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Optimization of process parameters for freeze-dried button mushroom: An extensive review

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Abstract
Button Mushroom (*Agaricus* spp.) is the most popular mushroom variety grown and consumed the world over. Mushrooms belong to a separate group of organisms called Fungi. In India, its production earlier was limited to the winter season, but with technology development, these are produced almost throughout the year in small, medium, and large farms, adopting different levels of technology. Freeze drying works on the principle of sublimation in which three steps involved such as freezing, primary drying, and secondary drying. In this study, we have tried to review mathematical models for freeze drying, button Mushroom (*Agaricus bisporus*), its quality attributes, drying methods for button mushrooms, Measurement of Response Parameters, color analysis, water activity, shrinkage ratio, rehydration ratio, protein content, ascorbic acid content, antioxidant content, artificial neural network (ANN), ANN in freeze drying, and response surface methodology.

Keywords: Button mushroom, freeze drying, artificial neural network, response surface methodology

Introduction
Freeze-drying or lyophilization is a process of drying by the principle of sublimation. It is used for drying bio-products that are heat sensitive or are otherwise degraded by conventional drying techniques involving heat treatment. It is a complex unit operation developed during World War II, as an efficient method to carry blood plasma for far-off distances. Despite its complexity, it is widely used in the pharmaceutical and biotechnology industry for a large number of applications (Nireesha *et al*., 2013) [38]. Freeze drying takes long process times and has a high capital investment. This may support the fact that it is still relatively new to the food processing sector and could be easily replaced by more economical drying processes. Even though these problems have been identified, freeze-drying is used due to its ability to deliver superior-quality products (Ratti, 2001) [43]. A typical freeze-drying process consists of three stages: freezing, primary drying cycle and secondary drying cycle. The primary drying cycle takes up most of the processing time (Tang and Pikal, 2004) [52].
In food processing, freeze-drying is still in its early stage of development. There are many unexplored research areas that need to be addressed. It is important to develop a sound understanding of the process before the issues can be tackled. The lyophilization process is initiated by freezing the material to be dried below its eutectic temperature. The frozen sample is then kept under conditions below the triple point of water (0.01 °C, 610.5 Pa), to remove the ice by sublimation (Fellows, 2000) [16]. A phase diagram explaining this principle is outlined in fig. 1.
Franks, (1998) [18] described the basic principles involved in the freeze-drying process and categorized it as a four-step process comprising freezing, primary and secondary drying, and removal of the collected ice in the condenser. The final step has not been considered in the current work due to its insignificant contribution to the model development process. Chamber pressure, condenser and shelf temperatures were identified as parameters that could be directly controlled with product temperature being an important parameter for which non-invasive measurement techniques were suggested. The glass transition temperature was quoted as one of the major factors in the design of suitable process cycles to reduce drying times. Keeping the sample temperature below its glass transition temperature was recommended to avoid melting back. Ratti, (2001) [43] compared freeze drying and hot air drying, taking shrinkage, glass transition temperature, drying kinetics, costs, process-quality interaction, and new improvements into account. The glass transition temperature (Tg) of food products was considered responsible for the deterioration mechanism of food processes and an indicator of stability.

