Importance of computational tools and artificial intelligence to improve drying processes for food preservation

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ABSTRACT

Computational tools, including mathematical algorithms, specialized software, and artificial neural networks, along with the advancements in artificial intelligence, have brought significant advancements to industrial processes. Specifically, in food drying processes, such as those employed for grains, fruits, and vegetables, these tools have been demonstrated to play a crucial role in preserving the food itself and its nutritional value. This work highlights how artificial intelligence and computational tools have facilitated the automation of industrial processes (Engineering 4.0). Furthermore, it sheds light on the future potential of the man-machine interface, which is expected to give rise to Industry 5.0. The application of artificial intelligence in drying processes has demonstrated its impact on optimizing this unit operation by reducing process times, improving operating conditions, and predicting final quality characteristics of the products with remarkable accuracy, without requiring extensive experimentation or pilot tests.

Keywords: drying, preservation of foods, artificial neural networks, artificial intelligence.

1 INTRODUCTION

Throughout history, ensuring the preservation and safety of the food we consume, especially grains, fruits, and vegetables, has been a fundamental concern for human beings. This objective remains a top priority for our subsistence. However, the current global challenges we face, like climate change, deforestation, soil contamination, and the rapid population growth worldwide have made it more crucial than ever to address these issues effectively. Drying process is one of the prevailing techniques used for preserving foods. The main objective of this technique is focused in reducing the content of moisture in foods like grains, fruits, meat, herbs, and vegetables, permitting them to be stored for more prolonged times. The achievement of low moisture contents in foods aids to inhibit the growth of microorganisms and reduce the incidence of enzymatic reactions that provoke spoilage. Additionally, a reduction in weight and size is occurred, facilitating the transport, packaging, and storage of dried products. From a technical perspective, the drying process comprises the water remotion from a solid matrix through evaporation, where a simultaneous transfer of heat and mass processes are occurred (Kalantari et al., 2023; Ju et al., 2023).

There is a great variety of drying techniques, including the air drying, freeze-drying, spray-drying, and vacuum drying. The selection and employment of the different technologies depend on the particular characteristics of the food matrix, the current harvest season, and the attributes looked-for the final products. For instance, the drying process for grains varied greatly from that used for fruits or vegetables. Though, the main purpose is to preserve and prolong the shelf life of the foods while maintaining their nutrients and producing foods with appropriate sensory characteristics that satisfy to consumers (Hamdi et al., 2023). Hence, the adequate definition, designing and control of the processing variables in drying process, like humidity, airflow, and temperature, are of great importance to accomplish better performance

and quality features in the dried products. From these variables, the temperature is considered the most significant factor, it can affect the physical, metabolic, and sensorial properties in foods. Moreover, the use of elevated temperatures in the process influences significatively on the quality attributes of final dried products, since it can cause the degradation and loss of nutrients like vitamins, antioxidants, phenolic compounds, carotenes, etc. Furthermore, the content of moisture, directly related to the water activity and available water content, act as a control parameter to inhibit the microbial growth, and reduces the incidence of deleterious chemical reactions. Thus, the appropriate selection of the drying technique and better control on the process parameter, become essential to reduce and even avoid the occurrence of detrimental effects, contributing to prolong shelf life of dried foods (Nwosu-Obieogu, Oke & Bright, 2022; Gilago et al., 2023).

One of the foremost techniques used by human beings to secure the food is the utilization of open-air sun drying. This technique, comprises the exposition of food to the sun's heat and natural convective airflow, letting to natural evaporation of moisture occurs. This is the simplest and more accessible technology and a cost-effective option for small-scale processing. It is also suitable to be employed for large scales, using large tracts of land where extensive amounts of food material are exposed to the sun. However, it is important to note that it requires favorable weather conditions, such as high temperatures and low humidity to achieved appropriate final characteristics in dried products. For large-scale production, the sun-drying process is mostly unsuitable because of the prolonged times required to achieve the final moisture content, in addition to the low control in the drying conditions due to the weather variations, possible pest infestation, and the inherent presence of dust and foreign materials (Verma et al., 2023).

