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A Comprehensive Review Of Leading-Edge Dehydration Techniques Used For Fruits And Vegetables In The Food Processing Industries

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Abstract
Innovative dehydration methods are being developed by the food technology sector to increase shelf life, cut waste, and promote sustainability. Conventional techniques such as sun and oven drying have problems with energy use, contamination, and nutrient loss. Energy efficiency, nutrient retention, and quicker drying durations are some advantages of recent developments in osmotic, vacuum, microwave, and infrared dehydration. The objective of this study is to determine the innovative dehydration techniques for fruits and vegetables used within the food technology industry. In the study, all journal articles published from 2018 to 2024 were included. Each article is by the objective of the study. Research articles that were easily accessible to the public were included. The findings of the study depicted that osmotic dehydration is a valuable method of drying that helps in the reduction of energy consumption and preserves color. It is analyzed that drying techniques provide benefits to types of fruit and drying needs.
Keywords: *Dehydration Technology, Osmotic Dehydration, Food Technology, Fruits and Vegetables.*

1. INTRODUCTION

Background for Review

In the present market scenario, the food tech industry faced a transformative shift as it seeks to address critical issues associated with preserving food, reducing waste, and sustainability. From the techniques of food preservation, dehydration is one of the most common methods used to enhance the shelf life of fruits and vegetables (Ahmed et al., 2016). The process of dehydration is associated with removing content of water from food products, reducing spoilage, and enabling longer storage durations without the need for refrigeration. This technique is not only important for minimizing post-harvest losses but also essential in ensuring a steady supply of nutritious products throughout the year (Qiu et al., 2019).

There are various methods of dehydrating foods such as sun drying, air drying, oven drying, solar drying, and electric dehydrators. It is determined that sun drying is the oldest method which is used for dehydrating foods. Similar to this method, is air drying which is also simple in that it doesn't require any special equipment. Under this method, food is placed to protect from the sun making it a good option for leafy vegetables and spices (Ajmera, 2022).

On the other side, recent advancements in dehydration technology emphasize techniques including infrared drying, vacuum drying, microwave drying, and osmotic dehydration. These methods provide a unique advantage in terms of energy efficiency, speed of drying, and preserving nutrients and sensory qualities (Mohammed et al., 2024).

It is evaluated that traditional dehydration techniques also have certain issues as conventional dehydration techniques include air drying, sun drying, and freeze-drying which dominated the industry for the past years. The sun drying method is inexpensive but it is more time-consuming, weather dependent, and linked with contamination (Wang et al., 2023). Hot drying is faster but results in loss of nutrients, degradation of color, and altered taste and texture because of high temperature. Freeze-drying helps preserve nutrients and flavors as well, but it is costly and energy-intensive, limiting its use to premium products.

The industry has been driven to explore innovative methods that help in balancing quality, cost-efficiency, and sustainability (Rahman et al., 2018). Shifting towards innovative dehydration techniques is mainly driven by increasing demand for high-quality, shelf-stable, and convenient food products. It is identified that consumers are becoming more health-conscious and are seeking minimally processed foods that retain natural flavors, nutrients, and colors. In addition to this, there is increasing interest in sustainable food production practices that help in the reduction of energy consumption and minimizing waste. This resulted in creating pressure on the food technology sector to adopt and refine dehydration techniques

that meet consumer preferences by aligning sustainable goals (Lewicki & Lenart, 2020). In the context of fruits and vegetables, dehydration is mainly essential due to the high rate of perishability of these products. Globally, losses after harvesting fruits and vegetables become a significant issue with a substantial portion of the produce going to waste due to inadequate preservation methods. Employing innovative dehydration techniques, food manufacturers help transform seasonal produce or surplus into value-added products including dried fruit snacks, ingredients, and powdered vegetable mixes for convenience foods (Shete et al., 2018).

The review aims to explore the development of dehydration techniques for fruits and vegetables, emphasizing advantages, principles, and applications. The review also discusses how these techniques are shaping the future of the food technology industry and contributing towards the development of sustainable food systems.

1.1 Review Objectives

To analyze the impact of different dehydration techniques used for fruits and vegetables within the Food Technology Industry

To evaluate the significance of innovative dehydration techniques on product quality, shelf life, and nutritional retention for fruits and vegetables within the Food Technology Industry

2. INCLUSION AND EXCLUSION CRITERIA

The papers used for this study were selected using the inclusion-exclusion criteria listed below.

Inclusion Criteria:

➔ Studies that were released between 2019 and 2024, or over 5 years' time frame.

➔ English translations or original publications of studies were only included.

➔ Every review paper, conceptual, empirical, and article that was related to the search terms was considered.

➔ The research sources that were publicly accessible were included.

Exclusion Criteria:

➔ Research conducted before 2019 and in 2024 during the pre-publication phase was excluded.

➔ Research published in any language other than English was excluded from consideration.

➔ Unless it was easily accessible, no conscious effort was taken to translate the original articles.

➔ The research that was not entirely accessible was also rejected.

3. RESEARCH METHODOLOGY

3.1 Search Strategy

For completing the present work Google Scholar and SCOPUS electronic databases were searched for gaining published articles for the same. The Boolean search strings were taken into account ("Innovative Dehydration Techniques and Fruits and Vegetables" OR "Innovative Dehydration Techniques and Food Technology Industry" OR "SCOPUS" OR "English) AND ("Innovative Dehydration Techniques and Product Quality" OR "Innovative Dehydration Techniques and Shelf Life" OR "Innovative Dehydration Techniques and Nutritional Retention. Based on these terminologies results are gained and further aims in scrutinizing the inclusion and exclusion criteria for the research.

