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NEURAL NETWORK MODELING AND OPTIMIZATION FOR SPRAY-DRYING COCONUT MILK USING GENETIC ALGORITHM AND PARTICLE SWARM OPTIMIZATION

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By

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NEURAL NETWORK MODELING AND OPTIMIZATION FOR SPRAY-DRYING COCONUT MILK USING GENETIC ALGORITHM AND PARTICLE SWARM OPTIMIZATION

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Chair : Assoc. Prof. Farah Saleena Taip, PhD
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Developing an accurate model of the spray drying coconut milk process is a complicated procedure. It involves application of engineering knowledge to describe the relationship between the processing conditions and the powder properties. The complexity of the both factors reduce white-box modelling accuracy in spray drying coconut milk modelling. As an alternate, neural network modelling with optimization technique is an alternative method that provide an accurate model of the system. The objective of this research is to develop and compare various ANN spray drying coconut milk models. Firstly, using MATLAB program, the ANN model is developed based on optimized topology and is then furthered optimized by genetic algorithm (GA) and particle swarm optimization (PSO) using MINITAB program. Using a rotational central composite design, the model development process is based on 20 experimental data consisting of inlet temperature (140°C-180°C), concentration of maltodextrin and sodium caseinate (0 %w/w – 10 %w/w), which are established as the input parameters. Moisture content (3.64%-5.1%), outlet temperature (76.5°C-104.5°C) and surface free fat percentage (0.35 mg/100g-34.51 mg/100g) are the output parameters for the neural network. Effect of spray drying parameter on the powder quality is further analyzed using response surface methodology (RSM) method. The ANN model topology is designed using selection from the best training algorithm, transfer function, number of training runs (1000-5000), number of hidden layers (1-3) and nodes (5-15). The ANN model is further improved using GA and PSO. Each algorithm has its own parameters and is further optimized using RSM. Firstly, minimizing all three responses of the coconut milk powder leads towards the spray drying of coconut milk at the inlet temperature of 140°C combined with the concentrations of maltodextrin and sodium caseinate at 8% and 5% (w/w) and was recommended as the condition for RSM optimization. Using statistical method of highest R^2 value and lowest MSE value, the ANN most optimum topology model consists of K-fold cross validation implements the Levenberg-Marquart training algorithm with hyperbolic

tangent sigmoid transfer function using 4500 times of training runs with optimal topology configuration of 3-8-2-3. Integration of global search algorithm into ANN model further improved the model performance. The optimized selected GA parameters values are at maximum population size (100), minimum crossover rate (0.2) and maximum mutation rate (1.0). The obtained PSO parameters chosen are recorded at optimum value of C_1 (4.0), C_2 (0) and number of particles (100). GA-ANN model outperformed ANN and PSO-ANN model as GA-ANN recorded the lowest MSE value and highest R^2 value. In engineering application wise, all four models are tested against external datasets to prediction accuracy and generalization capacity of all models, leading towards cost and time reduction in model development. Using linear regression analysis and comparative error analysis (MSE, R^2, SEP and MPE), GA-ANN model outperformed in all dependent variables and achieved lowest MSE, SEP and MPE values and highest R^2 values. This showed that GA-ANN model has the best prediction model for the spray drying of coconut milk system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMODELAN DAN PENGOPTIMALAN RANGKAIAN NEURAL UNTUK PENGERINGAN SEMBURAN SUSU KELAPA SANTAN MENGGUNAKAN ALGORITHMA GENETIK DAN PENGOPTIMUMAN KUMPULAN ZARAH