To overcome these disadvantages, modern technologies and devices have been developed and diversified, aiming of keeping dry agricultural products with desired moisture contents, minimizing physicochemical changes, and ensuring a high quality in the final products (Petikirige, Karim & Millar, 2022).

Nevertheless, in many industrial drying processes, some detrimental effects on the quality of the food can be occurred due to the lack of controlled operating conditions or inadequate selection of process parameters, which lead to undesirable chemical reactions and the degradation or partial decomposition of the nutritional properties of foods. Common degradation phenomena include the oxidation of vitamins, enzymatic and non-enzymatic darkening of foods, structural changes such as morphology, porosity, and textural alterations, nutritional, and sensory changes in terms of color, flavor, and aroma (Seerangurayar et al., 2019). These detrimental effects can compromise the overall quality of the dried foods.

The use and development of computational tools has emerged as an alternative to counteract deficiencies in the control of the drying process. These tools include mathematical algorithms, specialized

software, and artificial neural networks, as well as the so-called artificial intelligence. They allow a deeper understanding of the complex phenomena involved in drying by simulating and modeling the process, providing valuable information on the behavior of heat and mass transfer within the food material, allowing optimizing the process parameters to achieve more efficient and controlled drying conditions, predicting, and enhancing the final quality of food products. These technologies also help save time and resources and improve efficiency and productivity in the food industry. Therefore, the objective of this work is to show the importance offered using artificial intelligence, as well as different computational tools, in the prediction and improvement of the quality of food products during their drying processing.

2 METHODOLOGY

2.1 MAIN DRYING EQUIPMENT FOR FOOD PRESERVATION

Drying is a process that aims to remove a significant amount of water from food through evaporation or sublimation, facilitated by the application of heat, cold or vacuum conditions. To reduce the moisture content, the surface of the solid is commonly exposed to a stream of hot air, which is introduced into the food matrix allowing the liquid water to vaporize and be carried away. Numerous drying equipment are utilized for drying grains, fruits, and vegetables, and some of the most used ones include:

Tray Dryer or Cabinet Dryer. This type of dryer is the simplest in terms of geometric configuration. It consists of at least one cabinet containing perforated metal trays stacked parallel within the cabinet for food placement. The equipment is equipped with fan that supplies air to the system, which is heated using a set of electrical resistances. The airflow is directed over and under the trays through deflectors to facilitate the drying process. At an industrial scale, these equipment units are capable of processing approximately 20,000 tons of dry food per day (Espinosa-Vasquez et al., 2023).

Tunnel dryer. This industrial scale drying equipment comprises a lengthy insulated tunnel measuring approximately 25 meters. It is specifically designed for dehydrating fruits and vegetables in the form of cubes or slices. Within the tunnel, small carts are positioned, each equipped with metal trays to hold the food undergoing dehydration. The operation of this equipment involves the carts advancing from one end of the tunnel to the other, while a parallel flow of hot air circulates through the tunnel, contacting the trays and the food (Patil & Gawande, 2016).

Rotary Dryer. A rotary dryer is designed with a cylindrical metal casing set at an angle, which typically rotates at 4 to 5 rpm. Wet feed is continuously fed into the upper end of the casting, while dry product is discharged through a weir at the lower end. The operation comprises the location and arrangement of deflectors or blades on the inner surface of the metal casing. These blades work by lifting the food up whereas the casing rotates, allowing solids to fall and meet a current of hot air. These types

of dryers are generally utilized for drying grains, flour, and sugar, and considered as relatively fast processes, taking approximately 60 min at air speeds between 1.0-2.5 m/s to complete the process (Leilayi et al., 2023).

Freeze Drier. This drying equipment involves the use of a vacuum chamber with hot shelves, coupled to a vacuum pump and a condenser system. Like other drying equipment, the goal of this process is to remove a significant amount of water from the food, but unlike to other drying technologies, the removable water content is frozen. The main stages occurred during the freeze-drying process comprises the freezing of food by exposing it to chilled air; then water sublimation is undergone, and the water vapor is removed through the condenser system, and finally, the remained content of water adsorbed in the food structure is removed (Kumar & Yao, 2022).