The rehydration ratio for freeze-dried food was found to be 4-6 times higher than hot air-dried food. The vacuum freeze drying of strawberries showed slight degradation of color compared to air drying even on excessive heating up to 70 °C. This is supported by the fact that the product temperature is higher than Tg during the entire process of drying by heat rendering it susceptible to degradation. It was further discussed that freeze drying costs 3-4 times more than conventional drying with the sublimation period consuming almost half of the total process energy. Freezing utilized comparatively lower energy and therefore, has not been considered for energy measurement in the current work. Patel *et al*., (2010) [39] proposed methods to determine the end point of the primary drying stage during freeze-drying. It was quoted that the key to reducing processing times and expense was to minimize the duration for primary drying (PD) as it is the longest of the three-step process. Comparative pressure measurement, dew point monitor (electronic moisture sensor), process H_2O concentration from Tunable Diode Laser Absorption Spectroscopy (TDLAS), lyotrack (gas plasma spectroscopy), product thermocouple response, condenser pressure and pressure rise test (manometric temperature measurement (MTM) or variations of this method) were stated as methods for PD endpoint detection. Mannitol and sucrose each of 5% concentration were used as model systems for examination. In comparison, the Pirani, lyotrack, dew point and TDLAS methods showed no significant difference in the onset and offset of PD in 5% sucrose solution. Lyotrack method was discouraged for products sensitive to oxidation. TDLAS provides additional information along with meaningful endpoint determination but is an expensive process. The Pirani method was recommended for the proper determination of the onset and offset of PD. Nireesha *et al*., (2013) [38] discussed the different stages of freeze drying (freezing, primary and secondary drying) and its underlying principles. A general understanding of the process was articulated with some applications in biotechnology and pharmaceuticals. Xu *et al*., (2015) [55] demonstrated that Microwave Freeze Dryers (MFD) could replace traditional Freeze Drying (FD) equipments. The authors developed an MFD and compared the drying time and energy consumption results to that of FD and Atmospheric Freeze Dryers (AFD). Further, they absorbed that FD consumed the highest levels of energy with long drying times but yielded the best quality products. As compared to FD, AFD gave the poorest product quality with the longest drying times but with low energy consumption. The quality of the products was evaluated on the basis of moisture content, ascorbic acid content, color, bulk density, texture, rehydration ratio, shrinkage ratio and micro-structural analysis. MFD was reported to have high L* (Lightness) values and rehydration ratio and lower shrinkage and bulk density.

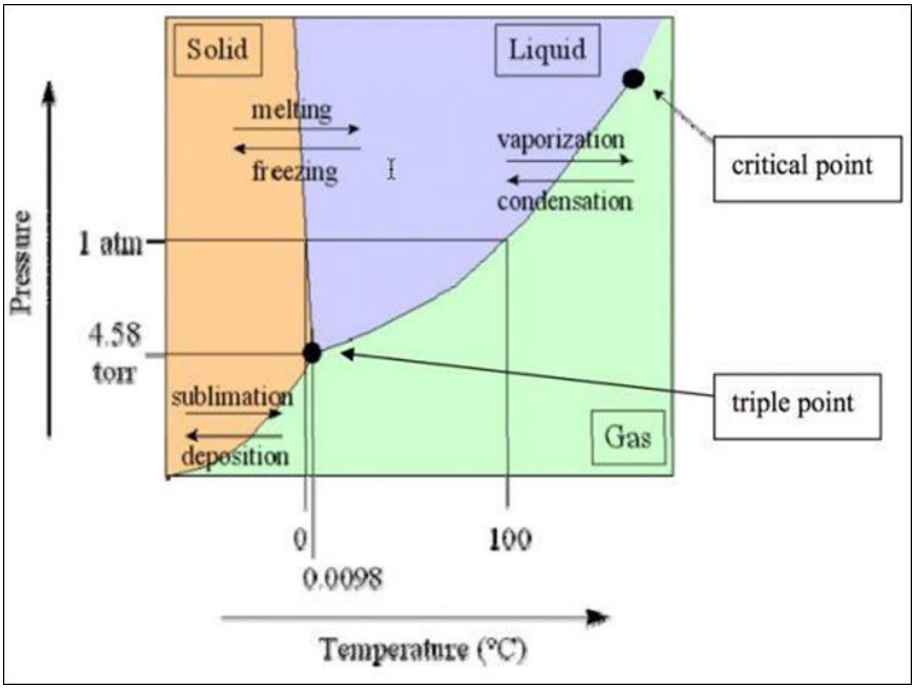

Fig 1: Principle of freeze drying on the phase diagram of water

Mathematical models for freeze drying

Numerous models describing the pharmaceutical freeze-drying process have been studied. There are a fixed set of parameters that have been reported to show a significant effect on the process product output. Mathematical equations based on heat and mass transfer operations using these parameters have been developed.