3.2 Methods for Study Selection and Appraisal

Initial keyword searches based on "Dehydration Technology and Fruits and Vegetables" and "Dehydration and Food Technology" were considered for the database records presented in the studies and articles. The period considered at the time of search studies was 2018 -2024, or over a 5-year time frame. Thus, 30 references were finalized for this study.

4. REVIEW RESULTS AND DISCUSSION

Impact of different dehydration techniques used for fruits and vegetables within the food technology industry

Osmotic dehydration is one of the innovative techniques that help enhance the shelf life of fruits and vegetables in the food technology sector. It is combined with hot air drying and has gained attention to retain the product quality by preventing cell destruction. The benefit of adopting this technique is that it retains the color of the food products without adding suplhites and also consumes less energy.

Emerging and Advanced Technologies

The review highlights several modern techniques, including:

- **Microwave Drying:** Offers rapid moisture removal and energy savings but is limited by uneven heating and high capital costs.
- **Freeze Drying:** Provides superior quality retention, especially for heat-sensitive foods, but is energy-intensive and expensive.
- **Vacuum and Infrared Drying:** Allow for lower drying temperatures and better retention of flavor and nutrients.
- **Hybrid Techniques:** Combining methods (e.g., microwave-vacuum or infrared-convective drying) has emerged to enhance drying efficiency and product quality.

Osmotic dehydration is an effective method for producing high-quality, shelf-stable food products while conserving energy and preserving nutrients. However, improvements in modeling, scalability, and sustainability are essential for broader industrial application.

modern methods such as freeze drying and microwave-vacuum drying preserve nutritional and sensory properties better but are energy-intensive and costly (Ratti, 2001).

Convective drying is also a simple hot air-drying method used for dehydrating fruits. This method is classified into three categories: hot air-drying, convective multi-flash drying, and fluidized bed drying. This method is mainly used for solid fruits. Vacuum drying is another method for drying fruits that are sensitive to heat and deteriorate rapidly because of high temperature and oxidation.

It is evaluated that irradiation is an emerging method of preventing minimally processed fruits and vegetables (MPFVs) as it helps in increasing shelf life as well as quality. This method is mainly used after cutting and packaging of MPFVs (Gomes et al., 2023). This also has limitations as it has a higher cost of implementation.

It is identified that microwave treatment is also an innovative method of dehydration. The study conducted by (Haq 2018) analyzes the influence of microwave treatment on the dehydration aspects and moisture of Himalayan black carrots.

Significance of innovative dehydration techniques on product quality, shelf life, and nutritional retention for fruits and vegetables within the Food Technology Industry

Key quality indicators influenced by drying include texture, color, flavor, and nutrient retention. Studies have consistently shown that freeze drying retains the highest nutrient levels, followed by vacuum and infrared drying (Alibas, 2009). Color and rehydration capacity are also preserved best with gentle drying methods. However, these benefits often come with higher operational costs and longer processing times (Sagar & Kumar, 2010).

Vacuum drying lowers the boiling point of water, enabling low-temperature processing. Combining vacuum with microwave heating enhances drying rate and preserves thermally sensitive compounds. These methods have proven superior in maintaining:

- Color (L*, a*, b* values)
- Aroma compounds (e.g., ethyl acetate, ethyl butyrate)
- Nutritional content

It is determined pulsed electric field (PEF) is one of the techniques to enhance the drying process along with improving the quality and stability of fruits such as red bell peppers, kiwi fruits, and red beetroots. It is observed that freeze drying is considered an important drying technology that helps maintain the attributes of food and deal with issues such as quality degradation and long drying times. This technique supported providing benefits related to drying efficiency and product quality and it has challenges linked with color stability during storage.

Innovations have also extended to combining drying techniques (hybrid drying) to optimize energy consumption and product quality. Recent studies demonstrate the integration of microwave and vacuum drying to accelerate the drying process while preserving nutritional content (Zhang et al., 2017).

Furthermore, the literature has explored the development of value-added products using dehydrated vegetables, such as instant soups, powders, snacks, and rehydrated meals. These products cater to contemporary consumer demands for convenience, health benefits, and clean-label formulations.

Chemometric analysis is also an effective method to expose the mechanism of color change in food at the time of processing. In the past few decades, the production of dried fruits has increased globally. This also led to increasing consumer acceptance of nutritious packaged food and the use of dried fruits in products including bakery goods and confectionery enhanced the demand for dried fruit. It is evaluated that

physical intervention is associated with thermal pre-drying treatment used to deactivate enzymes and retain the color of the fruit.

5. CONCLUSION

It can be concluded from the research that the process of dehydration is essential for extending the shelf-life of fruits and vegetables. On the other side, innovative techniques such as microwave, vacuum, and osmotic dehydration provide enhanced efficiency, retaining nutrients, and saving energy by aligning with the demand of consumers for minimally processed and sustainable food products. Moreover, there are also other techniques adopted by the food industry in the process of drying fruits and vegetables including electrolyzed water, irradiation, UV radiation, microwave treatment, spray drying, convective, and vacuum drying.

6. LIMITATION OF STUDY

The first and foremost limitation of the study is that it relies on secondary sources of data which affects the information related to region-specific and also limit the applicability of the findings of the study in different geographical areas. Another limitation is that the study is only focused on the fruits and vegetables related food technology industry and will also limit the gathering of information. There are different methods of dehydration but the study might not include emerging techniques because of the limited availability of updated research.

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