Despite this drying technology is pondered as the most expensive because of the high energy requirements, improved quality and superior attributes are obtained in the final products. Freeze-dried foods generally exhibit minimal structural changes, better rehydration properties due to the obtention of porous materials, and improved retention of nutrients, successfully preserving the sensory and nutritional properties in the final products (Zhu et al., 2022).

Osmotic Dehydration. This technology comprises the subtraction of water from food matrices, especially fruits and vegetables, by creating an osmotic pressure gradient when immersing the foods in saline or sugar solutions, generally defined as hypertonic or osmotic solutions. Unfortunately, this technology does not guarantee the required quality in the final products. During the osmosis process, the cell walls of the food matrices may release their nutrients or absorb undesirable solutes from the saline or sugar solutions, leading to products with unpleasant tastes. For fruit dehydration, osmotic solutions made from sucrose, fructose, or glucose are commonly utilized. In some cases, small amounts of salt are added to enhance the osmosis process and reduce the drying times. Vegetables, on the other hand, are typically dehydrated using saline solutions containing sodium chloride or starch syrup. The average duration for the dehydration of fruits or vegetables using this method ranges from 4 to 6 hours (Chaudhary et al., 2019).

Spray Drying. Spray dryers are specifically designed for drying heat-sensitive compounds including the nutrients found in food. The spray drying process consists of feeding fluids such as dispersions, emulsions, or solutions into the equipment. These fluids are atomized into a fine spray inside the dryer and will come into contact with a stream of hot air. This rapid contact causes instantaneous evaporation of the water within 1-20 seconds, resulting in the formation of a powdered product. The powder is then collected using a cyclone separator for the further processing or packaging (Oliveira et al., 2021).

2.2 APPLICATION OF COMPUTATIONAL TOOLS AND ARTIFICIAL INTELLIGENCE IN FOOD PRESERVATION

The first contribution of applied computer technology to improve the drying process was made by utilizing empirical mathematical correlations to describe the experimental observations. The resulting mathematical expressions aim to provide simple explanations to the phenomenology occurred during the drying process and develop simplified solutions for explicating the diffusion model equations.

Even though these empirical mathematical correlations offer good fit to the experimental data, the generalization of the parameters derived from this modeling process is not adequate, since large deviations in the model are observed when there are differences in food characteristics, such as moisture content or the shape and size, or when the conditions of the drying process are modified. To overcome these drawbacks, the implementation of analytical models was a feasible option that allows predicting and evaluating any phenomena occurred in the drying process. However, the result of the solution of this type of models is unreliable when applied to real drying systems, mainly because these models are based on the resolution of general differential equations where heat and mass transfer occur simultaneously under ideal conditions (Keskes et al., 2020).
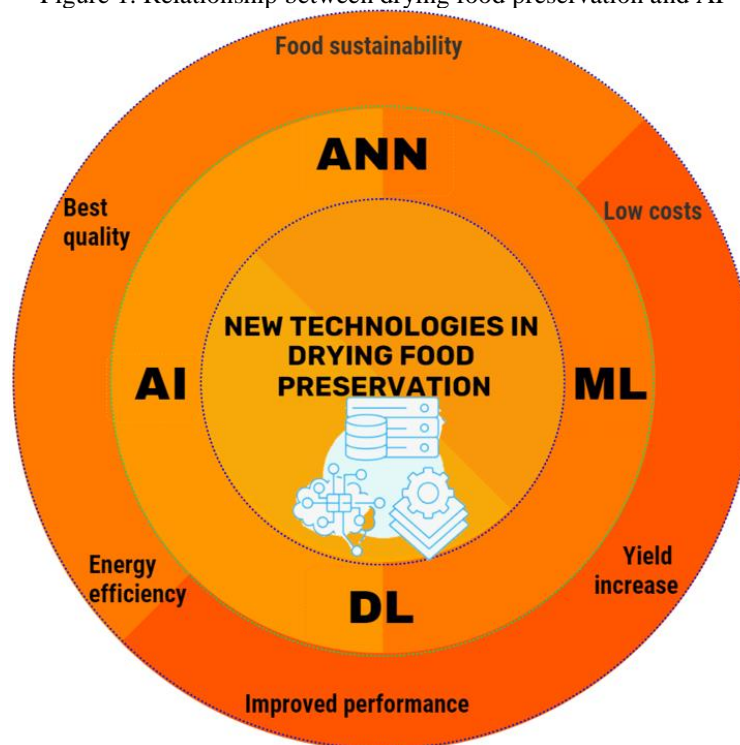
Since artificial neural network (ANN) models were developed, they have been used successfully in the chemical industry, specifically to predict reliable results in material processing. ANN can effectively take complex relationships and nonlinear dependencies between variables, and train patterns to generate accurate predictions. ANN models have been used in drying processes to describe the behavior of different natural materials by managing the relationship between the inherent physicochemical properties of foods and drying conditions, providing relevant information on the incidence of simultaneous heat and mass transfer through a porous material with specific characteristics. One of the most relevant advantages of ANN is the ability to process massive information, solve algorithms and generalize patterns to provide output data. This process involves learning and training processes that allow accurate predictions that contribute to making better informed decisions. This tool is made up of nodes, layers, and connections, and is based on how the human mind works (Martynenko & Misra, 2019).

