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PRODUCTION OF SOFT SUGAR-COATED *CHRYSALIDOCARPUS LUTESCENS* FRUIT WITH LOW SUGAR CONTENT

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ABSTRACT

Background. *Chrysalidocarpus lutescens* fruit is considered high in antioxidant compounds. However, its use in food products is limited due to its bitterness. One of the ideal products that could be produced from this fruit is a sugar-coated product.

Materials and methods. This research aimed to find the optimum conditions for processing a soft sugar-coated *Chrysalidocarpus lutescens* fruit with high levels of antioxidant compounds and acceptable sensory properties. Response surface methodology (RSM) was used to optimize the various conditions, including blanching time (5–15 minutes), sugar addition (35–45%), and mild heating time (45–55 minutes). A Box-Behnken design with 15 runs and three center points was conducted. Data obtained from RSM were subjected to analysis of variance (ANOVA) using a second-order polynomial equation.

Results. The results show that the model fit was significant ($p < 0.05$) for antioxidant compounds with a high coefficient of correlation ($R^2 > 80\%$). There was also a satisfactory correlation between actual and predicted values. The optimum conditions were found at a blanching time of 8.4 min, sugar addition of 39.8%, and mild heating for 49.8 min. Under these conditions, the optimal sample has a higher acceptance score than that produced by the traditional method.

Conclusion. This finding could be useful for upscale production of a sugar-coated *Chrysalidocarpus lutescens* fruit and has the potential to increase the techno-economic value of this fruit.

Keywords: *Chrysalidocarpus lutescens*, sugar-coated product, optimization, response surface methodology

INTRODUCTION

Vietnam is located in a tropical area with similar climatic conditions to the original area of the areca family, and it hosts a diverse number of species and genera from this family. Various members of the areca species are used in many different fields, as ornamental plants or in food, handicrafts, medicine, and construction materials. They are not only materially valuable but also have spiritual value associated with their role in traditional Vietnamese cultural life. However, there are few studies on the composition of *Chrysalidocarpus lutescens* fruit, tropical fruits of the *Arecaceae* family. A study by Silva et al. (2015) has shown that there are numerous nutritional compositions of and potential uses for Aceraceae fruit. They are not only an excellent

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source of carbohydrates and vitamins but also possess antioxidant potential. According to the report of Vafaei (2013), the total phenolic content in methanolic, ethanolic and water extracts from *Veitchia merrillii* fruit was found to be 17.8, 7.6 and 2.22 mg GAE/g, respectively. Other natural compounds, such as carotenoids, are also present in this fruit and have a wide range of benefits for human health, mainly due to their antioxidant properties, which protect the human body against oxidative stress, serve as precursors of vitamin A and lower glycemic index (Lu et al., 2021; Ngo et al., 2022; Van Tai et al., 2023). In particular, early use of large-dose antioxidants, such as vitamin C, may be an effective treatment for COVID-19 (SARS-CoV-2) pandemic patients (Cheng, 2020). Thus, fruits of the *Arecaceae* family could become valuable foods in the future.

In Vietnam, the planting area of *Chrysalidocarpus lutescens* is increasing in size. However, there is still a lack of research on the applications of this fruit. In general, fruits and their products are important in a healthy diet because of the abundance of nutrients they contain. Fruit can be processed in a variety of ways while retaining its nutritional and physiological qualities, such as in dried fruit, compote, jam, juices, marmalades, jellies, fruit candies, etc. However, because *Chrysalidocarpus lutescens* fruits are bitter, sugarcoating them is the best way to increase their commercial value and produce an appropriate taste. When fresh, frozen, or partially processed fruit or fruit pieces are boiled with appropriate amounts of sugar, pectin, and acid, a jelly-like consistency is produced (Stamatovska et al., 2017). Traditional products are made with an excess of sucrose, making them unsuitable for consumption by those who are overweight or obese, have diabetes, hyperglycemia, or other conditions. Traditional sugar-coated product (65% dry matter) have a high sugar content, which Parsayee et al. (2013) claim contributes to obesity and other health issues. In addition, optimization also showed the effectiveness of finding the optimum conditions for low-sugar products (Thuy et al., 2022a). The aim of this work was to perform optimization of the sugar-coating process using response surface methodology (RSM) in order to create a product with high antioxidant compounds and appropriate sensory values with less sugar added. This research may contribute to the creation of a new product, enriching the variety of products to provide consumers with more choices and ensuring safety for health, which could also lead to their potential use on an industrial scale.

