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# DRYING TECHNOLOGY – CURRENT RESEARCH AND INDUSTRIAL APPLICATIONS

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**REVIEW BASED BOOK CHAPTER**

# DRYING TECHNOLOGY: APPLICATIONS AND CHALLENGES IN FOOD INDUSTRY

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## Abstract

Drying process is a common food preservation technique that eliminates moisture from food goods to increase shelf life, stability, and convenience along countless applications in food sector. By reviewing of the basic ideas and mechanisms involved in drying processes, this chapter dives into the practical applications of drying techniques in a variety of food categories. It delves into the drying of fruits, vegetables, cereals, meats, dairy products, herbs, and spices, clarifying the special issues and obstacles connected with each food item. The notable impact of drying on the nutritional composition, sensory characteristics, and functional qualities of food items explored current trends, challenges and advances of drying technology in food sector. The processes such as energy consumption, cost-effectiveness, and sustainability of various drying procedures, offering insights into their overall viability and practicality in the food industry along reviewing the economic and environmental ramifications of drying processes. More innovative methods with accurate operative settings might enhance food preservation, quality, and market competitiveness by providing a greater understanding of the benefits and constraints connected with drying procedures.

**Keywords**
*Drying Process, Food Preservation, Shelf Life, Dry Powder, Drying Methods, Industrial Challenges*

## 1. Introduction

Drying processes are frequently employed in the food sector for a variety of applications, including dairy products, coffee, tea, flavors, powdered beverages, processed cereal-based meals, fruits, vegetables, and spices. Drying is employed in the manufacturing of malt, where the kilning procedure is utilized to remove water from wet

germinated grain. This drying stage is critical in the malting process since it contributes to the ideal color and flavor of the malt. Drying fresh food products requires complicated processes such as energy transfer, unbound moisture evaporation, and water particle movement inside the cellular structure. Drying is a heat-driven process that results in solid-dried goods. Vaporizing bound water is critical for producing a safe and dry product. Drying fresh food goods reduces bacteria development and extends the product's shelf life. The drying method consists of eliminating unbound moisture followed by the removal of interior moisture. The drying process also has an impact on enzyme activity, sensory qualities, and microbial proliferation in food. Various drying processes have been widely researched for their chemical and biological changes in food items, and changed through time as advanced equipment and optimized drying parameters are developed [1, 2].

Sun drying, hot air drying, contact drying, infrared drying, freeze-drying, fluidized bed drying, and dielectric drying are some of the most prevalent drying processes used in the food sector. Furthermore, drying food has been utilized as a technique of food preservation for millennia and may be used as an alternative or supplement to canning and freezing procedures. Individuals may now dry numerous foods at home year-round with current food dehydrators, which are great for hiking, camping, and other outdoor activities due to their lightweight, compact design and lack of refrigeration. Intermittent drying is another technology created to address the constraints of convective drying by enhancing drying kinetics, product quality, and lowering energy usage in the food sector [2, 3, 4].

## 2. General Overview and Drying Methods

Each drying method has its own set of advantages and disadvantages. Pre-evaporation, for example, allows for an increase in the dry substance content of wet material without the need for additional equipment, which can be beneficial in terms of efficiency and energy consumption. This approach can also be used in conjunction with specific dewatering equipment, such as presses or centrifuges, to improve the dry material content while consuming less energy throughout the drying process. Cabinet-type dryers, also known as dehydrators, provide controlled heat and air circulation for

drying food, making them a popular choice for home drying. Oven drying, on the other hand, requires the use of an oven to dry the food, which may limit its accessibility and convenience. Air drying, a more traditional method, can be done in a variety of settings, such as a shady porch or corner of the kitchen, offering flexibility and ease of use. This criterion includes various factors such as drying time, energy efficiency, protection from environmental elements, and the possible influence on the quality and appearance of the dried product [6, 7, 8].

### 2.1. Impact on Quality and Characteristics of Food Products

The drying process can have a considerable influence on the quality and features of food items. Dehydration procedures, for example, have been shown to preserve superior quality and nutritional content than sun drying. However, it is crucial to remember that drying processes in general might cause vitamin and nutritional loss in food items. Drying procedures might impact the water-holding capacity of food goods, particularly meat, where it may decrease. Cooking the items before drying helps to eliminate any bacteria that may be present and ensuring food safety. Lower temperatures can be employed in high-pressure drying (HPD) dryers to improve the overall quality of the dried product [5].