The most in-demand ANN tools are the multilayer perceptron networks (MLP), radial basis function networks (RBF), and recurrent neural networks (RNN). All of them work under the same operating conditions and structure but differing in the input and output layers or in the use of feedback connections. These types of ANN are used to describe experimental data obtained from different drying conditions and materials and can accept new sets of experiments and improving their performance while expanding the range of input parameters (Sharkawy, 2020).

On the other hand, artificial intelligence (AI) is not a new topic, its incorporation in industrial areas like manufacturing, robotics, automation, oil and gas, biotechnology, chemical and pharmaceutics dates

from second half of the 20th century. AI is defined in simple terms as the set of different computational technologies that, working in harmony, allow machines to detect, understand, act, and learn with levels of intelligence similar to those of people (Rios-Campos et al., 2023). Machine learning (ML) is a subcategory of the AI, associated with the process by which computers develop pattern recognition and thus develop the ability to continually learn and make predictions based on data, making settings automatically. In other words, AI is understood as the means to get the data while ML is the system utilized to analyze and learn from it (Alzubaidi et al., 2021). Since 1980s the utilization of AI and ML algorithms have been incorporated into food drying processes, contributing to improving the food industry, achieving technological advances, reducing costs and increasing not only profits but also the reliability and robustness of drying processes (Figure 1).

Figure 1. Relationship between drying food preservation and AI

Source: From the authors

The successful implementation of ML in food industry is based on the use of computers to analyze large amounts of data and generate appropriate models to describe any natural phenomena. In drying process, ML algorithms can predict the quality and shelf life of food products and improve the food attributes and properties while preservation and storage (Kushwah et al., 2022). Innovation on the way of carried out manufacturing processes through the application of ML has risen the so-called Industry 4.0. It is expected that in the near future, cooperative processes between human abilities, as well as creativity and decision-making, and machines will generate symbiotic relationships to develop advanced

technologies in which the entire value chain of food products is improved, developing the called Industry 5.0. This revolutionary industry will provide advantages to producers and consumers, since the industrial processes will be developed in a predictive, sustainable, customized, and ethically responsible manufacturing, where the useful life of each product can be evaluated more efficiently, optimizing the resource utilization and the product lifecycle (Khan et al 2020a; Raja Santhi & Muthuswamy, 2023).

The incorporation of AI in the drying process is feasible because the typical diffusive phenomenon of this operation can be described by differential and algebraic equations such as the Fick and Newton equations, which are obtained empirically or analytically. In many cases accurate and adequate results are obtained, but in other cases the results are not valid, therefore; it is necessary to adjust these models with experimental results to different conditions of the drying process and types of food materials. It is precisely in these circumstances when artificial neural network models are coupled to describe or predict the behavior of the food drying process (Khan et al., 2020b).

