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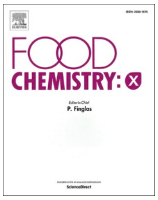

Impact of foam-mat drying conditions of “Gấc” aril on drying rate and bioactive compounds: Optimization by novel statistical approaches

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ABSTRACT

This study was conducted to optimize the foam-mat drying conditions to maximize quality [β-carotene and total polyphenol content (TPC)] and drying rate of “Gấc” aril powder by using two novel statistical techniques as Response Surface Methodology (RSM) and Artificial Neural Network (ANN) couple with Genetic Algorithm (GA). During production process, level of egg albumin (EA) used for foaming process and drying temperature mainly influenced the drying rate and content of antioxidant compounds in powder. ANN model of 3–10–3 showed more accuracy and faster prediction capacity than RSM model did. ANN-GA model predicted the optimal conditions to be 13.31 % EA, 0.26 % xanthan gum and drying temperature of 73.1 °C, with the drying rate of 1.89 g-water/g-dry matter/min, β-carotene content of 395.88 μg/g, TPC of 1.68 mgGAE/g. These results confirmed the suitability and promising of foam-mat drying for “Gấc” aril powder production, to be producing food ingredient containing highly bioactive compounds.

1. Introduction

“Gấc” fruit (*Momordica cochinchinensis* Spreng) is widely grown in Southeast Asian countries (Chuyen et al., 2015). In Vietnam, “Gấc” is the common name, and it has been used as food and medicine for a long time due to high content of nutritional and bioactive compounds that “Gấc” fruit possesses (Wimalasiri et al., 2020). A concentration of 892 μg/g fresh weight (FW) of total carotenoids was identified in “Gấc” aril, which includes 188 μg/g FW of β-carotene (Chuyen et al., 2015). This fruit also contains relatively high levels of polyphenols, lycopene, tocopherol, and flavonoids (Kubola & Siriamornpun, 2011), which are identified to have high antioxidant properties. Recently, the food and pharmaceutical industries have shown great interest in “Gấc” fruit and have produced products from it such as “Gấc” powder, oil capsules, juice and frozen product. Furthermore, these products have been marketed as food additives, in cosmetics and for medicinal and pharmaceutical purposes. When “Gấc” fruit is ripe and harvested, the problem that often occurs is that the firmness suddenly decreases just a few days later, and the rate of fungal diseases during storage is also very high. Therefore, after harvesting to the right maturity, the “Gấc” aril needs to be recovered and used immediately. One of common products that “Gấc” aril could be produced, which is the powder form through drying process.

Drying is an important method for preserving food in the food processing sector (Sagar & Suresh Kumar, 2010). In this process, the moisture content can be reduced to the range of 1–5 % (Asokapandian et al., 2016). As the drying process proceeds, it brings about changes in the spatial distribution, microstructure, which further affects the texture of the dried product. To remove the fruit pulp and juice, many new drying methods such as spray drying, vacuum drying, freeze-drying, microwave drying, and foam drying are used. The most important aspect of food dehydration is to maintain the quality and preserve the nutritional, physical, microbiological and chemical properties (Figiel & Michalska, 2016). Therefore, the biggest challenge is to find the most suitable food drying technique that results in negligible changes in color, nutrients and provides the desired texture, flavor, shrinkage and dehydration properties to the dried product. Among other novel drying methods, foam mat drying is the simplest and most alternative novel technology for powder formation as it helps to remove excess moisture from fruit and vegetable juices, pulps and purees without affecting the

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color, texture and nutritional properties (Sangamithra et al., 2015).

There are various drying techniques that can be used, such as convection drying, spray drying, drum drying, vacuum drying, and freeze drying (Pinthong et al., 2019). Convection drying, in which hot air is used as the heat carrier, appears to be a relatively low-cost way to remove moisture (Lewicki, 2006) and also provides satisfactory dehydration results at high drying rates (Figiel, 2010). However, degradation of important nutrients such as carotenoids along with discoloration is observed in the final products during convection drying. However, the disadvantages of other methods are low drying rates, leading to relatively low productivity, significant energy consumption and high cost (Zhang et al., 2006), investment and operating costs and very high technical requirements (Inyang et al., 2017). Among various drying methods, foam-mat drying is considered a relatively simple and low-cost drying technique that offers many advantages over other drying methods, such as short drying time and good hydration properties of the final product (Muthukumaran et al., 2008). This method has also been shown to be suitable for drying highly viscous juices or liquid foods with high total soluble solids content (Hardy & Jideani, 2017). This condition is particularly suitable for "Gấc" aril, which is highly viscous and has a high fat content. In this process, liquid or semi-liquid foods are whipped with a foaming agent to produce a stable foam by incorporating a sufficient proportion of air, creating a porous structure with high heat and mass transfer rates upon dehydration (Hossain et al., 2021). The total process time is significantly reduced at lower temperatures and, therefore, a product with better nutritional quality can be obtained (Abbasi & Azizpour, 2016). However, to be effective in this drying process, the foam must be kept in a mechanically and thermodynamically stable state to enable efficient water removal while maintaining product quality (Franco et al., 2015). Therefore, it is essential to use a foaming agent that provides uniform stability. One of the most widely used foaming agents in foam drying is egg albumin which is applied because of its ability to form a thick film around the protein gas bubbles, which helps to retain the associated gases and provide surface tension stability (Lomakina & Mikova, 2006). The effect of foam drying conditions on the physical and chemical properties and antioxidant properties of the dried product was studied by Auisakchaiyoung and Rojanakorn (2015). They used methylcellulose as the foaming agent, the effect of whipping time and drying temperature (60–80 °C) were identified. The optimal condition for foaming is 1.5 % methylcellulose after 25 min. Drying temperature of 70 °C for 60 min maintains the highest amount of lycopene, β-carotene, phenolic as well as the greatest antioxidant activity. The foam drying process has also been successfully performed for various ingredients (Asokapandian et al., 2016; Khamjae & Rojanakorn, 2018; Muthukumaran et al., 2008; Thuy et al., 2022; Van Tai et al., 2024). These reports have also implemented process optimization and extensively utilized response surface methodology (RSM). RSM is a comprehensive approach that utilizes statistical and mathematical techniques to design experiments, create models, assess the impact of independent factors on responses, and identify the optimal settings for process parameters. Statistical RSM is commonly employed to estimate polynomial models, particularly quadratic polynomials. Artificial neural network (ANN) relies on a substantial volume of data to generate a precise and reliable output. However, when the data in the input domain is statistically well-distributed, such as when using Design of Experiment (DOE) in RSM, ANN can be efficiently utilized to construct the model (Elfghi, 2016). Prior research has demonstrated that when using data collected from DOE for RSM and ANN modeling, ANN exhibited superior performance compared to quadratic polynomials in modeling the fermentation process (Desai et al., 2008; Elfghi, 2016). A genetic algorithm (GA) is an effective stochastic search technique that tackles challenging optimization issues by emulating the process of natural selection. The GA emulates the fundamental concepts of evolution, specifically the survival of the fittest and the random interchange of data during propagation. This process leads to the evolution of biological species, where the most superior one is chosen in a competitive setting (Desai et al., 2008; Elfghi, 2016). The input space of the ANN model can be optimized using GA, commonly known as ANN-GA. Furthermore, the process of optimization of foaming and drying conditions has not been considered in most of the literature, especially for "Gấc" aril as in this study. Therefore, this study is aimed to characterize the combined effects of foaming agents, foam stability and different drying temperatures on drying rate and bioactive compounds (β-carotene and total polyphenols). In addition, applying the RSM and ANN-GA techniques for predicting and optimizing the production process is reported in the first time for foam-mat dried "Gấc" aril powder.