It is also important to note that the storage and treatment of dried foods play an important role in keeping their quality. Dried food containers may be opened and reopened repeatedly without affecting the contents, making them easy to store and use. Canned goods, on the other hand, should be consumed quickly after opening to avoid spoiling while drying processes differ from evaporation as they produce concentrated liquid products with different properties than the original food product. The primary goal of drying is to increase the shelf-life of foods by decreasing their water activity and limiting the growth of microbes and enzymes that cause deterioration and undesirable chemical changes. To guarantee proper drying, elements such as time, temperature, and pre-treatment of the food goods must be considered. Starting with high-quality ingredients is critical for getting optimum drying outcomes. Low humidity, low heat, and excellent air circulation are crucial for efficient drying since they help keep the natural flavor, nutritional content, and scent of the food goods. Drying at low

temperatures can also minimize or eliminate the requirement for flavor and scent additions in food items [1, 6].

It should be noted that hastening the drying process by raising the temperature might have a detrimental impact on the quality and attributes of the food items. Higher temperatures might cause food to cook rather than dry, resulting in a lesser quality end product. This can also cause "case hardening," in which the food is cooked on the exterior but stays moist on the interior, potentially leading to mold growth, later in storage. As a result, it has been advised that food to be dried at the optimal temperature of 140°F to produce the maximum outcomes. Different drying methods, such as utilizing a dehydrator, oven, microwave, or air-drying, can affect the quality and features of food items. Oven drying, for example, is more difficult to manage than dehydrating and takes longer, resulting in increased energy use. Blanching vegetables and pre-treating fruits before drying can help preserve food quality. Furthermore, keeping dried goods in a dark, cold place and insect-proof containers is required to retain their quality over time. By choosing the optimal drying process and executing suitable storage practices are critical for keeping food product quality and qualities [4, 6, 7].

## 3. Role of Drying Techniques for Food Safety and Quality

Drying techniques are utilized for various purposes and products (Figure 1) in food sector, few of them discussed below:

### 3.1. Preservation of Food Products

Drying is a common, oldest and most basic food preservation method, with a recorded history in many civilizations and communities [10, 11, 13]. The primary purpose of drying methods is to eliminate moisture from food products, which limits the growth of bacteria, mold, and yeast that cause spoilage. The shelf life of foods may be greatly extended by using the right drying techniques and storage setups while drying also decreases the water content of foods, making them lighter and easier to store and transport, as dried foods are lightweight, take up little room, and do not require refrigeration along their suitability for outdoor activities like trekking and camping. Drying may be accomplished in a number of ways, including the sun, an oven, or a

food dehydrator set to the ideal temperature, humidity, and airflow. Food enzymes are not entirely deactivated by drying, even if it slows down their activity. However, combining drying with additional preservation processes like freezing or canning might improve the overall preservation process. Drying is essential for food preservation as it removes moisture and creates an environment that prevents the growth of bacteria that cause degradation [9, 11, 12, 14].

**Figure 1** Preservation of different food products [15, 16, 17]

### 3.2. Inhibition of Bacterial Growth

Drying inhibits the development of microorganisms in food by lowering water activity, which is a fundamental element in microbial survival and growth. The process of drying has an impact on the microorganisms and their methods for survival, which inhibits or delays their growth. Dry foods are hygroscopic, meaning they can draw and hold moisture. When the equilibrium between relative humidity and moisture content is disrupted, this feature produces an appropriate moisture environment for mold development. For this reason, it's critical to maintain the proper relative humidity in the storage environment to limit microbial development in dried foods. However, drying may not entirely eradicate germs and spore cells, which can survive for months and create health concerns. Due to the elimination of water, drying causes several changes in the structure of microorganisms, including denaturation of proteins and damage to cell walls. Additionally, microorganisms defend against cellular damage rather than repair it, in response to drying stress. The drying process also diminishes the efficacy of the resonance strength of water molecules, which helps prevent membrane protein

denaturation even at high temperatures. As a result of drying, bacteria are exposed to stressful settings that might inhibit or inactivate them. These environments can include ones with high or low temperatures, increased osmolality, and acidic pH [18]. Various drying processes and technologies have been developed to efficiently suppress microbial growth and assure microbiological safety in dried items. A combination of approaches is sometimes required to efficiently inactivate or kill microorganisms during the drying process to make it an effective method for delaying the development of microbes in food and extending the shelf life of dried goods.