In 2010, a technological leap was made with the incorporation of deep learning (DL), which is considered as a subfield of ML. These networks are designed to learn and pinpoint complex patterns and relationships in data through hierarchical feature extraction. The challenge of this technology is the creation of artificial neural networks handling large amount of unstructured or high-dimensional data (images, audio text, sensor data, etc.), to improve their recognition and processing. This technology is defined as DL because the structure of its ANN is made up of many inputs, outputs, and hidden layers. Its effectiveness is qualified by the ability to correctly perform prediction tasks. In this way, the correct programming of algorithms makes the computer learn through its own processing of the information from the input data. In food drying processes, where the physicochemical characteristics of the products are sequentially analyzed, such as size, color, weight, etc., DL is extremely important in the operation of the subcategories in charge of image analysis and recognition (Zhu et al., 2021).

3 RESULTS

The industrial segment reveals several of the most outstanding contributions of AI applied in food drying processes, where productivity improvement, manufacturing cost reduction and the product quality improvement have been successfully achieved. From the scientific point of view, the contribution of AI to develop innovative technology has facilitated the informed and accurate selection of the ideal and most suitable physicochemical properties like color, shape, texture, volume, weight, and optimal control parameters such as, drying time, air temperature, air flow velocity, area difference, moisture content, and final thickness, to modernize food processing by improving the yield and quality of all types of food products (Khan et al., 2020b; Kushwah et al., 2022).

In addition, scientific findings demonstrate the relevance of incorporation of AI in food drying processing technology and its contribution as an effective alternative to optimize industrial processes. Its application has made it possible to guarantee the nutrimental quality of processed food products on a par with fresh wet foods. Likewise, AI has demonstrated to overcome the challenges of real-time application, allowing monitoring of specific product parameters and quality control throughout the manufacturing process, taking advantage of cloud-based information storage and continuous accessibility (Zhu et al., 2021; Raja Santhi & Muthuswamy, 2023).

The use of AI on the industrial sector, beyond the food industry, has provided various advantages for both manufacturers and consumers. AI has made it possible to produce and make available to consumers, articles with the highest quality, in addition to developing better controlled processes, not only at the level of unit operations, but throughout the product value chain. That is, designing innovative processes to manage the steps going from obtaining and pre-treating the raw materials to obtaining the finished product, coupled to the processes of distribution, logistics, storage, marketing, sales, and customer satisfaction.

Today, the food industry is undergoing a transformation as it embraces advances in computer technology. This renovation allows it to offer products with remarkable quality to meet the high expectations and demands of today's consumers, attributing this outstanding advance to the integration of AI in the production processes. Moreover, food sustainability can be safeguarded, due to AI contribution to increasing the efficiency of production processes and reducing the production of sub-products and wastes and energy consumption. Currently, these advantages and benefits are achievable thanks to the application of AI, the implementation of training procedures and the improvement of computational tools such as decision trees, artificial neural networks, expert systems, machine learning, and hybrid models (LSTM-ALO, ANFIS-GBO , ELM-PSOGWO, LSSVM-IMVO, SVR -SAMOA, ANN-EMPA, ELM-CRFOA), which allow the construction and advancement of suitable applications to meet current technological demands (Martynenko & Misra, 2019; Sharkawy, 2020; Zhu et al., 2021; Przybył et al., 2021).

4 CONCLUSIONS

Ensuring the preservation of food while maintaining its quality represents the greatest concern of the human being. It is considered a priority to harnessing the potential and power of the artificial intelligence, particularly artificial neural networks, to optimize drying processes. Its objective is to reduce processing times, manufacture foods with desirable characteristics and functional properties, while minimizing production costs and wastes. Despite the satisfactory advances in the application of artificial intelligence in the food drying process, the forthcoming challenges are not only focused on the

improvement of technology itself, but also allow it to continue supporting men in their work activities without jeopardizing their position at work.

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