MATERIALS AND METHODS

Materials

The areca used in the study is grown in Mo Cay Nam, Tien Giang Province, Vietnam. Raw materials were manually harvested by authors at the mature stage about 160 days after the fruit set to ensure the areca pulp was sufficiently soft and supple (Fig. 1). The methods used to analyze its nutritional profile followed those described by Thuy et al. (2020b) and showed that areca pulp contained 2.2% carbohydrate, 81.2% moisture content, 2% protein, and 2.55 mg GAE/g of polyphenol. Sugar and other ingredients were purchased from the local market. All the materials were food grade.

Fig. 1. Flesh and pulp of *Chrysalidocarpus lutescens* fruit

Sugar-coated *Chrysalidocarpus lutescens* fruit preparation

The areca was halved into half-fruit and peeled. Pulp was obtained and blanched in water at a 1:5 ratio of material to water. The blanching solution also contained 1% citric acid to prevent browning. For each treatment, 250 g of areca pulp were used. The areca pulp was blanched at boiling temperature for 5–15 min to reduce its bitterness (Choo et al., 2014). The areca was then mixed with sugar in different proportions according to the experimental design, mixed well and exposed to mild heat (60°C) for 45–55 min. It was then dried at 50°C for 5 hours. The products were collected and analyzed for criteria including polyphenol content and flavonoid content.

Box-Behnken Design (BBD)

A preliminary study was conducted and showed that the addition of sugar content from 35% to 45% enjoyed high acceptance by consumers. Therefore, a BBD with three factors and three levels was applied to evaluate the optimal combination of blanching time, sugar addition, and mild heating time to produce sugar-coated *Chrysalidocarpus lutescens* fruit with a high content of phytochemicals and acceptance by panelists. The factors and levels were coded and are given in Table 1. The design consisted of 15 runs with three center points. The total polyphenol content (TPC) was analyzed by the Folin–Ciocalteu method, while antioxidant properties were analyzed using the reaction with 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution (Van Tai et al., 2021).

Table 1. Factor and coding levels of the Box-Behnken combination experiment design

Factors	Coding level		
	–1	0	1
X_1 Blanching time (min)	5	10	15
X_2. Sugar addition (%)	35	40	45
X_3 Mild heating time	45	50	55

The control sample was operated at optimal blanching and heating times with 65% sugar addition, as recommended by the traditional method (Ghnimi et al., 2017).

The acceptance test for the attributes of color, appearance, odor, and flavor was applied using a structured nine-point hedonic scale (9 = Liked very much to 1 = Disliked very much) by fifty panelists (40% male and 60% female). In addition, an intensity scale for the texture/hardness attribute using the seven-point hedonic scale (1 = Very hard to 7 = Very soft), a preference test and a purchase intention test were also applied. The sensory tests followed the methodology of Galdino et al. (2021).

Data analysis

STATGRAPHIC was used to analyze and fit the model to the experimental data. The model (Equation 1) for each response (Y) was:

$$Y = b_o + \sum_{n=1}^{3} b_n X_n + \sum_{n=1}^{3} b_{nn} X_n^2 + \sum_{n \neq m=1}^{3} b_{nm} X_n X_m \quad (1)$$

where

b_o is the Y intercept (constant)

b_n is the regression coefficient for the linear effect of X_n on Y

b_{nn} and b_{nm} are the regression coefficients for the quadratic effect on Y

X_n and X_m are independent values.

The selected equation fits the obtained data based on the coefficients of determination (R^2 value).

RESULTS AND DISCUSSION

Effect of production conditions on the product's antioxidant properties

The TPC and the antioxidant properties of sugar-coated *Chrysalidocarpus lutescens* for the different treatment conditions ranged from 1.80 to 2.66 mg GAE/g and from 66.7% to 90.1%, respectively. The results of the analysis of variance are shown in Table 2.