### 3.3. Production of Powdered Products

Drying processes are critical in the manufacturing of powdered commodities, serving different uses and providing numerous benefits. To ensure the goods' long-term stability and availability all year round, one of the main goals is to eliminate moisture from them. Drying processes enable simpler storage and transportation by converting liquid material into dry, powdery form. Furthermore, drying processes are regarded Best Available processes in the industry since they not only preserve the product but also improve its quality. For example, drying improves the re-hydrating characteristics of powdered commodities, resulting in higher quality powders with improved sensory attributes. Drying procedures restrict bacterial development and microbial activity by eliminating moisture from the fresh food, extending its shelf life. Additionally, drying techniques and factors affect not only the bulk density of dried goods but also how big and how angular they appear to be to the client [19, 20]. Drying techniques enable the production of powdered commodities that may be used as coatings, flavorings, or full meals depending on the unique food product, increasing convenience and diversity in food consumption. Drying techniques are essential for generating stable, useful, and superior-quality powdered goods [21]. In order to maintain the quality and increase the shelf life of powdered commodities, drying processes are essential as the volume and weight of the items may be decreased using these methods, which lowers the expenses associated with packing, storage, and transportation. Drying procedures achieve a water activity level of less than 0.3, effectively inhibiting microbe development and undesirable chemical reactions and thereby extending the storage duration of powdered commodities. Depending on the unique properties of the raw material,

different drying procedures may be used to protect the quality and shelf life of powdered commodities, including thermal drying, osmotic dehydration and mechanical dewatering [20].

For example, freeze-drying is advised for retaining the functional integrity of powdered items, but osmotic pre-treatment can be employed to minimize elasticity and viscosity loss during rehydration. Drying procedures have the ability to alter the flavor and texture of the items in addition to keeping their physical qualities, resulting in the creation of novel and healthier snack choices. Color, bulk density, porosity, phytochemicals, sugars, proteins, volatile substances, and sensory qualities are used to evaluate the quality of dried items. The best drying method may differ based on the particular material being dried, hence careful analysis of drying protocols is required in order to suggest particular drying parameters for each product. In order to preserve the quality and lengthen the shelf life of powdered items, moisture must be removed, and microbiological contamination must be kept to a minimum [20, 22, 23, 24]. Examples of powdered products are given in Table 1 along their visuals in Figure 2.


**Figure 2a** Spray-drying Machine for powdered goods [30]

**Table 1** Different dried food products in market

| Product name | Description | Reference |
|---|---|---|
| **Egg powder** | Egg powder is a dried version of eggs that may be reconstituted with water and used in place of fresh eggs in cooking and baking. It is manufactured by eliminating the moisture from eggs, generally by a spray-drying technique, and grinding them into a fine powder. When compared to fresh eggs, this powder has a longer shelf life and is easier to store and transport | [25] |
| **Milk powder** | Milk powder, often known as powdered milk or dry milk, is a dairy product prepared by evaporating milk to eliminate its moisture content. The powder that results can be reconstituted with water to make liquid milk or utilized as a component in a variety of culinary and beverage applications | [26] |
| **Coffee powder** | Coffee powder, often known as instant coffee, is a form of coffee that is produced by drying. It entails removing soluble chemicals from brewed coffee and then dehydrating the liquid to get a dry, powdered form | [27] |
| **Orange powder** | Orange powder is commonly used to describe a powdered version of oranges or orange zest. Oranges or their peels are dried and ground into a fine powder to make it | [28] |
| **Strawberry powder** | Strawberry powder is a powdered version of strawberries created by drying and crushing the fruit into a fine powder. It's a common natural flavoring and coloring component in a variety of food and beverage applications | [29] |