Sadikoglu and Liapis, (1997) [47] constructed a mathematical model to describe the behavior of freeze drying of pharmaceuticals during primary and secondary stages. The model calculations indicated insignificant quantities of bound water removed during primary drying as compared to the secondary drying cycle. Energy and material balance equations were used to develop the model incorporating the concentration of bound water with time. The theoretical results obtained were compared with the experimental data obtained during the freeze-drying of skimmed milk. The results were found to be in good agreement for all practical purposes. Pikal *et al*., (2005) [40] developed non-steady state models to obtain information about moisture distribution and product temperature during primary and secondary drying processes for sucrose formulations. Differential equations defined by the constraints imposed by energy and mass balance were used. The theoretical models showed

comparable results to experimental data. The residual water content with an increase in secondary drying time and the product temperature with process time was evaluated.

Button Mushroom (Agaricus bisporus)

Button mushrooms are cultivated in temperate, northeastern hilly areas and the hilly areas of Uttarakhand. The primary consumers of these mushrooms are Chinese restaurants, clubs, hotels, and general households. It has extensive potential for export as a food delicacy. Mushrooms are a good source of minerals, vitamins, and antioxidants but are susceptible to enzymatic browning and microbial attack due to their high moisture content. Freeze drying has been proven to be effective in solving these problems as compared to drying by heat treatment.

Quality attributes

Mushrooms are rich in minerals, phenolic components, and ascorbic acid.

Matilla *et al*., (2001) [33] estimated the nutritional properties of cultivated mushrooms. Vitamin B2 niacin, vitamin C, and folate content in dried A. bisporus (white) were estimated at 5.1 mg, 43 mg, 17 mg, and 450 µg per 100 g respectively. Considerable quantities of K, P, Zn, and Cu were also determined with K being the major mineral. The content of phenolic acids was found low and under the limits of detection in all the analyzed mushrooms. Jagadish *et al*., (2009) [22] reported inhibition of cell proliferation by A. bisporus extracts. It was also shown that the medicinal properties of the mushrooms were unaffected when cooked or boiled. Further, antimicrobial activities were tested against several bacteria including Pseudomonas aeruginosa and Escherichia coli among others. Guizani *et al*., (2013) [22] quantified the relationship between dried mushroom stability and glass transition temperatures. It was also stated that the characteristic end point of freezing (Tm') could be used to determine the stability of frozen storage. It was found that the endpoint for freezing had proportional relations between temperatures and moisture contents. For instance, the Tm was -5.9 °C for 95% m.c. whereas it lowered to -20 °C for 60% m.c. The total unfreeze water in the mushroom was measured as a 0.218 g/g sample. This data is essential as it quantifies the amount of bound water which needs to be removed during the secondary drying phase. Liu *et al*., (2013) [30] determined the antioxidant activity in ethanolic extracts of white button mushrooms. The major phenolic compounds in the extract were also determined as gallic acid, protocatechuic acid, catechin, caffeic acid, ferulic acid, and myricetin. The radical scavenging property of ethanolic extract was found to be significantly greater than the methanolic extract for DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. Further, button mushrooms were recommended as natural antioxidants in food and therapeutics.

Drying methods for button mushroom

The drying kinetics of Calocybe indica (milky mushroom) was studied by Arumuganathan *et al*., (2009) [3] studied a fluidized bed dryer. The sample thickness was taken as 10mm with air temperatures of 50 °C, 55 °C, and 60 °C. The final moisture was brought to 11.34% to 13.13% (w.b.) Drying times were reduced with an increase in temperature with lower activation energy. Argyropoulos *et al*., (2011) [1] analyzed the effects of hot air, combined hot air, microwave vacuum, and freeze-drying on the product quality of mushrooms. Pre-treatment of 0.25% potassium metabisulfite and 0.1% citric acid for 5 min was provided to avoid browning during drying. Color measurements revealed higher L* in hot air and combined drying methods representing darker samples as compared to freeze-dried samples. The samples dried by conventional hot air resulted in higher density followed by combined and freeze- drying methods which ascribe to the fact that hot air caused considerable shrinkage and collapse of cell walls. Freeze drying showed minimal shrinkage thereby preserving the primary structure of the sample. The rehydration characteristics were also studied at 25 °C and 100 °C. Higher temperatures showed the lesser time for reconstitution. Combined hot air microwave vacuum showed higher rehydration ratios followed by freeze drying and hot air. This was explained by the fact that the combined drying technique created high water vapor pressure inside the mushroom slice. Textural analysis showed that the freeze-dried samples had the softest and hot air-dried samples had the hardest texture.