The lack of fit test is used to examine whether the model chosen is sufficient to explain the observed data or whether a more complex model should be employed. The test is run by contrasting the variability of the present model residuals to the variability of observations made at repeated settings of the factors. At the 95.0% level of confidence, the model is suitable for the observed data because the P-value for lack-of-fit in the ANOVA table is greater than or equal to 0.05. Besides, the R^2 is higher than 80% for both models, indicated that they were a good fit to the actual data. Because the effects of some terms were insignificant, the regression model was reduced as shown in Equation 2 and 3.

$$Y_1(\text{TPC}) = -48.59 + 0.5949X_2 - 0.0025X_1^2 - 0.0073X_2^2 - 0.0158X_3^2 \quad (2)$$

$$Y_2(\text{DPPH}) = -1517.73 + 2.0105X_1 + 50.5624X_3 + 0.0317X_1X_2 - 0.0445X_1X_3 - 0.0631X_1^2 - 0.2186X_2^2 - 0.5045X_3^2 \quad (3)$$

Table 2. Analysis of Variance for TPC and DPPH

Model parameters	TPC, mgGAE/g	DPPH, %
Intercept	–48.59*	–1 517.73*
Linear		
X_1	0.0088	2.0105*
X_2	0.5949*	16.829
X_3	1.5782	50.5624*
Interaction		
X_1X_2	0.0004	0.0317*
X_1X_3	0.0003	–0.0445*
X_2X_3	–0.0003	0.0064
Quadratic		
X_1^2	–0.0025*	–0.0631*
X_2^2	–0.0073*	–0.2186*
X_3^2	–0.0158*	–0.5045*
R^2	84.64	95.19
Adjusted R^2	80.69	93.95
p-value	<0.0001	<0.0001
f-value	18.92	73.41
p-value of Lack-of-fit	0.0932	0.3452

*p-value < 0.05.

The contour plots show the effects of the independent variables on the total phenolic content and antioxidant properties of the product (Figures 2 and 3).

It can be seen that all variables affected the total phenolic content of sugar-coated *Chrysalidocarpus lutescens*. Blanching reduces the bitterness of raw materials, as previously metioned. However, it is also the reason for fluctuations in the phytochemical content. In general, blanching could leach some components into the blanched solution due to mass transfer. However, it could also make the food matrix softer for the extraction of the antioxidant components. This suggestion is in agreement with the increase in antioxidant compounds in the first stage. However, antioxidant compounds declined when the blanching time was prolonged. Degradation and oxidation by heat are the main processes that could reduce antioxidant compounds in the product (Thuy et al., 2020c). Heat treatment tends to free bound phenolic components, and the results of the present study suggest that the levels of bound phenolics increased in most cases with increasing blanching time (Feumba Dibanda et al., 2020). While it has also been reported that phenolic compounds function as carbonyl trapping agents (via electrophilic aromatic substitution reactions) of key transient Maillard precursors known as sugar fragments, the concomitant observation of an increase in free phenolic content calls into question the exact mechanism of this effect of blanching on free and bound phenolic compounds (Feumba Dibanda et al., 2020). The increase in TPC also leads to increased antioxidant activity (Ha et al., 2021).

Sugar addition also changes the total phenolic content of the product. By adding sugar, mass transfer can be enhanced, water can leave the material and sugar can come into the food matrix according to the law of mass transfer (Nguyen et al., 2022; Tai and Thuy, 2023). Different osmotic pressures can potentiate the bioavailability of free pharmacologically active natural compounds by preventing the binding of polyphenols to the plant matrix (Thuy et al., 2022b). High temperatures would make the components at the surface of the material active and cause them to move quickly; the gas components would simultaneously move from the inside of the cell to the environment. The energy from heating could be absorbed by the material through heat exchange, the raw material would heat up, and the peroxidase and polyphenol oxidase enzyme systems could be destroyed, so the material would not become darker. However, when high heating for a long time destroys the chromophores, the Maillard reaction causes darkening and a reduction in TPC is observed (Feumba Dibanda et al., 2020).