Oleh

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Januari 2022

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Penghasilan modal pengeringan semburan santan kelapa yang tepat merupakan proses yang rumit. Proses ini melibatkan aplikasi ilmu kejuruteraan dalam mengaitkan hubungan antara keadaan pemprosesan dan qualiti serbuk. Kerumitan kedua-dua faktor menyebabkan pengurangan ketepatan pemodelan kotak putih dalam pemodelan pengeringan semburan santan. Pemodelan rangkai neural dan teknik pengoptimuman merupakan kaedah alternatif yang dapat menghasilkan modal sistem yang tepat. Objektif penyelidikan ini adalah untuk menghasilkan dan membandingkan variasi pelbagai ANN modal pengeringan semburan santan kelapa. Menggunakan MATLAB, modal ANN dikembangkan berdasarkan pengoptimuman topologi dan kemudian dioptimumkan menggunakan *genetic algorithm* (GA) dan *particle swarm optimization* (PSO) dengan sistem MINITAB. Menggunakan reka bentuk komposit pusat putaran (RSM), proses pembangunan modal terdiri daripada 20 data eksperimen melibatkan suhu saluran masuk, kepekatan maltodekstrin dan sodium kaseinat yang merupakan parameter input. Kandungan lembapan, suhu saluran keluar dan peratusan lemak bebas di permukaan merupakan parameter keluaran untuk rangkaian neural. Kesan setiap parameter pengering semburan kepada kualiti serbuk dianalisis menggunakan kaedah RSM. Topologi model ANN direka menggunakan kriteria pemilihan daripada pemilihan terbaik Latihan algoritma, fungsi rangkap pindah, bilangan Latihan, (1000-5000), jumlah lapisan tersembunyi (1-3) dan nod (5-15). Model ANN ditambah-baikkan dengan algoritma GA dan PSO. Setiap algoritma mempunyai parameter tersendiri dan ditambah baik lagi menggunakan kaedah metodologi permukaan tindak balas (RSM). Pertama, meminimumkan ketiga-tiga tindak balas serbuk santan menyebabkan pengeringan semburan santan pada suhu masuk 140°C digabungkan dengan kepekatan maltodekstrin dan natrium kaseinat pada 8% dan 5% (b/b) dan disyorkan. sebagai syarat untuk pengoptimuman RSM. Parameter GA terpilih yang dioptimumkan mempunyai saiz populasi maksimum (100), kadar persilangan minimum (0.2) dan kadar mutasi maksimum (1.0).

Paramter PSO terpilih merekodkan nilai optimum C_1 (4.0), C_2 (0) dan jumlah partikel (100). Menggunakan kaedah statistik pemilihan nilai R^2 tertinggi dan nilai MSE terendah, model ANN yang mempunyai topologi paling optimum mempunyai K-fold validasi silang, algoritma latihan Levenberg-Marquart, fungsi rangkap pindah sigmoid tangen hiperbola, 4500 kali latihan dengan topologi optimal konfigurasi 3-8-2-3. Integrasi algoritma carian global dalam ANN meningkatkan prestasi model. Modal GA-ANN merekodkan pretasi yang lebih bagus daripada model ANN dan PSO-ANN kerana GA-ANN merekodkan nilai MSE paling rendah dan nilai R^2 paling tinggi. Dari persepsi kejuruteraan aplikasi, keempat-empat modal diuji dengan data eksperimen luaran untuk ketepatan ramalan dan keupayaan generalisasi setiap modal, menuju ke arah pengurangan kos dan masa dalam pengembangan modal. Menggunakan analisis regresi linear dan analisis ralat perbandingan MSE, R^2, SEP and MPE, modal GA-ANN adalah lebih baik dalam setiap pembolehubah bersandar dan mencapai nilai MSE, SEP dan MPE terendah dan nilai R^2 tertinggi. Ini menunjukkan model GA-ANN adalah model ramalan terbaik untuk proses pengeringan semburan santan kelapa.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research and the writing of this thesis were done under our supervision;
- supervisory responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2015-2016) are adhered to.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
ANOVA	Analysis of Variance
CCD	Central Composite Design
CV	Coefficient of Variance
DE	Dextrose Equivalent
GA	Genetic Algorithm
MPE	Model Error Prediction
MSE	Mean Square Error
PSO	Particle Swarm Optimization
RMSE	Root Mean Square Error
RSM	Response Surface Methodology
SEP	Standard Error Prediction

CHAPTER 1

INTRODUCTION

1.1 Spray Drying of Coconut Milk

Spray drying is a well-established unit operation application for converting liquid feed material into powder form. The conversion involves liquid feed atomized through a device, forming droplets that is sprayed into hot air medium. Droplets of liquid feed undergo heat treatment are then converted into dried powdered products (Anandharamakrishnan et al., 2007b; Masters, 1987) Dried powdered solid particles can be found in the form of powdered granules or agglomerated product, and these attributes directly depend upon the unit operation design and properties of the feed (Patel & Chen, 2005).

