MF (1988) Cellular solids: Structure and properties. Oxford: Pergamon Press.

28. Kampf N, Nussinovitch A (1997) Rheological characterization of κ-carrageenan soy milk gels. Food Hydrocolloids, 11: 261-269.

29. Nussinovitch A, Peleg M, Normand MD (1989) A modified Maxwell and a non– exponential model for characterization of the stress relaxation of agar and alginate gels. Journal of Food Science, 54: 1013-1016.

30. Peleg M, Calzada JF (1976) Stress relaxation of deformed fruits and vegetables. Journal of Food Science, 41: 1325-1329.

31. Dybowska BE, Fujio Y (1998) Optical properties of the pre-gel and gel state of soy proteins gelled by GDL under different physical conditions. Journal of Food Engineering, 35: 471-482.

32. Huber KC, Embuscado ME (2015) Edible Films and Coatings for Food Applications. Springer.

33. Kaushik N, Dadhich AP (2018) Advances in Potato Chemistry and Technology. Academic Press.

34. Mujumdar AS, et al. (2007) Handbook of Industrial Drying. CRC Press.

35. Schellekens M (2007) Application of Novel Food Drying Techniques. Drying Technology, 25: 1003-1013.

36. Li H, et al. (2018) Effects of pore size distribution and porosity on water absorption properties of freeze-dried porous alginate hydrogels. Journal of Food Engineering, 238: 123-131.

37. Zhang Y, et al. (2016) Effect of Pore Characteristics on Rehydration Behavior of Freeze-Dried Strawberry. Drying Technology, 34: 1605-1614.

38. Nussinovitch A, Zvitov-Marabi R (2008) Unique shape, surface and porosity of dried electrified alginate gels. Food Hydrocolloids, 22: 364-372.

39. Mizuno M, Kobayashi S, Ogoshi Y, YanagidaY, Iguchi T (2006) Physical properties of freeze-dried soybean curd as affected by various freeze-drying conditions, Journal of Food Engineering, 75: 58-63.

40. Peleg M, Normand MD (1983) Comparison of two methods for stress relaxation data presentation of solid foods. Rheologica Acta, 22: 108–113.

41. Peleg M (1977) An empirical model for the description of moisture sorption curves. Journal of Food Science, 42: 19-21.

42. Khan MK, et al. (2019) Role of color in food acceptability and choice: potato chips. Food Science & Nutrition, 7: 3238-3245.

43. Oliveira FD, et al. (2016) Color Measurement in the Assessment of Potato Quality. In: The Potato Crop (pp. 1-27). Springer, Cham.

44. Palazoglu TK, et al. (2017) Modeling color changes in stored potatoes: A comparison of approaches. Computers and Electronics in Agriculture, 135: 114-125.

45. Demircan B, Velioglu YS (2024) Control of Browning, Enzyme Activity, and Quality in Stored Fresh-cut Fruit Salads through Chitosan Coating Enriched with Bergamot Juice Powder. Foods, 13: 147.