Measurement of Response Parameters

For optimization, nine output parameters were chosen. Of these parameters three (Moisture Content, Drying Rate, and Water Activity) were obtained during the study of freeze-drying kinetics, and the rest (Color, Protein content, Free Radical Scavenging Activity, Ascorbic Acid content, Rehydration and Shrinkage Ratio) were estimated by chemical analysis. The basis for the choice of methods has been outlined in the following sub-sections. The output parameters under evaluation were observed to be most significant for defining the quality attributes of a button mushroom.

Color analysis

Color is a sensory quality that affects the selling capability of any commodity. It is important, therefore, to monitor and reduce color changes during processing to enhance the value of the resulting product. Various color measuring techniques have been developed.

Yam *et al*., (2004) [56] stated that the L* a* b* colour is device independent and is frequently used in food research. Further, they developed a simple imaging technique using standard illuminants, a 2.1-megapixel digital camera, and Adobe Photoshop software. Color measurements were done for microwaved pizza and the average color distribution was estimated under 'Lab mode' via a histogram generated by the software. Two other methods for color determination were explored. The first method involved dividing the image into grids and determining L* a* b* values for each x-y coordinate. The noise level, however, in this method was high. The second method was developed for color comparison between multiple image samples. Different sections of the pizza were divided on the basis of the ratio of a circular section radius to the radius of the entire pizza. The sections were then separately analyzed for average color values. Mendoza *et al*., (2006) [35] compared different color spaces and suggested the L*a*b* system as a suitable color space for foods with curved surfaces. The concept of color was specified as being affected by the reflectivity of the sample, the light source, and the visual sensitivity of the observer. Based on this concept, they developed a Computer Vision System (CVS) consisting of standard illuminants (D65) at an

angle of 45˚ and a digital camera with an image resolution of 1024x768 pixels tagged with an image acquisition system. The camera was located 30 cm over the background. The image was processed using codes written in MATLAB version 6.5 and the normalized values for L* a* b* were evaluated. Lightness (L*) was seen to be most affected by the curvature of the food sample among the three. Leon *et al*., (2006) [29] presented five models for the conversion of RGB colors to L* a* b* colour units. As commercial colorimeters take a small non-representative unit of the sample for color measurement, deriving L* a* b* values from digital images in RGB mode provides better quality control opportunities in food industries. Out of the five models, the Neural Network (NN) model showed the highest accuracy for conversion. The images for analysis were taken in a closed wooden box under two standard 18 W, 60 cm long fluorescent lights placed at 45˚ from the horizontal axis. A 4-megapixel camera was placed 22.5 cm vertically above the sample. The NN model was developed in MATLAB with 8 hidden layer neurons. The conversion was completed with an error of 0.93% in the NN model as compared to linear, quadratic, gamma and direct models where the error exceeded 1%. Jouybari *et al*., (2011) [24] developed a correlation between L* a* b* values obtained from a hunter colorimeter to that obtained from digital imaging using a 6-megapixel camera. The setup was similar to the one developed by Leon *et al*. 2006 [29]. Linear, quadratic, and Neural Network (NN) models were generated for correlation. Mazafati's date was taken for image analysis. The changes in the color of the date during the ripening process were monitored. The NN model gave a 99.4% average correlation. Digital image analysis was done in Photoshop software.

Water activity

The prime factor for the deterioration of food is high water activity. Most of the product quality parameters are dependent on it. The range for safe storage of water activity has been defined for almost all food materials.

