Alexandria Engineering Journal (2013) 52, 507–516

FACULTY OF ENGINEERING
ALEXANDRIA UNIVERSITY

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Artificial neural network and response surface methodology modeling in mass transfer parameters predictions during osmotic dehydration of *Carica papaya* L.

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Received 12 January 2013; revised 17 April 2013; accepted 20 June 2013
Available online 9 July 2013

KEYWORDS

Artificial neural network;
Response surface methodology;
Papaya;
Mass transfer;
Osmotic dehydration

Abstract In this study, a comparative approach was made between artificial neural network (ANN) and response surface methodology (RSM) to predict the mass transfer parameters of osmotic dehydration of papaya. The effects of process variables such as temperature, osmotic solution concentration and agitation speed on water loss, weight reduction, and solid gain during osmotic dehydration were investigated using a three-level three-factor Box-Behnken experimental design. Same design was utilized to train a feed-forward multilayered perceptron (MLP) ANN with back-propagation algorithm. The predictive capabilities of the two methodologies were compared in terms of root mean square error (RMSE), mean absolute error (MAE), standard error of prediction (SEP), model predictive error (MPE), chi square statistic (χ^2), and coefficient of determination (R^2) based on the validation data set. The results showed that properly trained ANN model is found to be more accurate in prediction as compared to RSM model.

1. Introduction

India is the second largest producer of fruits and vegetables contributing about 12.4% to the total world fruit and 13.3% to vegetable production. India ranks first in the production of mangoes (41%), banana (28%), papaya (30%), and peas (30%) and second in brinjal (29%), cauliflower (29%), onion (18%), and cabbage (8%). Papaya (*Carica papaya* L.) is rich in carbohydrate, vitamin A, calcium, iron, and fiber and has negligible saturated fat. Apart from this, it contains niacin,

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

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http://dx.doi.org/10.1016/j.aej.2013.06.007

foliate, vitamin E, magnesium, phosphorus, potassium, lipids, and amino acids. Papaya is the only natural source of papain – an effective natural digestive aid – which breaks down protein and cleanses of the digestive track. Papaya is highly seasonal fruit and only available during the month of March to June in India, and it is mostly cultivated in the states of Andhra Pradesh, Karnataka, Gujarat, Orissa, West Bengal, Assam, Tamil Nadu, Kerala, Madhya Pradesh, and Maharashtra. Since it is a perishable commodity, papaya becomes much cheaper in terms of selling price during the peak season and also it leads to more financial losses to the grower resulting from the spoilage of fruits in larger quantities. Preservation of these fruits can prevent a huge wastage and make them available in the off-season at remunerative prices [1].

Removal of water from solid food is a form of food preservation, inhibiting the growth of microorganisms, besides preventing a large part of biochemical reactions that occur due to the presence of moisture [2]. Among various methods used for extending the shelf life of fruit such as Papaya (*Carica papaya* L.), osmotic dehydration is one of the simplest and inexpensive processes that are not only energy-saving and also low-capital investment. Osmotic dehydration is used as a pre-treatment to many preservation processes such as freezing, freeze-drying, microwave drying, and air-drying to improve nutritional, sensorial, and functional properties of fruits without changing their integrity [3]. Osmotic dehydration is widely used for the partial removal of water from plant tissues by immersion in a hypertonic (osmotic) solution. The driving force for the diffusion of water from the tissue into the solution is provided by the higher osmotic pressure of the hypertonic solution. During osmotic dehydration, water removal from the product is always accompanied by the simultaneous counter diffusion of solutes from the osmotic solution into the tissue [4]. The osmotic solution used must have a low water activity (a_w), and moreover, the solute must be harmless with good taste. The type of osmotic agent used for osmotic dehydration is a very important factor that determines the rate of diffusion and quality of the final product. Jaggery is concentrated sugar cane juice containing 75–85% sucrose, which is widely used as a substitute of white and refined cane sugar in India. Jaggery is used as ayurvedic/traditional medicines for treating throat and lung infections and also used for the preparation of sweet confectionery items [5]. Among the various osmotic agents used in the literature, jaggery is found to be more suitable because of its medicinal characteristics and its nutritional value [6]. The number of publications has been reported in the literature to know the influence of variables such as temperature, concentration of the osmotic solution, the size and geometry of the material, the solution to material mass ratio, and the level of agitation of the solution on mass transfer rates for different products using different osmotic solutions. [7–12].

The response surface methodology (RSM) has been widely and effectively used method in process and product improvement. It is widely used to examine and optimize the operational variables for experiment designing, model developing, etc., [13,14]. RSM is typically used for mapping a response surface over a particular region of interest, optimizing the responses, or for selecting operating conditions to achieve target specifications or consumer requirements [15]. Several studies on the optimized conditions for the osmotic dehydration process using RSM have been published for papaya, potato, diced pepper, and banana [16–18].

Artificial neural network (ANN) is a powerful modeling technique that offers several advantages over conventional modeling techniques because they can model based on no assumptions concerning the nature of the phenomenological mechanisms and understanding the mathematical background of problem underlying the process and the ability to learn linear and nonlinear relationships between variables directly from a set of examples. Artificial neural networks have already been applied to simulate processes such as fermentation [19], cross-flow microfiltration [20], drying behavior of different food and agricultural materials such as carrot [15,21], tomato [22], ginseng [23], cassava, mango [24], and osmotic dehydration [25]. Hence, the main motivation behind the study is to develop an approach for the evaluation of mass transfer during osmotic dehydration process by using RSM and ANN techniques.

In this study, a response surface methodology and artificial network model (ANN) models were developed to predict the mass transfer during osmotic dehydration of papaya. A number of experiments were carried out based on Box-Behnken experimental design to collect the output variables such as water loss (WL), weight reduction (WR), and solid gain (SG) as a function of osmotic temperature (30, 40, and 50 °C), osmotic solution concentration (40, 50, and 60 °brix), and agitation speed (100, 150, and 200 rpm). An effective RSM model and a feed-forward neural network on back-propagation were developed utilizing the experimental data, and the efficiency of both models was compared.

2. Materials and methods

2.1. Raw materials

Papaya (with similar maturity and weight) was used as raw materials in the experiments and was purchased from a local market near Erode, Tamil Nadu. Samples were stored at 4 °C prior to the experiments. Osmotic solution was prepared by mixing of appropriate amount of jaggery with the proper amount of water.

2.2. Experimental procedure

For each experiment, the papaya was washed, peeled manually, and cut into 1 cm × 1 cm × 1 cm cubes. The papaya cubes were washed in water to remove the fines adhering to the surface of the cubes. The desired concentration of osmotic solution of jaggery was prepared and the known weight of papaya cubes was immersed in the Erlenmeyer flasks which contain osmotic solutions of different concentrations (40, 50, and 60 °brix) at different temperatures (30, 40, and 50 °C) and agitation speeds (100, 150, and 200 rpm). Osmotic dehydration was carried out in a temperature and agitation controlled incubator shaker (GeNei, model SLM-INC-OS-16, India). To prevent evaporation from the osmotic solution, Erlenmeyer flaks were covered with a plastic wrap during the experiments. During the osmotic treatment, every half-an-hour the cubes were removed from osmotic solution and weighed after removing the solution adhering to the surface using filter paper (Whatman No 1), and this procedure was continued until the weight of the samples remained constant. Experi-