Optimizing multi-response problems has become an increasingly relevant issue when more than one correlated product quality characteristic must be assessed simultaneously in a complicated manufacturing process

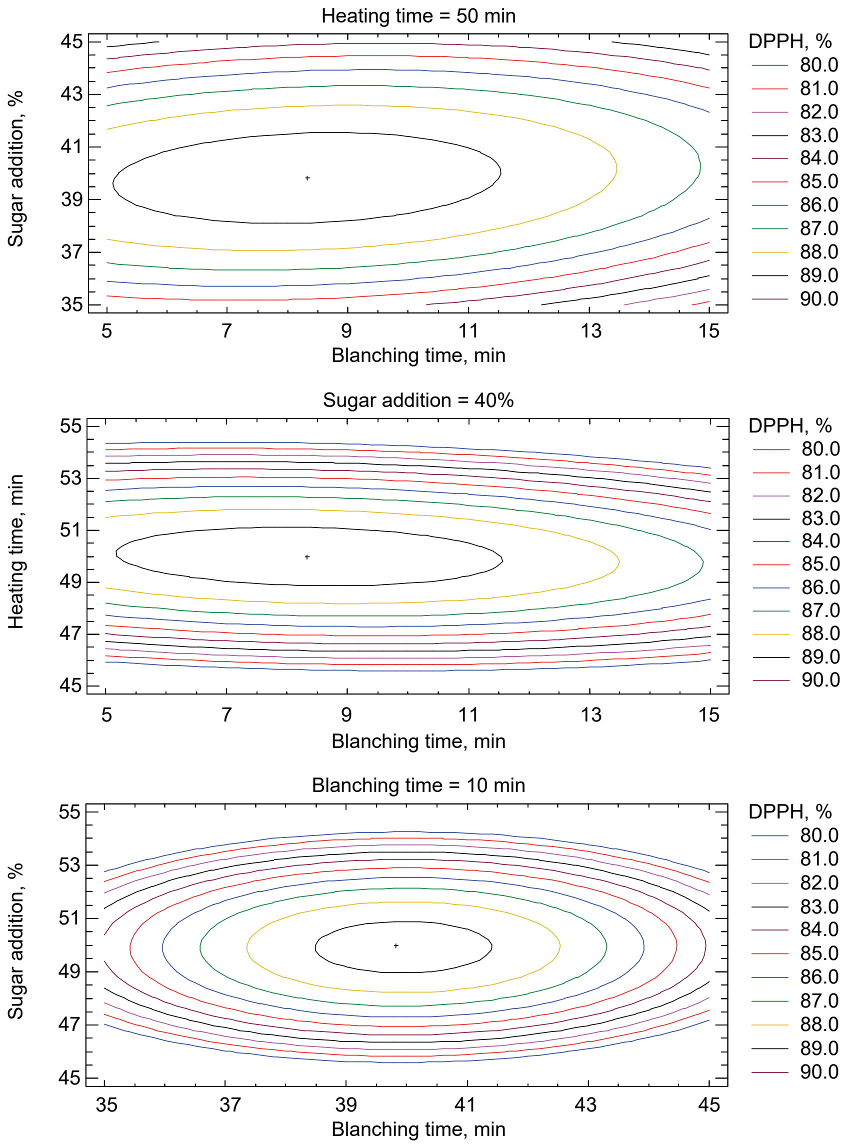

Fig. 2. Contour plots of effect of treatment conditions on product's TPC

(Tong et al., 2005). Multiple response analysis showed that the optimum conditions (highest TPC and antioxidant properties) for the product were a blanching time of 8.38 minutes, 39.84% sugar and a heating time of 49.88 minutes, as shown in Figure 4. The optimization points were also validated, and there was no significant difference between the actual and predicted experiments.