Table 1
Independent variables and their levels in the Box-Behnken design (BBD).

Factors	Independent variables	Units	Levels		
			−1	0	1
X_1	Egg albumin (EA)	%	9.2	12.2	15.2
X_2	Xanthan gum (XG)	%	0.1	0.24	0.38
X_3	Drying temperatures	°C	65	70	75

2. Materials and methods

2.1. Preparation of "Gấc" aril foam

"Gấc" fruits (*Momordica cochinchinensis Spreng.*) were harvested at 11 weeks after fruit set, had orange or completely red skin, yellow flesh and red aril as shown in our prevous study (Tien et al., 2024). The fruits also were free from scratches, pests and mechanical damage. Fruit is washed and dried naturally. When used, the fruit is split in half, "Gấc" arils were collected and put into PE zippers bags and stored at -18 °C for further experiment.

The ethanol solution 20 % was prepared, then use a 3:1 ratio of ethanol and "Gấc" aril. The mixture was blended to form a puree (using a Philips HR2041/10 Blender). Next, the concentrations of egg albumin (EA) and xanthan gum (XG) were added (according to the experimental setup, as describing in Table 1) and the mixture was whipped (using a Philips HR 3705–300 W machine) for 6 min (Thuy et al., 2022). "Gấc" aril foam with a thickness of about 3 mm was spread on a tray lined with wax paper (Kadam & Balasubramanian, 2011). The foam was dried in a drying unit (MEMMERT, UN260, Bavaria, Germany) at an air velocity of 1.0 m/s at different temperatures (Table 1) until the sample reaches equilibrium moisture content (about 4 %). The dried foam samples were ground to 50–70 μm in size, contained in a PE zippers bags and stored at −18 °C.

2.2. Box-Behnken experimental design

The experiment was set up based on the Box-Behnken model using Statgraphics Centurion XV·I software (USA). In this experimental design, three coding levels for each variable were selected: −1, 0, and +1 representing low, center, and high levels of each independent variable, respectively (Table 1). The experimental range was selected based on the results of preliminary experiments and previous studies (Thuy et al., 2022). The independent variables included EA (9.2–15.2 % w/w), XG (0.1–0.38 % w/w), and drying temperature (65–75 °C). The dependent variables/responses included drying rate, β-carotene content, and TPC.

The number of experiments (N) required for the development of Box-Behnken were determined as Eq. 1.

$$N = 2k(k-1) + C_o \tag{1}$$

where k is number of factors and C_o is the number of central points. Because some systematic errors and therefore some unexplained variability may occur in the observed responses, experiments were replicated (six replications) in the center of design to make the approximation of pure error possible (Qiu et al., 2010).

To investigate the behavior of the response surfaces, a second-order polynomial equation was fitted to the experimental data of each independent variable (Eq. 2).

$$Y = \beta_o + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_{ii}^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \tag{2}$$

where, Y is the estimated response (drying rate, β-carotene content, and TPC); β_0, β_i, β_{ii}, and β_{ij} are constant coefficients and X_i and X_j represent the coded independent variables. The adequacy of regression model and the goodness of fit were determined by model analysis, lack-of-fit, and coefficient of determination parameters (Kaur et al., 2009).

2.3. Drying rate determination

The drying rate indicates the amount of moisture lost from the sample per unit time; this rate is calculated using Eq. 3 (Ojediran et al., 2020).

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \tag{3}$$

where $M_{t+\Delta t}$ is the moisture content at t + dt (kg water/kg dry matter), t is time (min), Δt is the time difference (min).

2.4. β-Carotene determination

β-carotene content was analyzed according to the method of Fikselová et al. (2008) and calculated according to Eq. 4.

$$\beta - carotene\ (mg/100mL) = \frac{A \times d \times V}{E_{1cm}^{1\%} \times w} \tag{4}$$

where A is absorbance, d is dilution, $E_{1cm}^{1\%}$: coefficient of absorbancy (2592 for petroleum-ether), W is weight of sample (g), and V is volume (mL).

2.5. TPC determination

Total polyphenol content was determined by the Folin–Ciocalteu method (Olsson et al., 2006). Results were expressed as milligrams of GAE/g of sample (mgGAE/g).

2.6. ANN modeling and GA optimization

During the optimization phases for drying conditions, three independent input variables were selected as previous shown in Table 1. The experimental settings and output of drying rate, content of TPC and β-carotene, which were devised by BBD, were simulated using ANN. Subsequently, the circumstances were fine-tuned by employing Genetic Algorithm (GA) in conjunction with the Artificial Neural Network (ANN) model, with the objective of maximizing drying rate, content of TPC and beta-carotene. The ANN and GA were implemented using the Deep Learning Toolbox 12.1 and Optimization Toolbox 8.3 in MATLAB software (Version R2023b, The MathWorks, Inc., Natick, MA, USA), respectively.

A two-layer feed-forward neural network with sigmoid activation functions in the hidden layer and linear activation functions in the output layer was employed to perform non-linear analysis of lentinan extraction. The artificial neural network (ANN) model is composed of an input layer including three neurons (X_1, X_2, and X_3), a hidden layer consisting of 10 neurons, and an output layer containing three neurons (drying rate, TPC, and β-carotene). The experimental datasets were partitioned into three subgroups using random selection. The training subset consisted of 70 % of the data, the validation subset consisted of 15 % of the data, and the testing subset consisted of 15 % of the data. The ANN model underwent iterative training using the Levenberg-Marquardt technique to iteratively adjust the weight vector and bias of the neural network. The process was continued until the artificial neural network (ANN) achieved the lowest mean square error (MSE) and the highest regression correlation coefficient (R), closely approximating the real extracted model. This resulted in an ANN model with exceptional prediction capabilities.