Labuza, (1980) [28] reviewed that all bacterial growth was observed to cease below a water activity (aw) of 0.9, for yeast this was below 0.85 and below 0.7 for molds. It was indicated that all foods, with a few exceptions, were stable at a aw<0.6 and were categorized under dehydrated foods. He also showed that decreased water activity levels led to an increment in activation energy required for chemical kinetics involving food spoilage. A change in aw also had an effect on the dilution of the concentration of the reacting species. The reaction order was also reported to decrease with a decrease in aW. Khalloufi *et al*., (2000) [25] developed a correlation between equilibrium moisture content as a function of water activity and temperature. They found a significant decrease in water activity with an increase in temperature for freeze-dried mushrooms. Consequently, sorption isotherms were plotted from which it was inferred that temperature played a significant role in the equilibrium moisture content of mushrooms. The water activity at 27 °C and a moisture content range of 2-16% varied between 0.339 and 0.570.

Shrinkage ratio

Shrinkage is a common phenomenon during drying. Its estimation is tricky and therefore, the identification of parameters affecting it the most is necessary. Mayor and Sereno, (2004) [34] defined and modeled the mechanism of shrinkage and emphasized that drying under a vacuum (as in freeze drying) in general, leads to lower levels of shrinkage. The drying rate, the volume of water removed, and the mobility of the solid matrix was identified as major factors contributing to the magnitude of shrinkage. The ratio of shrinkage was defined as the ratio of reduced volume to the actual volume of the sample. The models were developed taking into account the porosity, bulk density, and geometry of the samples. Porosity was rendered insignificant in the prediction of bulk shrinkage. Several empirical as well as fundamental models were compared. Both types of models showed an acceptable fit to the experimental data. Dursun and Dursun, (2005) [14] investigated several physical properties of caper seed's geometry, density, angle of repose, and porosity among others. Although their work contains intricate details of the determination of each of these properties; only the method for measurement of density has been taken for the sake of determining the shrinkage ratio. The authors measured the true density of caper seeds by the toluene displacement method. Toluene (C7H8) has been reported to have a lesser tendency of being absorbed as compared to other chemicals including water. Therefore, it allows for more precise measurements of volume by recording the amount of toluene displaced.

Rehydration ratio

The rehydration properties of a product determine its usability after processing. Dried products need to regain their structure to provide the same texture and mouthfeel as that of the original product. Hence, a greater rehydration ratio would mean that the product is closer to the original commodity. Rehydration characteristics have been studied for a wide number of bio-products.

Maskan, (2001) [32] estimated the rehydration ratio in hot air and microwave-dried kiwifruit. He immersed a known quantity of dried samples into the water at 50 °C for 50 minutes. Weight measurements were taken every 10 min interval after draining the excess liquid on the samples. The rehydration ratio in terms of percentage weight gain was determined. Microwave-dried kiwifruit samples showed lower rehydration capacity but faster water absorption rates. Arumuganathan *et al*., (2003) [2] assessed the rehydration characteristics of button mushroom drying by several methods including fluidized bed drying, cabinet air-drying, sun drying, freeze-drying, and Osmo-air drying. The rehydration was done by heating 5g of dried mushroom sample in 100 mL distilled water under covered conditions. The water was drained out after 5 minutes and the mushroom weight was recorded. Freeze-dried mushrooms showed the highest rehydration ratio of 1:6.62 followed by cabinet-air dried (1:3.3) and sun-dried mushrooms (1:2.9). The moisture content on a wet basis (w.b.) for rehydrated freeze-dried mushrooms was recorded as 88% as compared to fresh mushroom moisture content of 89.8% w.b. Jambrak *et al*., (2007) [23] studied the effects of ultrasound pre-treatment on the rehydration characteristics of button mushrooms dried by conventional methods. Freeze drying was used for comparison of the results obtained. The rehydration properties were determined by immersing a 3g sample in distilled water at a temperature of 80 °C. The time of immersion was varied from 1 to 15 min with a 2 min interval. The samples were allowed to drain for 60 seconds over a mesh before weight measurements. The rehydration ratio was defined as the ratio

of the weight of the rehydrated sample to the sample's dry weight. Although ultrasound-treated mushrooms showed reduced drying times due to surface softening; freeze-dried mushrooms showed the highest degree of rehydration followed by ultrasound treatment at 40 KHz for 3 min.