### 3.4. Production of Ready-to-Eat Meals

Preserving ready-to-eat meals by air drying is a widespread practice; however, it might negatively affect the food's quality and shelf life. Exposure to air and moisture during

the drying process might reduce the overall quality of the food, therefore specific care must be taken to keep it fresh and extend its duration of storage. It is critical to store dried foods in airtight containers to avoid moisture reabsorption and retain quality [31]. Additionally, it is advised to regularly inspect the dried food during storage to make sure it is still dry and shows no symptoms of mold or rotting and to avoid spoiling, removal of any moisture from the food and re-drying should be done. The shelf life of air-dried meals is also significantly influenced by the surrounding storage conditions. Storing dried food in a cold, dry, and dark environment with a temperature below 60°F will help to increase its shelf life. However, if the humidity is excessive, the food may begin to mold before it dries by shortening its shelf life. In order to avoid moisture reabsorption and preserve the quality of air-dried ready-to-eat meals, it is crucial to take into account the storage conditions and implement the necessary steps [22, 31].


**Figure 2b** Left Freeze-dried variety soup box [32]; Right: Instant Asian ready-to-eat meals [33]

Freeze-drying is a particularly beneficial preservation technology for the creation of ready-to-eat meals. Freeze-dried meals have a number of benefits, including a lengthy shelf life that makes them perfect for long-term distribution and storage. Freeze-drying helps to keep key minerals and phytochemicals in foods, ensuring that ready-to-eat meals retain nutritious value, also, freeze-dried meals are lightweight, simple to handle, and transportable, which makes them practical for both producers and customers [34, 35]. Fruits and tiny vegetables are particularly well-suited for ready-to-eat meals since they may be freeze dried without losing quality or taste. Additionally, customers may quickly and easily rehydrate freeze-dried meals by just adding water, making them handy [36]. This technology makes it feasible to efficiently preserve freeze-dried dairy

and egg products, something that is not achievable with conventional preservation methods [37]. The quality of freeze-dried foods is substantially superior to that of conventional drying processes, retaining fragrance, rehydration characteristics, and general bioactivity. In terms of making ready-to-eat meals, freeze-drying has a lot of benefits, including better quality preservation, a longer shelf life, and ease of handling and reconstitution. However, no possible drawbacks of freeze drying in the preparation of ready-to-eat meals are mentioned in the literature [35]. Some novel drying techniques for the Food Industry are presented in Figure 3.