Table 2
Analysis of variance for drying rate.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
X_1	0.268393	1	0.268393	79.98	0.0000
X_2	0.036504	1	0.036504	10.88	0.0020
X_3	3.75409	1	3.75409	1118.68	0.0000
X_1X_1	0.0311646	1	0.0311646	9.29	0.0040
X_1X_2	0.000310083	1	0.000310083	0.09	0.7627
X_1X_3	0.00063075	1	0.00063075	0.19	0.6669
X_2X_2	0.00033275	1	0.00033275	0.10	0.7544
X_2X_3	0.0139401	1	0.0139401	4.15	0.0480
X_3X_3	0.131018	1	0.131018	39.04	0.0000
Lack-of-fit	0.00311433	3	0.00103811	0.31	0.8185
Pure error	0.137588	41	0.0033558		

R^2 = 96.78 % R^2 (adjusted for d.f.) = 96.12 % Standard Error of Estimate = 0.058.

The fitness function is employed in genetic algorithms (GA) to identify the best value within the constraints of the extraction condition. The fitness function of the GA solver in this study was implemented using the created neural network function. It is important to mention that the Genetic Algorithm constantly seeks to maximize the minimal value of the fitness function. The GA optimization toolkit utilizes default settings for several parameters including population size, fitness scaling, selection method, reproduction strategy, mutation rate, crossover technique, migration scheme, constraint handling, hybrid function, and stopping criteria.

3. Results and discussion

3.1. RSM modeling

3.1.1. Effect of egg albumin, xanthan gum concentration and drying temperatures on drying rate

Optimization of parameters EA (%), XG (%) and drying temperature (°C) was performed by response surface methodology (RSM). The statistical significance of the model was tested through analysis of variance (ANOVA) at 95 % confidence level. The results of statistical analysis are presented in Table 2. The results showed that the linear effects (X_1, X_2, X_3); the square effects (X_1X_1, X_3X_3) and the interaction (X_2X_3) had a significant influence on the drying rate ($P < 0.05$). The analysis results also showed that there was no contribution of the interaction of X_1X_2, X_1X_3 and the square effect of X_2X_2 to the drying rate ($P > 0.05$). The insignificant interactions were removed from the equation and a fitting model was established (Eq. 5).

A good correlation model requires a good fit between the actual data and the model predictions. The correlation model built from the experimental data satisfied the condition with high correlation coefficients R^2 and R^2_{adj} (0.968 and 0.96, respectively, along with a *P*-value

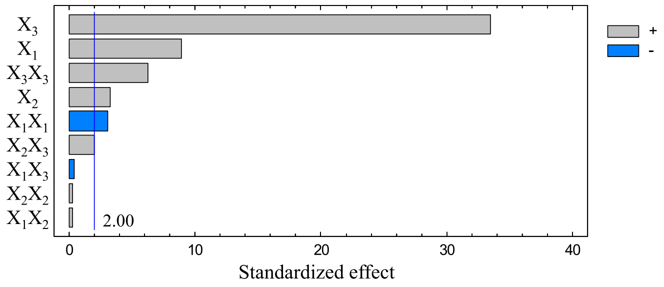


Fig. 1. Standardized Pareto chart for drying rate.

of Lack-of-fit greater than 0.05 (0.819). Therefore, the quadratic model was fitted well to the data of the experiment by ANOVA.

$$Y_1 = 15.29 + 0.17X_1 – 3.13X_2 – 0.5X_3 - 0.0054X_1X_1 + 0.048X_2X_3 + 0.004X_3X_3 \tag{5}$$

where Y_1 is drying rate (g water/g dry matter/min), X_1 is EA concentration (%), X_2 is XG concentration (%) and X_3 is drying temperature (°C).

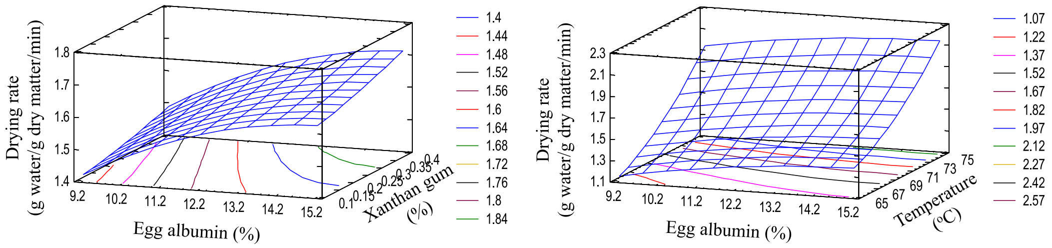
The Pareto chart is helpful for making decisions in a study because it lets you figure out the important steps that you need to take to get the desired results. It can also be said that the Pareto chart is a technique that allows you to graphically classify information from most to least relevant, aiming to recognize the most important problems that you should focus on and solve. In this case study, the observation can be highlighted on a Pareto chart of standardized effects, as shown in Fig. 1. The effects have been standardized and are proposed in order of relative importance and impact of the factors (sources) on drying rate. The length of the bars is proportional to the absolute magnitude of the estimated effect coefficients while the vertical line represents the minimum magnitude of the effects that are significant for the response under study, with a range of 95 % confidence interval. The results showed that the linear effect of X_3, X_1, X_2; the square effect of X_3X_3 and the interaction of X_2X_3 had a positive effect on the drying rate in this experiment. Similarly, the square effect of X_1X_1 had a negative effect on the drying rate.

The response surface and contour plots showing the correlation between drying rate and influencing factors are presented in Fig. 2. The drying rate in this study ranged from 1.16 to 2.18 g water/g DW/min. From Fig. 2a, when the EA and XG ratios increased, the drying rate increased. The increased use of foaming agent (EA) led to increased air penetration into the foam structure, increasing the porosity of the structure, thereby increasing the contact area and moisture diffusion capacity of the foam. The results also showed that increasing the foam stabilizer (XG) helped stabilize the foam, prevent the foam from collapsing and separating water, thereby helping the foam to stabilize its structure. Figs. 2b and Fig. 2c showed that the drying rate increased linearly with the drying temperature. The increase in air temperature reduced the moisture content due to the rapid heat transfer due to the temperature difference between the foam and the drying air temperature (Mishra et al., 2014). Drying rate is a function of temperature and time, higher temperature corresponds to higher drying rate and faster drying time while the effect of air velocity is almost negligible or has little impact (Caparanga et al., 2017). With the goal of maximizing the drying rate to 2.23 g water/g DW/min, the optimal values of EA, XG content and drying temperature were determined to be 15.2 %, 0.38 % and 75 °C, respectively.

Table 3
Analysis of Variance for β-carotene.