Protein content

Food rich in protein is good for body build-up. During drying, protein is often deteriorated due to heat treatment or chemical reactions inside the food material. The protein content is, therefore, a strong indicator of the nutritional quality of a product.

Braaksma *et al*., (1996) [8] determined protein content in Agaricus bisporus by Kjeldahl method. The nitrogen-containing compounds in protein were extracted using ice-cold sodium phosphate buffer and centrifuged at 12000g for 20 minutes. The supernatant and pellets were collected and weighed. The pellet was further extracted in 0.5N sodium hydroxide, heated at 80 °C and centrifuged to obtain the final supernatant and pellet. The protein measurement methods generally used, including Kjeldahl were proved to be unreliable as non-protein nitrogen-containing compounds may interfere with the protein estimation process. Amino acid analyses from the extracts have been considered to provide more reliable estimates of protein. Bradford method was found to overestimate the protein content and the results were extended to other mushroom species as well. The usual protein content in button mushrooms is reported to be 19-38% which was proved to be 4 times more than the actual protein content. Winters *et al*., (2005) [53] showed that Polyphenol Oxidase (PO) activity in plant-derived compounds gave underestimated protein content. Due to the formation of protein-phenol complexes, a marked decrease in the protein estimated from the actual content by several procedures (Lowry's, Smith's, and bicinchoninic acid methods) was seen. A modified Lowr's method was suggested to overcome this problem. The method involves setting an upper bound of 40µg mL-1 on the phenol concentration and taking into account the variation in response of ortho-diphenols in the presence and absence of copper. The results showed a 20-50% variation in protein estimated by Lowry and modified Lowry methods. Responses obtained for protein content were closer to the actual with a reasonable error margin. Pomory, (2008) [41] investigated the time required for a stable photometric response during the estimation of protein by Lowry's method. He found that even for varying concentrations, the absorbance readings (at 660 nm) increased between 30-120 minutes and decreased gradually across 24 hours. The most stable period for recording absorbance was between 2-3 hours after the addition of the Folin-Ciocalteu reagent.

Ascorbic acid content

Vitamin C is highly heat sensitive and is highly difficult to retain during conventional drying procedures. A deficiency of vitamin C could cause gum disease and scurvy. The amount of ascorbic acid provides an estimate of the vitamin C content in food. Ascorbic acid retention in food is, therefore, a necessity. There are many techniques to estimate ascorbic acid content the most common method was proposed by Ranganna, (1986) [42]. He developed a titration method for the determination of ascorbic acid in fruits and vegetables using 2,6-dichlorophenol indophenol dye. The method involved the preparation of the sample extract using 3% metaphosphoric acid and titrating it against standardized indophenol dye. The standardization was accomplished by determining the dye factor using the L-ascorbic acid standard.

Antioxidant content

Antioxidants provide resistance against cell damage due to free radicals generated during body metabolisms. Food materials carry small quantities of natural antioxidants in the form of Tocopherol (vitamin E). Barros *et al*., (2006) [5] reported lower levels of ascorbic acid, β-carotene, and lycopene in wild Portuguese mushrooms. The phenolic content, however, was in significant quantities. Three different species of mushrooms were analyzed for radical scavenging activity. BHA and α-tocopherol were taken for standard curve generation. The sample preparation was done using methanolic extracts of mushrooms at different concentrations. The extracts were mixed with 2.7 mL DPPH radical-containing methanolic solution. The discoloration in DPPH was measured at 517 nm using a spectrophotometer. The highest antioxidant activity for 50% inhibition (IC50) was reported in Agaricus arvensis species as 3.5mg/mL. Cheung *et al*., (2003) [11] determined the antioxidant activity of Shiitake mushrooms and straw mushrooms. Total polyphenols were extracted by methanol and water from which the latter showed better extraction than the former. However, polyphenol yield was found better in methanolic extracts. Hence methanol was seen as a potent solvent for antioxidant determination in the current research work. Extracts of mushrooms of concentration between 1.5-3 mg/mL showed a positive correlation with Scavenging Activity (SA). Concentrations above 3mg/mL showed higher SA% for methanolic extracts of Shiitake mushrooms. Higher quantities of total phenolics represented higher antioxidant activities. Sharma *et al*., (2009) [49] showed that buffered methanolic extracts were suitable for obtaining stable absorbance of DPPH at 517 nm. Ascorbic acid, BHT, and Propyl gallate were taken as standards. The reaction of DPPH with ascorbic acid was instantaneous and gave consistent absorbance with time.