The final product has a good structure and is highly accepted by consumers (Table 3). Consumer acceptance is one of the most important criteria when selecting conditions for up-scaling (Thuy et al., 2020a; Too et al., 2022). Sugar is added to create the characteristic sweetness of products, give them beautiful colors, increase product preservation, prevent the growth of microorganisms, and prevent product oxidation (Rawat, 2015). Cell membranes of fruits and microorganisms are selectively permeable, which can allow certain solvents or solutes to pass through them,

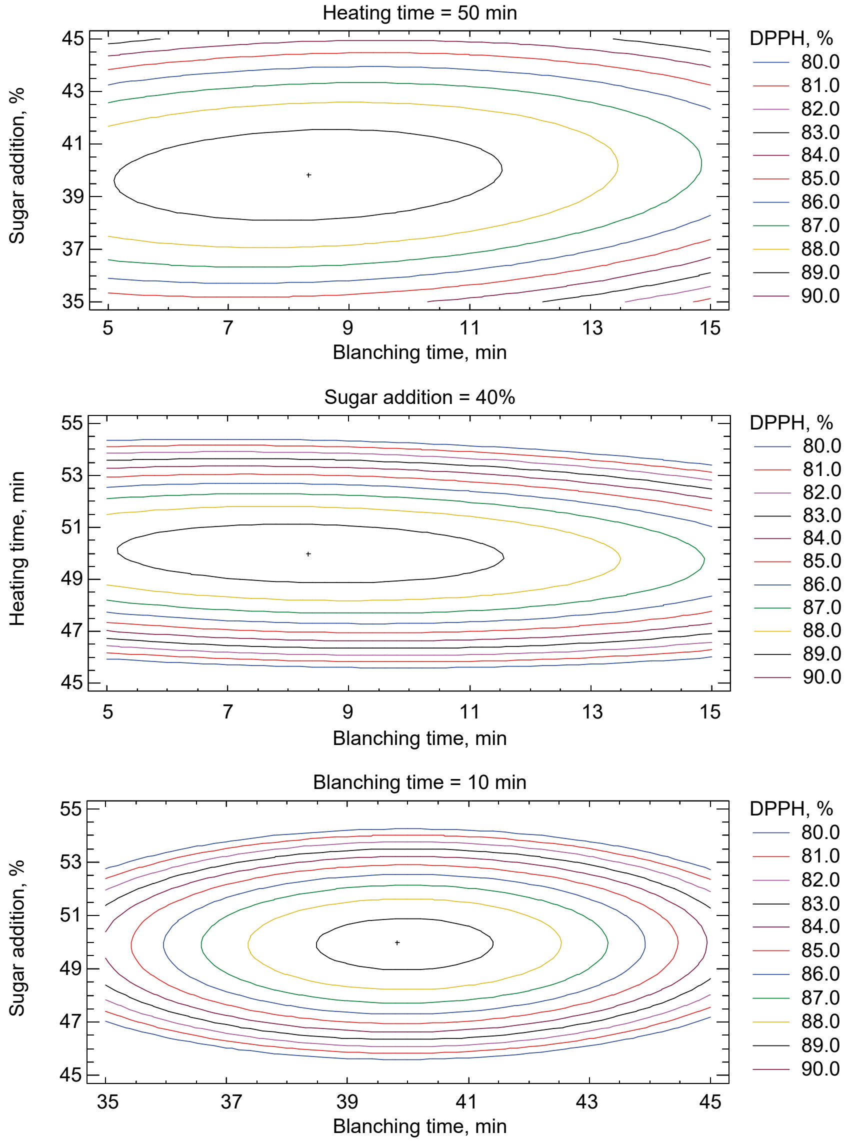

Fig. 3. Contour plots of effect of treatment conditions on antioxidant properties of product

depending on whether the solute concentration is high or low in the environment outside the cell. Thus, in sugar-coated fruit, the high sugar content in the external environment would cause microorganisms to shrink and die. When the percentage of added sugar is low, the product does not have a beautiful color, the taste is not harmonious, and the product cannot be preserved for as long as desired. When the percentage of added sugar is high, the product has a beautiful color, but the taste is not good. When cooking sugar-coated products, it is easy to caramelize and darken the product. On the other hand, if the sugar addition rate is too high, the residual sugar that cannot be absorbed into the areca remains in the form of syrup and then crystallizes, causing a lot of sugar loss. At the same time, caramelization occurs. High sugar content also