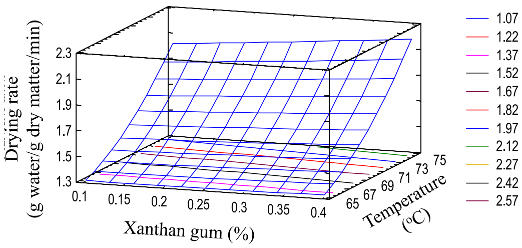
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
X_1	6556.53	1	6556.53	6556.53	0.0000
X_2	1648.3	1	1648.3	1648.3	0.0043
X_3	21,035.4	1	21,035.4	21,035.4	0.0000
X_1X_1	4759.28	1	4759.28	4759.28	0.0000
X_1X_2	51.394	1	51.394	51.394	0.5965
X_1X_3	1198.96	1	1198.96	1198.96	0.0137
X_2X_2	2872.89	1	2872.89	2872.89	0.0003
X_2X_3	1453.83	1	1453.83	1453.83	0.0070
X_3X_3	88,581.8	1	88,581.8	88,581.8	0.0000
Lack-of-fit	474.653	3	158.218	158.218	0.4612
Pure error	7401.86	41	180.533		

R^2 = 94.61 % R^2 (adjusted for d.f.) = 93.50 % Standard Error of Est = 13.44.



a. Temperature 70°C

b. Xanthan gum 0.24%



c. Egg albumin 12.2%

Fig. 2. Response surface and contour plots estimate the effect of variables on drying rate (g water/g DW/min).

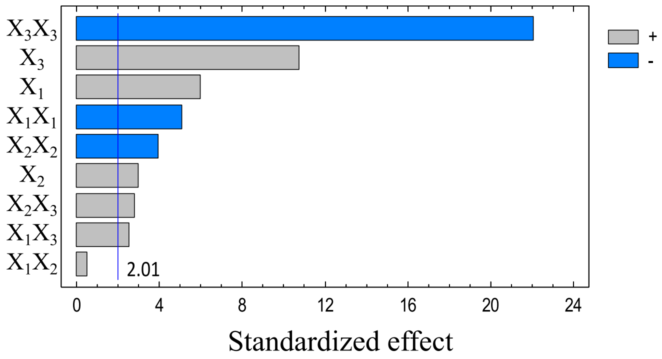


Fig. 3. Standardized Pareto chart for β-carotene.

3.1.2. *Effect of egg albumin, xanthan gum concentration and drying temperature on β-carotene content in "Gấc" aril powder*

The results of variance analysis and reliability are shown in Table 3. The linear effect (X_1, X_2, X_3), the interaction (X_1X_3, X_2X_3) and the square effects (X_1X_1, X_2X_2, X_3X_3) all showed high reliability (*P*-value <0.05) when participating in the model, except the interaction of X_1X_2 showed an insignificant effect ($P > 0.05$).

The high values of R^2 (94.61 %) and R^2_{adj} (93.50 %) for the model describing the relationship between the dependent variable and the independent variables, together with Lack-of-fit = 0.46 ($P > 0.05$), showed that the selected model was accurate enough to explain the characteristics and predict β-carotene content from the influencing factors. After excluding the terms with P-value >0.05, Eq. 6 describing the relationship between β-carotene content and the independent variables was established.

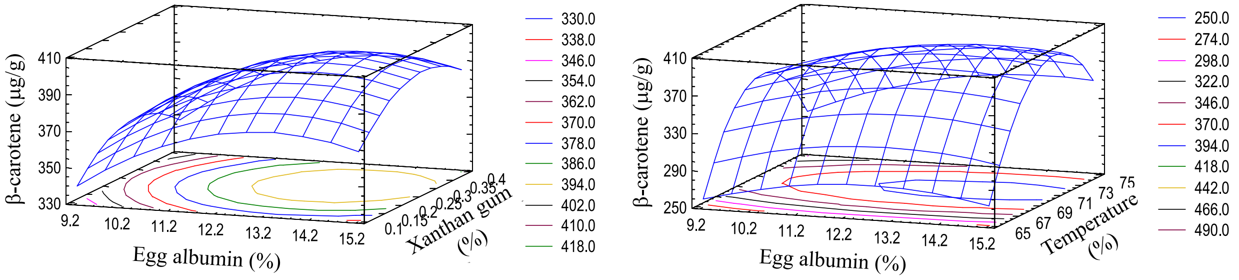
$$Y_2 = -15748.4 + 10.56X_1 - 678.7X_2 + 454.67X_3 - 2.12X_1X_1 + 0.66X_1X_3 - 755.82X_2X_2 + 15.72X_2X_3 - 3.29X_3X_3 \tag{6}$$

where Y_2 is β-carotene content (μg/g), X_1 is EA concentration (%), X_2 is XG concentration (%) and X_3 is drying temperature (°C).

In addition, pareto diagrams was added to detect the effects of the most important factors and interactions on the optimization, shown in Fig. 3. From the figure, the square effect (X_1X_1, X_2X_2, X_3X_3) was determined to have a negative impact. The linear effect (X_1, X_2, X_3) and the pair interactions (X_2X_3, X_1X_3) were determined to have a positive impact, meaning that the impact had a positive influence on the β-carotene content in "Gấc" aril powder obtaining by foam-mat drying. From the results obtained with BBD, it is inferred that drying temperature and EA were found to be the most significant.

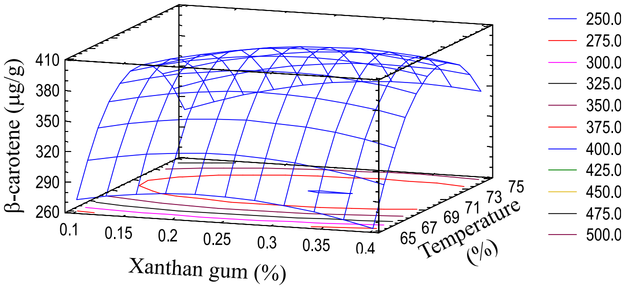
Similarly, the response surface plot for the effect of independent variables (X_1, X_2 and X_3) on β-carotene content is shown in Fig. 4. The EA content, XG content and drying temperature all influenced β-carotene content. The β-carotene content ranged from 267.76 μg/g to 410.62 μg/g. At a fixed drying temperature of 70 °C (Fig. 4a), when the EA concentration increased from approximately 12.2–15.2 % and XG from approximately 0.15–0.35 %, the β-carotene content remained higher than other conditions. This is probably because when EA and XG increased, the foam expansion also increased, thus increasing the surface contact area of the foam. This resulted in faster drying time and less destruction of β-carotene content. However, when increasing past the optimum point (EA = 13.75 % and XG = 0.3 %), the β-carotene content tended to decrease, probably due to the dilution effect of β-carotene in the presence of these compounds. In the study of Karabulut et al. (2007) on the degradation of β-carotene in apricots, they found that increasing the drying time caused a significant degradation of β-carotene compared to increasing the drying temperature.