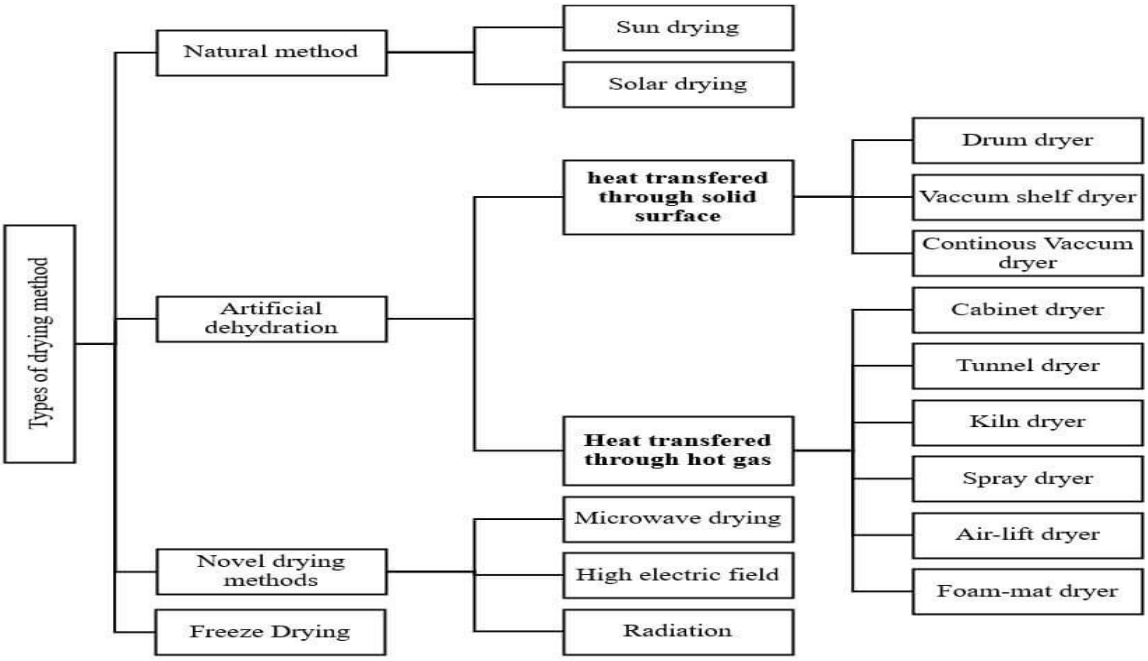


**Figure 3** Novel Drying Techniques for the Food Industry [38]

## 4. Industrial Drying Processes and Challenges in the Food Industry

Effective industrial drying procedures are essential for preserving product quality, increasing shelf life, assuring food safety in the quick-paced and constantly changing food business. However, the obstacles that these drying processes encounter are diverse and frequently complicated. The food business is continuously looking for novel solutions to get around these challenges, from lowering energy use and costs to

preserve product purity and fulfilling regulatory requirements [39]. This topic will cover the major issues encountered by industrial drying processes in the food industry, as well as the cutting-edge technology and methods that firms are using to optimize their drying operations.

### 4.1. Energy Usage

Food sector industrial drying operations face a number of difficulties that may reduce effectiveness and productivity. The problem of energy usage is one of the biggest obstacles. Food goods need to be dried with a lot of heat, which uses a lot of energy. Reducing energy use is essential as energy prices increase and sustainability gains much importance. Finding solutions to optimize drying operations and reduce energy use without sacrificing product quality is a perennial problem for food makers [40, 41].

### 4.2. Product Integrity

Another difficulty in industrial drying procedures is maintaining product integrity. The drying process must take into account the distinctive qualities and sensitivities of various food items. Delicate fruits and vegetables, for example, may be damaged or lose nutrients if exposed to high temperatures for a lengthy period. However, meat or fish items need specialized drying conditions to preserve food quality and avoid spoiling specialized food safety characteristics. It takes careful monitoring and management to strike the right balance between the demand for effective drying and the preservation of product quality and safety [42, 43].

### 4.3. Regulatory Compliance

Ensuring regulatory compliance to protect consumer safety, the food business is subject to follow stringent laws and standards. Specific standards for drying procedures, such as temperature limits, moisture levels, and sanitation procedures, are frequently stipulated by these rules. Compliance with these rules while preserving operational efficiency can be a difficult endeavor that necessitates constant monitoring, documentation, and adherence to best practices [44].

### 4.4. Environmental Concerns

Drying procedures in the food sector have major environmental implications, particularly in terms of energy usage and greenhouse gas emissions. Several solutions have been put out to reduce these effects. One strategy is to optimize drying process parameters such as temperature, humidity, and air velocity in order to reduce energy usage while preserving product quality. Utilizing renewable energy sources, such as solar energy, to power the drying process is another tactic. The utilization of developing technologies like as microwave drying, hoover drying, and freeze-drying can cut energy use while minimizing nutritional and flavor loss, therefore contributing to environmental sustainability [45, 46].

## 5. Best Practices for Overcoming Challenges in Industrial Drying Processes

To tackle the constraints of industrial drying processes, food producers are implementing a number of best practices that improve productivity, product quality, and regulatory compliance. One such practice is the use of quality management systems, such as Hazard Analysis and Critical Control Points (HACCP), to assure food safety throughout the drying process. These systems entail seeing possible risks, putting precautions in place, and then periodically checking to see if they are working. Food producers can reduce the chance of product contamination or safety concerns by proactively addressing possible hazards [47, 48]. By investing in personnel training and education is critical for tackling the obstacles of industrial drying operations. Employees who have received the appropriate training are aware of the nuances of drying, including the effects of various drying settings on product quality and safety and became able to efficiently monitor and manage these metrics, spot possible problems, and swiftly implement remedial measures. Employees are kept current with the most recent legal requirements and technical developments in drying processes to ongoing training and education programmers [49].

Collaboration and information exchange within the food industry is also critical for addressing obstacles in industrial drying processes. Food producers may exchange best practices, learn from one another's experiences, and work together to solve problems by taking part in trade groups, attending conferences, and working on cooperative

research initiatives. Innovative solutions to improve drying processes and increase overall efficiency and sustainability may be created by utilizing the industry's pooled knowledge and skills [50].