The advantage of spray drying is the capability to control the particle size and morphology of the dried powder by manipulating process parameters and feed formulation. The principle and process of spray drying is applied in many industries including food, household and pharmaceutical products. The spray drying resourcefulness lies in its continuous operation, wide range of operating temperatures, short residence times, flexibility in capacity design and suitability of multiple heat sensitive and resistant materials. The principle and process of spray drying is applied in many industries including food, household and pharmaceutical products. The spray drying resourcefulness lies in its continuous operation, wide range of operating temperatures, short residence times, flexibility in capacity design and suitability of multiple heat sensitive and resistant materials. Despite its advantages, the spray dryer has low thermal efficiency as the process required a larger volumetric flow of air for drying relatively smaller amount of feed. The development in spray drying technology involves (Masters, 2004):

i) Cost reduction in production of powder
ii) Producing powders that meet market demands regarding powder specification
iii) Undesirable and excessive deposition of powder to be reduced
iv) Health, safety and environmental protection to be met on demand

With the growth of development in the spray drying technology and the market demand for specification of products, spray drying technique present high commercial viability; production with largest capacity by a simple operation at lowest possible cost. Alternative to spray drying techniques such as freeze drying and drum drying are not capable in producing high specification products in a continuous flow. Improved spray drying method has used to produce nanoparticles powders (Arpagaus, 2012).

1.2 Artificial Neural Network Modeling

Artificial Neural Network (ANN) was put forwards as an alternative modelling method for the spray drying process. The ANN method focuses on the topology configuration as a basis design configuration towards the spray drying model development and its effectiveness. Therefore, topology configuration and optimization has been critical in the food drying industry that encovers convective drying, vacuum drying and thin-layer drying (Beigi & Ahmadi, 2018; Chen et al., 2001; Gorjian et al., 2011). On the other hand, the performance of ANN requires large numbers of datasets to achieve robustness and reliability. A large number of datasets offset the poor precision and accuracy of the model.

In view of these limitations of the ANN, global search techniques such as genetic algorithm (GA) and particle swarm optimization were brought to attention as method to overcome these drawbacks (Clow & White, 2004). In the same context, the similarity of both evolutionary algorithms is the proses-by-proses to generate and evaluate solutions by performance, initialization, evaluation and generation of new selection. Both GA and PSO have similar all three mentioned main processes to ensure that feasible solutions are attained. Furthermore, both GA and PSO tend to produce generations of many feasible solutions that often ‘clustered’ around one or more good solutions as the search involved. Based on previous sections, both evolutionary algorithms are programmed to follow the good solution and build a convergence of populations towards that solution (Kachitvichyanukul, 2012).

1.3 Problem Statement

From the eye of industrialists, the spray drying system is an important drying system since the 1900s. Regardless of that, optimization of spray drying system heavily on experimental data from pilot-scale plants and design experiences (Huang, Kumar, & Mujumdar, 2006). The complexity of spray drying process involves simultaneous heat, mass and momentum transfer between drying medium and feeds, while considering the cost efficiency and restriction placed into production. Furthermore, the properties of feeds such as viscosity, glass transition temperature and agglomerations make the prediction of spray drying design and operating parameter more challenging. Therefore, the complexity of physical, chemical and mechanical properties should pave a path for developing a white box model of spray drying system. The consideration of a white box (theoretical) model over a black box model has the essentials of better operability study and understanding of the process performance of a spray drying system.

A wide range of operating variable (inter-dependent) are involved in the spray drying process that can be varied to optimize the process. These include flow rate and temperature of feed, drying gas temperature, nozzle arrangement and feed solid concentration. All of these affect the dried powder characteristic including powder size distribution, morphology, flow ability and moisture content

(G. R. Chegini et al., 2008). Conventional modelling method using response surface methodology (RSM) based model is proven less significant in comparison with ANN models by evaluation of experimental data with both models. RSM model showed greater deviation in average mean absolute error (MAE), root mean square error (RMSE) and R^2 value. (Youssefi et al., 2009). The complexity of spray drying process is also influenced by the correlative relationship between independent variables in the system, as it leads to multiple-layer common linear phenomenon occurrence resulting towards inconsistent end product characteristic (moisture content, particle size and etc.). The interaction between both independent variable, inlet air temperature and feed concentration have statistically significant interaction on moisture content of powder compared to other independent variable (Avila et al., 2015).