With the XG and EA concentrations fixed at 0.24 % (Fig. 4b) and 12.2 % (Fig. 4c), when the drying temperature increased from 65 °C to the optimum point (71.2 °C), the β-carotene content in the sample was still quite high, however, when the temperature reached 75 °C, the β-carotene content tended to decrease. The carotenoid all-trans-



a. Temperature 70°C

b. Xanthan gum 0.24%



c. Egg albumin 12.2%

Fig. 4. Response surface and contour plots estimate the effect of variables on β-carotene (μg/g).

Table 4
Analysis of variance for TPC.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
X_1	0.741313	1	0.741313	143.54	0.0000
X_2	0.037367	1	0.037367	7.24	0.0103
X_3	0.097665	1	0.097665	18.91	0.0001
X_1X_1	0.973668	1	0.973668	188.53	0.0000
X_1X_2	0.0107401	1	0.0107401	2.08	0.1569
X_1X_3	0.35055	1	0.35055	67.88	0.0000
X_2X_2	0.0118912	1	0.0118912	2.30	0.1368
X_2X_3	0.0672003	1	0.0672003	13.01	0.0008
X_3X_3	2.00277	1	2.00277	387.79	0.0000
Lack-of-fit	0.00721875	3	0.00240625	0.47	0.7076
Pure error	0.211749	41	0.00516461		

R^2 = 95.53 % R^2 (adjusted for d.f.) = 94.62 % Standard Error of Est = 0.072.

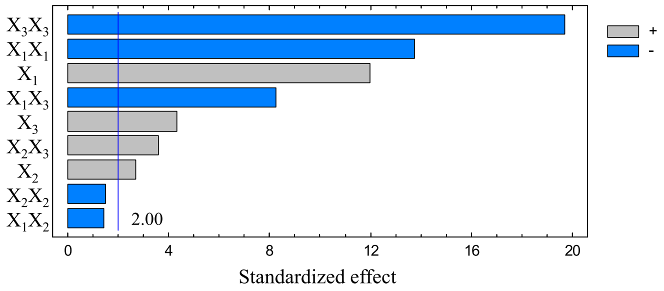


Fig. 5. Standardized Pareto chart for TPC.

β-carotene has the highest vitamin A activity, which is partially converted to its *cis* isomer during processing. The formation of the 13-*cis* isomer is then mainly due to heat treatment (Chen et al., 1995). Guarte et al. (2005) suggested that severe loss of provitamin A substances occurred at 90 °C. From 50 and 60 °C, thermal degradation was only related to the rate of 13-*cis* isomerization, while at 40 °C, β-carotene degradation was attributed to enzymatic reactions leading to a severe reduction of provitamin A compared to the effects of temperature. Khamjae and Rojanakorn (2018) studied the foam drying of passion fruit peel (1 mm thick) at 70 °C for 90 min and showed the highest ascorbic acid, β-carotene and antioxidant activity. With the aim of maximizing the β-carotene content in "Gấc" aril powder to a value of 405.49 μg/g, the optimal conditions of EA, XG and drying temperature were determined to be 13.75 %, 0.3 % and 71.2 °C, respectively.

3.1.3. Effects of egg albumin, xanthan gum concentration and drying temperatures on TPC in "Gấc" aril powder

ANOVA for TPC showed that the *P*-values of the linear effect (X_1, X_2, X_3); the interaction (X_1X_3, X_2X_3) and the square effect (X_1X_1, X_3X_3) had a significant effect on TPC (Table 4) with a high level of confidence ($P < 0.05$) when participating in the TPC prediction model. However, the interaction of X_1X_2 and the square effect of X_2X_2 did not have a significant impact on the model ($P > 0.05$), therefore, they were removed from the model.

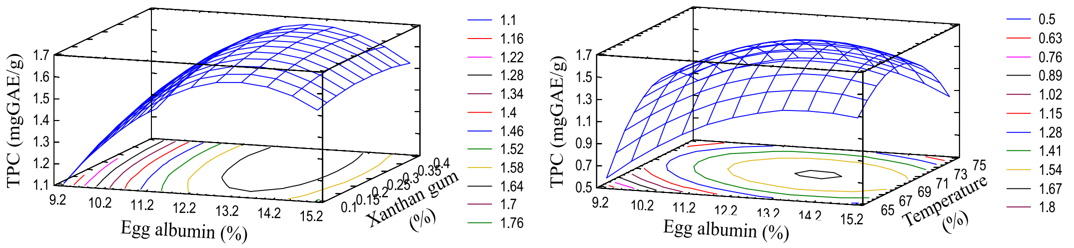
The correlation model between EA, XG concentration and drying temperature was reconstructed (Eq. 7) with high correlation coefficients (R^2 = 95.07 % and R^2_{adj} = 94.33 %), demonstrating a high degree of compatibility between predicted and experimental data.

$$Y_3 = -89.72 + 1.603X_1 - 7.20X_2 + 2.33X_3 - 0.031X_1X_1 - 0.011X_1X_3 + 0.107X_2X_3 - 0.016X_3X_3 \tag{7}$$

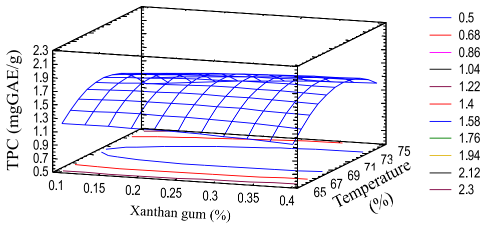
where Y_3 is TPC (mgGAE/g), X_1 is EA (%), X_2 is XG (%) and X_3 is drying temperature (°C).

The Standardized Pareto chart for TPC (Fig. 5) showed that the square effect (X_3X_3, X_1X_1) and the paired interaction (X_1X_3) are determined to have a negative impact, meaning that these effects have a negative impact on TPC. The linear effect (X_1, X_3) and the interaction (X_2X_3) are determined to have a positive impact, meaning that the effects have a positive impact on TPC. In addition, X_2X_2 and X_1X_2 have no impact on TPC because they lie to the left of the line. From the results obtained, it can be observed that drying temperature and EA had the most significant effect on TPC (including X_3X_3, X_1X_1, X_1, X_1X_3) because the bar length reached the longest level compared to the remaining bars.

Similar to drying rate and β-carotene, the response surface plot for the effects of independent variables (X_1, X_2 and X_3) on TPC is shown in



a. Temperature 70°C b. Xanthan gum 0.24%



c. Egg albumin 12.2%

Fig. 6. Response surface and contour plots estimate the effect of variables on TPC (mgGAE/g).