Artificial Neural Network (ANN)

The development of computer models for food processes is advantageous. ANN models can adapt themselves to changing situations and are one of the widely used computer models today due to their robustness. Basheer *et al*., (2000) [7] provided a preliminary understanding of ANN and its analogy to the functioning of a human brain. They explained that ANN is empirical in nature, has fault tolerance, and is adaptable with parallel and non-linear interconnectivity. It is widely used for the generalization of fuzzy or imprecise data. Various learning algorithms were presented with an emphasis on the back propagation algorithm. The general issues pertaining to ANN development were addressed and reasonable causes and remedies were provided. The article was written from a microbiological perspective and therefore modeling of growth cultures of S. flexneri was described as an ANN application among other general applications which were reported.

ANN in freeze drying

The process of freeze-drying is complex and is, therefore, difficult to maneuver through mathematical models. ANN models, however, can understand the complexity and

recognize patterns in such processes. Limited work has been carried out in the ANN modeling of freeze drying.

Menlik *et al*., (2010) [37] developed ANN models for the drying behaviors of apple slices. An experimental setup was prepared for continuous measurement of weight loss and sample and chamber temperatures using a load cell and thermocouples respectively. A back propagation learning algorithm with FERMI transfer function was used with 3 hidden layers containing 14 neurons. Moisture ratio (MR), moisture content (MC), and drying rate (DR) were kept as outputs while the sample thickness (Sth), pressure (P), chamber temperature (CT), relative humidity (RH) and drying time (Dt) were kept as inputs. ANN predicted the drying behavior of apple slices in the freeze-drying process with a high level of accuracy (R2=0.999). Similar work on strawberries was also conducted using the same set of parameters in an earlier year. Dragoi *et al*., (2012) [12] devised a neuro-evolutive tool for monitoring in-line product temperatures based on neural networks. The model made it possible to identify the completion of secondary drying and if the maximum allowable temperature for the product has trespassed.

Response surface methodology

The applications, credits, and limitations of Response Surface Methodology (RSM) as an optimization tool for different chemical and biochemical processes were reviewed by Bas and Boyaci, (2007) [6]. RSM was compared to classical optimization methods and it was inferred that it consumes less time and is capable of handling multiple parameters interaction effects as opposed to a single variable in earlier methods. Since RSM involves multiple regression to determine second-order equation coefficients, it was advised to normalize the parameters before optimization to obtain an evenly affected response. Although RSM is widely used and recommended for biochemical processes, it lacks the ability to fit all trends of data (hyperbolic, rectangular, etc.) to a second-order polynomial. A method suggested by the authors to overcome this situation is by converting the experimental data into a form that can be more conveniently explained by a second-order model.

Conclusion

The study on the effect of primary and secondary drying cycles on product response is important. The review suggests primary drying cycle affects the product significantly and takes the longest process time. The temperature for primary drying was suggested to be kept low for better product quality. Secondary drying temperatures were kept high as per the literature. The product sensitivity is to be considered in setting the highest level of secondary drying temperature. Samples for determining drying kinetics were kept in slices or cubes. Important quality parameters were reviewed and their protocols were studied. Quality characteristics taken under study included water activity, rehydration ratio, shrinkage ratio, ascorbic acid content, antioxidant content, protein, and color.

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