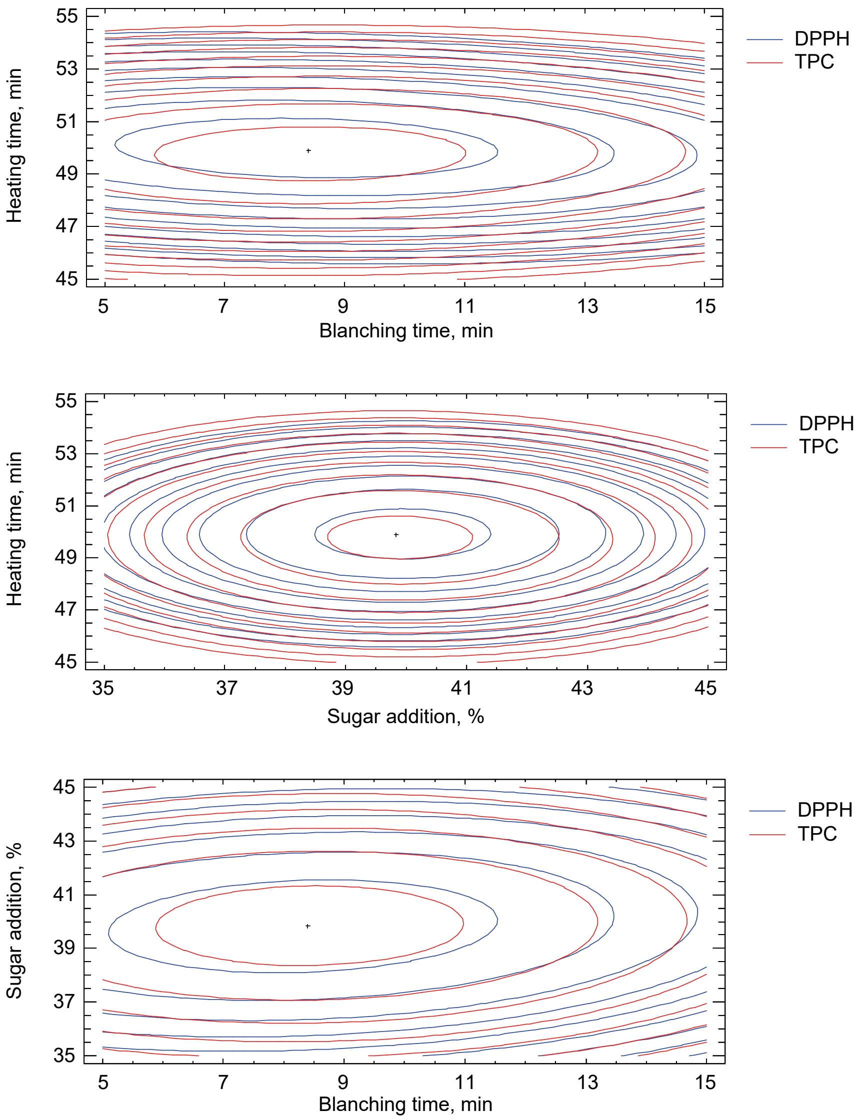

Fig. 4. Overplay plots for optimization conditions (⁺optimal point)

gives the product a less harmonious sweet taste, and the appearance of the product is not appealing because the residual sugar recrystallizes into a thick coating around the product, causing loss of ingredients and affecting the taste. The brightness of the product decreases with high sugar addition, which leads to a decrease in the acceptance score.

One of the key components affecting the rheological characteristics of a product is the presence of sugar (Thuy et al., 2022a). This lengthens the product's shelf life, improves the texture and flavor of the product, and has an impact on its organoleptic features. Due to its lower tendency to recrystallize than glucose, sucrose is thought to be a superior choice for products (Javanmard and Endan, 2010). Heating time also affects the hardness of the sample (Thuy et al., 2022a). From the obtained data, the results show that the product was softer at lower levels of sugar addition. The heating process reduces the water content and increases the dry matter content in the product, thereby inhibiting

Table 3. Sensory properties of samples

Sample	Color	Odor	Appearance	Flavor	Texture	Overall acceptance
Control sample	7.57 ±0.4[a]	6.76 ±0.23[a]	6.57 ±0.45[a]	8.43 ±0.57[a]	3.33 ±0.34[a]	6.87 ±0.45[a]
Optimal sample	8.67 ±0.3[b]	7.57 ±0.2[b]	8.45 ±0.55[b]	8.47 ±0.46[a]	5.65 ±0.2[b]	8.12 ±0.67[b]

Note: Data are expressed as mean ± standard deviation (S.D.) of 10 mice. Data were analyzed using one-way ANOVA followed by Duncan's multiple range test. Different superscript letters indicate statistical significance ($p < 0.05$).

the development of microflora, helping to prolong the product's shelf life and creating color. It can be seen that the product was high in antioxidant compounds, which could promote consumer health. Besides that, the moisture content was 14.2%, which could prolong storability. The product also has a good appearance, as shown in Figure 5.