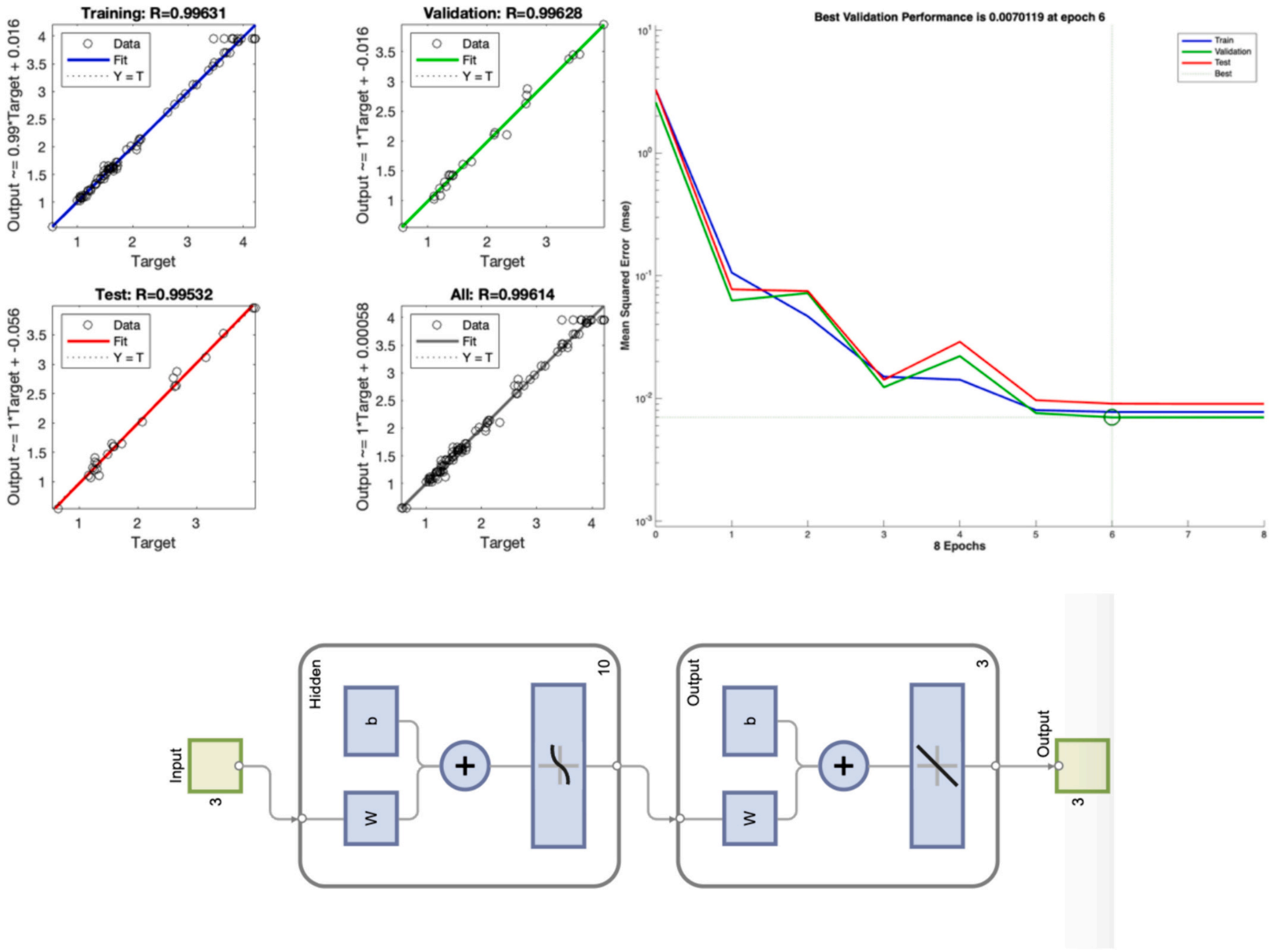


Fig. 7. ANN regression performance and scheme.

Fig. 6. EA, XG content and drying temperatures all have an effect on TPC. TPC analyzed in this experiment ranged from 0.55 mgGAE/g to 1.73 mgGAE/g. At a fixed drying temperature of 70 °C (Fig. 6a), when EA and XG concentrations increased, foam expansion increased (Thuy et al., 2022), which increased the surface contact area of the foam mass, the drying time was greatly shortened, resulting in less destruction of TPC. In addition, the combination with protein can also protect polyphenols from degradation and increase good antioxidant activity (Li et al., 2021). With the XG and EA concentrations were kept constant at 0.24 % (Fig. 6b) and 12.2 % (Fig. 6c), respectively, when the drying temperature increased from 65 to 70.4 °C, TPC remained quite high in the "Gấc" aril powder. This increasing trend was due to the decrease in drying time as the drying temperature increased, reducing the time the product was kept in the drying oven, so the phenolic content was less degraded (Di Scala et al., 2011). Drying at 70 °C was most suitable for antioxidant compounds, and at the same time, reduced processing time (Thuy et al., 2024). To achieve the maximum TPC in the "Gấc" aril powder (1.69 mgGAE/g), the optimal EA, XG contents and drying temperature were determined to be 12.98 %, 0.33 % and 70 °C, respectively.

3.2. ANN prediction model development

Artificial neural network (ANN) is being used to simulate complex linear and nonlinear systems in science and engineering. Artificial neural networks are designed to resemble human brain neurons (Gopan et al., 2018). Additionally, these networks contain connected neurons. Neural cells store and use information. A collection of weighted and biassed connection links, an increment, and an activation or transfer function make up the network. An amplifier uses an activation or transfer function to convert input signals into output (Lau et al., 2023). ANN training in this study supervised learning method, which labeled data to train neural network parameters to minimize model output and projected value errors (Gopan et al., 2018; Van Tai et al., 2024). Moreover, ANN are trained using back-propagation with multi-layered topologies. Perceptrons learn by producing an output, comparing it to the real output, and adjusting it to fit the network features (Pavani et al., 2024). Iterative training teaches enough perceptrons to imitate the desired behavior (Shende et al., 2024). The sum of squares of the difference between multilayer perceptron (MLP) data and objective outcomes is minimized to train network parameters in supervised mode (Shende et al., 2024). This study uses the following criteria to evaluate