### 5.1. Innovations and Advancements in Industrial Drying Technology

The limitations of industrial drying processes in the food sector are constantly dealt by investigating and implementing new technology. The application of microwave drying technology is one such development. Unlike traditional drying processes that rely on hot air, microwave drying directly heats the food product. This method has a number of benefits, including shorter drying periods, less energy use, and better product quality. Microwave drying is especially advantageous for heat-sensitive goods since it provides for exact temperature control while reducing the danger of over-drying or nutrient loss [51, 52].

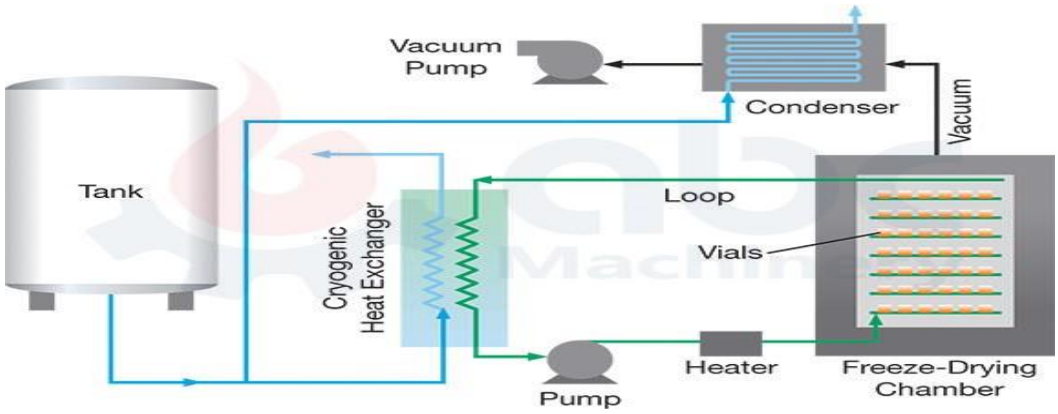


**Figure 4** Vacuum Drying Process in Food Chemical Industry [53]

Advancement in industrial drying technology is the introduction of hoover drying devices. Vacuum drying (Figure 4) includes releasing the drying chamber's air pressure, which lowers water's boiling point and speeds up evaporation. This approach is very useful for drying heat-sensitive or fragile food goods since it reduces exposure to high temperatures. Additionally, hoover drying improves the preservation of the food product's natural color, flavor, and nutritional value, producing higher-quality finished goods [54].

**Figure 5** Revolutionizing Manufacturing with AI and Machine Learning [55]

Additionally, the optimization of drying processes by food producers is revolutionized by the use of artificial intelligence (AI) and machine learning algorithms (Figure 5) into industrial drying processes. AI-powered systems can analyze massive volumes of data in real time and automatically modify drying settings to obtain the desired drying output. These systems are able to recognize patterns, anticipate possible problems, and efficiently use energy. Food producers may increase the accuracy, control, and productivity of their drying operations by utilizing AI and machine learning [55, 56].

## 6. Conclusion

In conclusion, the uses of drying processes in the food industry have shown to be very significant in a variety of ways. Throughout this study book chapter, the authors have looked at the various drying procedures used in the food sector and their uses. These techniques, which include air drying, freeze drying, spray drying, and others, are beneficial in preserving and improving the quality, shelf life, and safety of food items. The benefits of drying technologies are obvious in their capacity to decrease water content, hence reducing microbial development and enzymatic activity that led to deterioration. Drying processes lengthen shelf life, improve mobility, and promote customer convenience by eliminating moisture, reducing product weight and inhibition of bacterial growth. Furthermore, these approaches have aided in the preservation of nutritional content and sensory qualities of food, ensuring that critical nutrients are kept

even after the drying process. Industrial drying procedures in the food sector encounter various issues, including energy usage, product purity, and regulatory compliance while food producers are overcoming these challenges by the use of cutting-edge technologies, best practices, and cooperative initiatives. From energy-efficient drying systems and sophisticated control technologies to the incorporation of renewable energy sources and breakthroughs in drying technology, the future of industrial drying in the food sector appears promising. The food sector can fulfill the expanding needs of customers while guaranteeing the safety and integrity of its goods by continually aiming for efficiency, sustainability, and product quality.

***Author Contributions***

Conceptualization, A.J.; validation, M.S.H. and U.J.; writing—original draft preparation, A.J. and R.A.; writing-review and editing, and visualization, U.J., R.A. and M.S.H.

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***Conflicts of Interest***

The authors declare no conflict of interest.

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