Fig. 5. Sugar-coated *Chrysalidocarpus lutescens* fruit

CONCLUSION

The results of the study confirm that all the analyzed factors influence product quality. The response surface methodology was successfully applied to optimize production conditions based on the desired quality. Multiple regression analysis of empirical data could allow the generation of useful equations for general use, which could be used to predict the behavior of the system under different combinations of factors in food processing. The optimal values could be utilized in the preparation of sugar-coated *Chrysalidocarpus lutescens* fruit with good quality and higher nutritional value.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

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REFERENCES

Cheng, R. Z. (2020). Can early and high intravenous dose of vitamin C prevent and treat coronavirus disease 2019

(COVID-19)? Med. Drug. Discov., 5, 100028. https://doi.org/10.1016/j.medidd.2020.100028

Choo, W. S., Yap, J. Y., Chan, S. Y. (2014). Antioxidant properties of two varieties of bitter gourd (*Momordica Charantia*) and the effect of blanching and boiling on them. Pertanika J. Trop. Agric. Sci., 37(1), 121–131.

Feumba Dibanda, R., Panyoo Akdowa, E., Rani, P. A., Metsatedem Tongwa, Q., Mbofung, F. C. M. (2020). Effect of microwave blanching on antioxidant activity, phenolic compounds and browning behaviour of some fruit peelings. Food Chem., 302, 125308. https://doi.org/10.1016/j.foodchem.2019.125308

Galdino, P. O., Queiroz, A. J. d. M., Figueirêdo, R. M. F. d., Santiago, Â. M., Galdino, P. O. (2021). Production and sensory evaluation of dried mango. Rev. Bras. de Eng. Agricola e Ambient., 25. https://doi.org/10.1590/1807-1929/agriambi.v25n1p44-50

Ghnimi, S., Umer, S., Karim, A., Kamal-Eldin, A. (2017). Date fruit (*Phoenix dactylifera* L.): An underutilized food seeking industrial valorization. NFS, 6, 1–10. https://doi.org/10.1016/j.nfs.2016.12.001

Ha, H. T. N., Van Tai, N., Thuy, N. M. (2021). Physicochemical characteristics and bioactive compounds of new black cherry tomato (*Solanum Lycopersicum*) varieties grown in Vietnam. Plants, 10(10), 2134. https://doi.org/10.3390/plants10102134

Javanmard, M., Endan, J. (2010). A survey on rheological properties of fruit jams. Int. J. Eng. Res. Appl., 1(1), 31–37. https://doi.org/10.7763/IJCEA.2010.V1.6

Lu, W., Shi, Y., Wang, R., Su, D., Tang, M., Liu, Y., Li, Z. (2021). Antioxidant Activity and Healthy Benefits of Natural Pigments in Fruits: A Review. Int. J. Mol. Sci., 22(9). https://doi.org/10.3390/ijms22094945

Ngo, T. V., Kusumawardani, S., Kunyanee, K., Luangsakul, N. (2022). Polyphenol-Modified Starches and Their Applications in the Food Industry: Recent Updates and Future Directions. Foods, 11(21), 3384. https://doi.org/10.3390/foods11213384

Nguyen, M. T., Dinh, T. N., Vo, Q. M., Van Tai, N. (2022). Osmotic dehydration of white radish (*Raphanus sativus* L.) slices: mass transfer characteristics and modeling. J. Microbiol. Biotechnol. Food Sci., 12(3), e4940. https://doi.org/10.55251/jmbfs.4940

Parsayee, S. A., Zonuz, A. A., Zadeh, B. G., Ayase, A. (2013). Low calorie sour cherry jam: optimization of ingredient levels using response surface methodology. Int. J. Appl. Sci. Eng. Res., 2(1), 35–43. https://doi.org/10.6088/ijaser.020100005

Rawat, S. (2015). Food Spoilage: Microorganisms and their prevention. Asian J. Plant Sci., 5(4), 47–56.