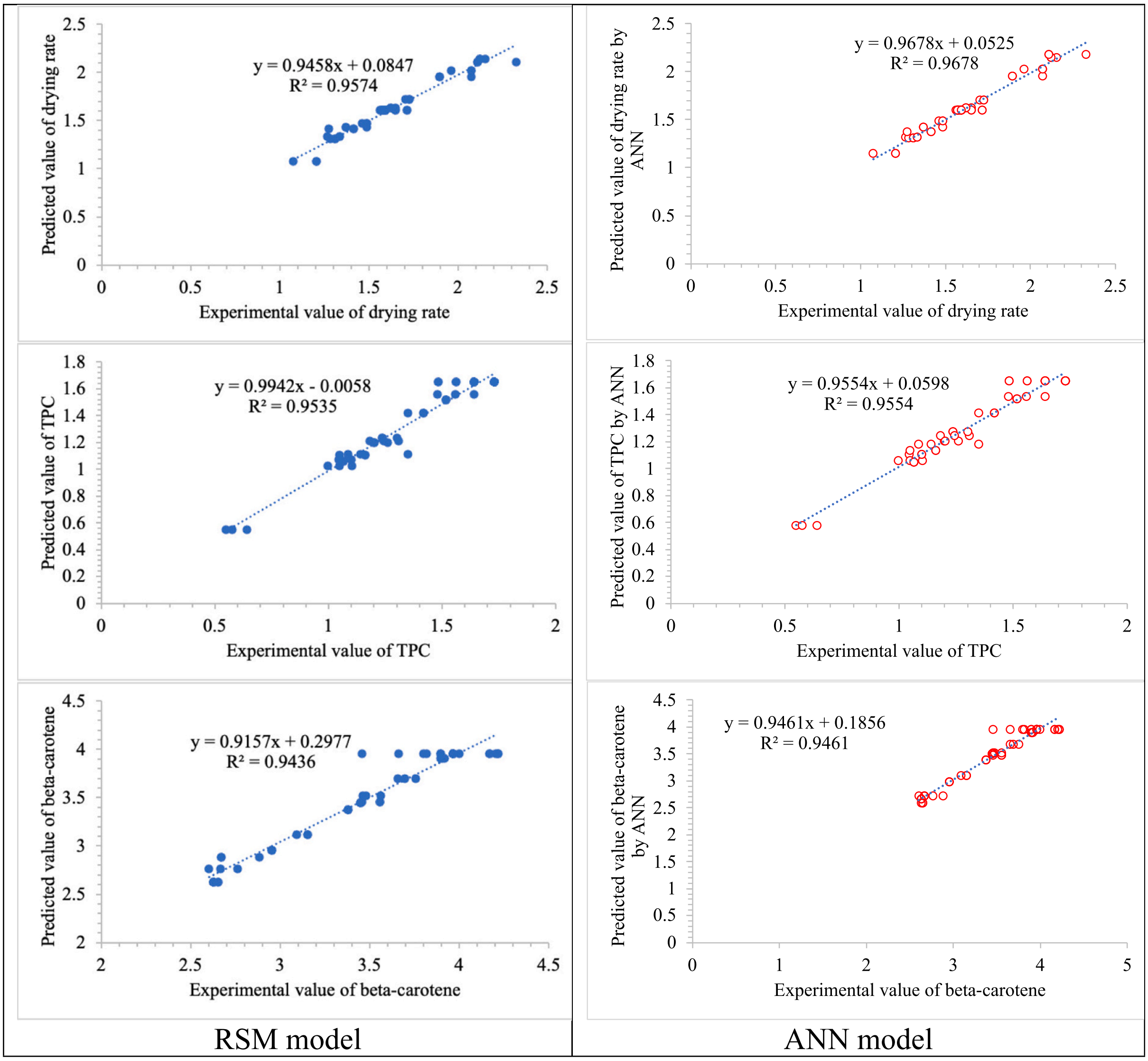


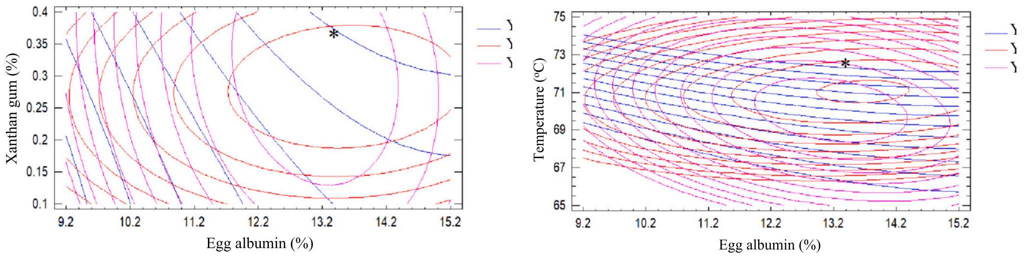
Fig. 8. Performance of prediction capacity.

perceptron layer neural network models for foam-mat powder drying rate and antioxidant properties prediction.

The experimental data of drying rate, TPC and β-carotene were obtained by performing drying process according to experimental in Table 1 and it was used for ANN modeling. The best ANN model was established by repeatedly training the network with the goal that the model has good performance in all three datasets, that is, minimum MSE and maximum R. The statistical study of the outputs from 10 neural network topologies reveals that the most optimal model produced values that approach value of 1. This optimal ANN model with a topology of 3–10-3 is determined by the connection weights and bias values between the layers, as shown in Eqs. 8–11. w_1 and b_1 is the link between input layer and hidden layer, whereas w_2 and b_2 is the link between hidden layer and output layer.

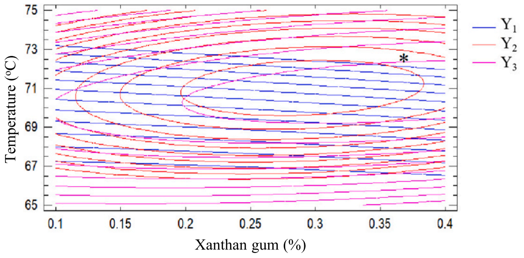
Moreover, the highest R value for the predicted drying rate and antioxidant properties, obtained by the Artificial Neural Network (ANN), was observed to be 0.99631 for the training dataset, 0.99532 for the test dataset, 0.99628 for the validation dataset, and 0.99614 for the total dataset (Fig. 7). The results show good agreement between the actual values and the ANN model predicted values of responses, which demonstrates the reliability and predictive capability of the model.

$$b_1 = \begin{bmatrix} 3.6087 \\ -2.0076 \\ -1.8352 \\ 0.9037 \\ 0.7178 \\ 0.0884 \\ 1.4425 \\ 81.7966 \\ 1.5641 \\ -3.7254 \end{bmatrix} \tag{8}$$



a. Temperature 70°C

b. Xanthan gum 0.24%



c. Egg albumin 12.2%

Fig. 9. The overlaid contour plot of drying rate, β-carotene and TPC.
* is optimal point; Y_1 is drying rate (g water/g dry matter/min), Y_2 is β-carotene content (μg/g), Y_3 is TPC (mgGAE/g).