As a branch study of evolutionary computation, both genetic algorithms (GAs) and particle swarm optimization (PSO) are adaptive heuristic search algorithm that focused on determining optimal solutions. The search method used by GA are based on the principles of natural selection and genetics, in that they patterned biological processes of reproduction and natural selection to produce the best solution or 'fittest' solutions (Kalathingal et al., 2019). PSO is a population based stochastic optimization algorithm which based on the movement of animal behaviors attributed by Eberhart Kennedy (Rane, 2013). The PSO algorithm initialized a set of random particles to search for optimal solution iteratively in the search space. The PSO algorithm simulates this movement as the algorithm creates a swarm of particles that moves around in a search space, with a purpose of attaining a set of goals that suits the particle need given by a fitness function (cost) (Clow & White, 2004).

Using MATLAB, the complexity of spray drying system consisting of multiple parameters can be analysed using a powerful simulation and optimization tool through neural networking and artificial intelligence. The most optimum path of inter-linked processing parameters and powder properties which became a major challenge can be identified. This will benefit the industry to produce best process yield and optimum particle characteristics with higher efficiency and adaptability in spray drying processing.

1.4 Research Objective

The research of this study is based on the four main objectives which are:

1. To optimize and study the effect of spray drying parameters on the quality of the coconut milk powder through RSM

2. To develop a spray drying of coconut milk model using artificial neural network (ANN) by implementation of experimental design using response surface methodology (RSM).

3. To optimize and compare the spray drying ANN model using two different optimization technique, particle swarm optimization (PSO) and genetic algorithm (GA)

4. To compare the performance of coconut milk spray drying model of RSM, ANN, GA-ANN and PSO-ANN

1.5 Research Significance

To reduce the percentage of surface free fat in the coconut milk powder, proposed alternative additive such as sodium caseinate is used together with maltodextrin during the preparation of coconut milk. The sodium caseinate provide a protective layer on the powder particle, thus ensuring the surface free fat is not exposed and leads towards rancidity of the powder. For this study, the combination of maltodextrin and sodium caseinate acts as filler and protective layer improve the quality and quantity of coconut milk powder produced.

ANN is used as an alternate modelling method compared to the white box model method as it required only experimentation data to produce a model, whereas white box model requires intensive knowledge on relating powder quality with spray drying processing conditions. Furthermore, the ANN model is enhanced by global search algorithm such as GA and PSO to provide better performing models. This could increase the versatility of ANN modelling as a functional spray drying model and provide researchers and engineers an alternative way in developing models and simulation, thus reducing costing and time for model development and extending the application of ANN in food control and simulation.

1.6 Project Outline

The thesis is organized into six chapters, in which Chapter One provides an introduction on artificial neural network and spray drying of coconut milk. The first chapter also further refine the problem statement and the objectives of the study are stated.

In the following chapter, Chapter Two provides a detailed literature review of the spray drying process of coconut milk and its parameters, response surface methodology, artificial neural network and optimization techniques such as genetic algorithm.

Chapter Three elaborates on the case study of spray drying of coconut milk for the artificial neural network modeling. The chapter further elaborates on the stages of research conducted from experimental works, modeling and optimization techniques and comparison performance of both model

Chapter Four presents the results of the spray drying parameters on the powder quality through optimization technique of RSM. This chapter also presented the development of the FANN modeling of the spray drying of coconut milk process. The ANN model developed is then further optimized using GA and PSO optimization technique.

Chapter Five presented the development of the ANN modeling of the spray drying of coconut milk process. The ANN model developed is then further optimized using GA and PSO optimization technique.

Chapter Six presents on the comparison of all four-model developed from Chapter 4 and Chapter Five, which are RSM model, ANN, GA-ANN and PSO-ANN model using selected parameters

Last but not least, Chapter Seven concludes the finding of the research and the target values of the objectives. The chapter also includes the recommendation for the further study on the modeling of spray drying coconut milk.

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