Silva, R., B., Silva-Júnior, E. V., Rodrigues, L. C., Andrade, L. H. C., Silva, S. I. D., Harand, W., Oliveira, A. F. M. (2015). A comparative study of nutritional composition and potential use of some underutilized tropical fruits of Arecaceae. An. Acad. Bras. Cienc., 87. https://doi.org/10.1590/0001-3765201520140166

Stamatovska, V., Karakasova, L., Babanovska-Milenkovska, F., Nakov, G., Blazevska, T., Durmishi, N. (2017). Production and characterization of plum jams with different sweeteners. J. Hyg. Eng. Des., 19, 67–77.

Tai, N. V., Thuy, N. M. (2023). Optimization of osmotic dehydration process for improving the quality of vacuum fried "Vinh Chau" shallots at the pilot stage. Acta Sci. Pol. Technol. Aliment., 22(2), 133–141. http://dx.doi.org/10.17306/J.AFS.2023.1120

Thuy, M. N., Phoukham, K., Tai, V. N. (2020a). Formulation and quality evaluation of pearl oyster mushroom soup powder supplement with some kinds of legumes and vegetables. Acta Sci. Pol. Technol. Aliment., 19(4), 435–443. https://doi.org/10.17306/J.AFS.2020.0813

Thuy, N. M., Phuong, N. P., Suong, C. T. D., Tai, N. V. (2020b). Physical and chemical characteristics of goldenberry (*Physalis peruviana*) grown in Lam Dong province, Vietnam. Food Res., 4(4), 1217–1225. https://doi.org/10.26656/fr.2017.4(4).085

Thuy, N. M., Tan, H. M., Van Tai, N. (2022a). Optimization of ingredient levels of reduced-calorie blackberry jam using response surface methodology. J. Appl. Biol. Biotechnol., 10(1), 68–75. DOI: 10.7324/JABB.2021.100109

Thuy, N. M., Tuyen, N. T. M., Tai, N. V. (2020c). Combination of mild heat and calcium chloride treatment on the texture and bioactive compounds of purple shallot. Food Res., 4(5), 1681–1687. https://doi.org/10.26656/fr.2017.4(5).245

Thuy, N. M., Tham, N. T. N., Minh, V. Q., Vu, P. T., Van Tai, N. (2022b). Evaluation of water loss and solute uptake during osmotic treatment of white radishes (*Raphanus sativus* L.) in salt-sucrose solution. Plant Sci. Today, 9(1), 191–197. https://doi.org/10.14719/pst.1422

Tong, L.-I., Wang, C.-H., Chen, H.-C. (2005). Optimization of multiple responses using principal component analysis and technique for order preference by similarity to ideal solution. Int. J. Adv. Manuf. Technol., 27(3), 407–414. https://doi.org/10.1007/s00170-004-2157-9

Too, B. C., Van Tai, N., Thuy, N. M. (2022). Formulation and quality evaluation of noodles with starchy flours containing high levels of resistant starch. Acta Sci. Pol. Technol. Aliment, 21(2), 145–154. https://doi.org/10.17306/J.AFS.2022.1011

Vafaei, A. (2013). Antioxidant and cytotoxicity activities of *Veitchia merrillii* fruits. Dissertation submitted infulfilment of the requirments for the degree of master of Biotechnology Institute of Biological Sciences Faculty of Science University of Malaya Kualalumpur.

Van Tai, N., Linh, M. N., Thuy, N. M. (2021). Optimization of extraction conditions of phytochemical compounds in "Xiem" banana peel powder using response surface methodology. J. Appl. Biol. Biotechnol., 9(6), 56–62. https://doi.org/10.7324/JABB.2021.9607

Van Tai, N., Minh, V. Q., Thuy, N. M. (2023). Food processing waste in Vietnam: Utilization and prospects in food industry for sustainability development. J. Microbiol. Biotechnol. Food Sci., e9926. http://doi.org/10.55251/jmbfs.9926