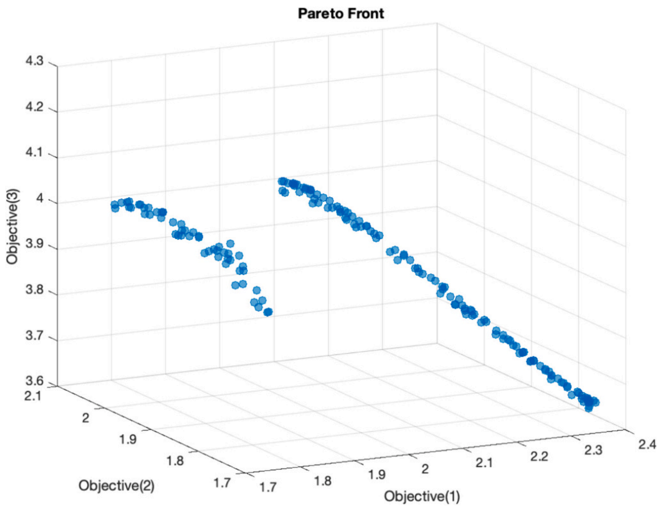


Fig. 10. Patero chart of three responses (objectives) during ANN-GA optimization.

Table 5
Performance of RSM and ANN-GA optimization.

Model	Process conditions			Predicted value			Actual value		
	EA (%)	XG (%)	Drying temp. (°C)	Drying rate (g water/g dry matter/min)	TPC (mgGAE/g)	β-carotene (μg/g)	Drying rate (g water/g dry matter/min)	TPC (mgGAE/g)	β-carotene (μg/g)
RSM	13.37	0.37	72.6	1.90	1.61	396.13	1.89	1.59	378.27
ANN-GA	13.31	0.26	73.1	1.89	1.68	395.88	1.89	1.67	396.24

$$w_1 = \begin{bmatrix} -0.8106 & -0.3717 & 2.5155 \\ 0.8778 & -1.1053 & 2.9811 \\ 1.5778 & -1.4150 & 1.8356 \\ -1.3889 & -1.9324 & -1.5222 \\ -0.1667 & 2.9750 & -1.7951 \\ 0.0664 & 3.3019 & 1.3622 \\ 0.4253 & 3.1528 & 0.9973 \\ 1.6624 & -2.2518 & 2.0099 \\ -0.8606 & 0.0916 & 3.3820 \\ -0.9554 & -0.9316 & 1.9067 \end{bmatrix} \tag{9}$$

$$b_2 = \begin{bmatrix} 0.0369 \\ -0.8699 \\ -1.4772 \end{bmatrix} \tag{10}$$

$$w_2 = \begin{bmatrix} -0.3176 & 0.6615 & -0.1057 & 0.0718 & 0.2635 & 0.3407 & -0.2451 & 0.2944 & 0.1742 & -0.2033 \\ -0.2627 & -0.4151 & 0.7480 & 0.7692 & 0.8714 & 1.1236 & -0.7598 & 0.8970 & 0.1676 & -0.8001 \\ 40.5688 & -0.9162 & 0.7984 & 0.0921 & 0.2661 & 0.1359 & 0.0931 & 0.4020 & 0.4608 & -0.3357 \end{bmatrix} \tag{11}$$

The correlation between actual and experimental results indicate that the constructed ANN prediction model has good performance than RSM prediction (Fig. 8), which also present similar report by (Van Tai et al., 2024).

3.3. Simultaneous optimization by RSM and ANN-GA

Overlaid contour plots are used to overlay individual RSM optimizations and are useful when assessing the impact of multiple variables on response. The numerical optimization results showed that the desired maximum value (0.80) could be achieved by using the optimal EA, XG concentrations and temperatures of 13.37 %, 0.37 % and 72.6 °C, respectively. At these maximum levels, the predicted values of responses such as drying rate, β-carotene and TPC were 1.9 g water/g dry matter/min, 396.13 μg/g and 1.61 mgGAE/g, respectively, shown by an asterisk (*) in Fig. 9. The verification of the optimal values of this study was also performed. When these optimal values were entered into experimentally, the drying rate, β-carotene and TPC in foam-mat dried "Gấc" aril powder were determined to be 1.86 g water/g dry matter/min, 381.27 μg/g and 1.63 mgGAE/g, respectively. The experimental and predicted values are almost identical, with only slight differences (from 1.23 to 3.75 % $<$ 5 %). The regression equations Y_1, Y_2 and Y_3 fitted from this study can be used to produce dried "Gấc" aril powder by foam drying method with the highest drying rate along with the highest content of β-carotene and TPC were maintained in the dried product.

The optimization process involved the use of a genetic algorithm (GA) to maximize drying rate (Objective 1), TPC (Objective 2) and β-carotene content (Objective 3). The independent parameters, namely EA concentration, XG level and drying temperature were subjected to optimization through the GA methodology. The patero chart of three objectives during ANN-GA optimization shown in Fig. 10. The best conditions for drying process of "Gấc" aril as followed: 13.31 % of EA, 0.26 % of XG and 73.1 °C of drying temperature, with predicted the drying rate of 1.89 g water/g dry matter/min, β-carotene content of 395.88 μg/g, TPC of 1.68 mgGAE/g. It could be seen in Table 5 that ANN-GA could find the conditions with lower level of foaming ingredients used for foaming process, and the predicted value almost same with actual conditions than RSM did. These experimental values fitted well with the predicted values and illustrated the good prediction and optimization abilities of the generated ANN-GA model.

4. Conclusions

This study found that all variables, including EA, XG concentration and drying temperature, had significant effect on values of drying rate, β-carotene content and TPC. RSM proved to be successful in optimizing the production process by utilizing simultaneous optimization technique. However, ANN model could provide highly efficient and accurate to predict the effect of production process on all responses. ANN-GA model also could select the optimal conditions for producing "Gấc" foam-mat dried powder with maximize drying rate and content of bioactive compounds, which also validated by actual experiment. From the obtained results by ANN-GA, the optimal conditions for foaming were established under the conditions of using the optimal EA and XG content of 13.31 % and 0.26 %, respectively. The product was dried effectively at 73.1 °C. Under these optimal conditions, "Gấc" aril powder was dried at the highest drying rate of 1.89 g water/g dry matter/min, the foam-dried "Gấc" aril powder product maintained the highest β-carotene content (395.88 μg/g) and TPC (1.67 mgGAE/g). This study highlighted potential of production powder from "Gấc" aril, a high viscous material and rich in bioactive compounds, by using foam-mat drying technique. The results also showed that using artificial approach to optimize foam-mat drying conditions to maximize nutritional value of various foods was possible. Further studies should be considered about different foaming agents/stabilizers as well as the novel drying techniques, which could utilize, optimize and reduce the production cost and energy for enhancing economic value and sustainable aspect.

CRediT authorship contribution statement

Nguyen Minh Thuy: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Conceptualization. **Vo Quoc Tien:** Writing – original draft, Investigation, Formal analysis. **Tran Ngoc Giau:** Writing – review & editing, Visualization, Formal analysis. **Hong Van Hao:** Writing – review & editing, Validation, Formal analysis. **Vo Quang Minh:** Writing – review & editing, Methodology, Conceptualization. **Ngo Van Tai:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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