CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

SALEP MUCILAGE COATING USAGE FOR STUCK-POT RICE BASED ON POTATO AND EVALUATION THE EFFECTS OF FRYING OIL CONDITION

Kosar Mahmood-babooi[1], Mohammad Ekrami[2], Parisa Sadighara[1], Mohammadreza Rostami[1], Ebrahim Molaee-aghaee[1,3]✉

[1.] Division of Food Safety & Hygiene, Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

[2.] Department of Food Science, Technology and Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Tehran, Iran

[3]Department of Food Science and Technology, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, Tehran, Iran

✉emolaeeaghaee@tums.ac.ir

https://doi.org/10.34302/crpjfst/2024.16.3.11

Article history:
Received:
January 3rd, 2023
Accepted:
August 19th, 2024

Keywords:
Salep mucilage;
Frying oil;
Central-composite design;
Acrylamide;
Optimizing.

ABSTRACT

Coating hydrocolloids are appropriate barriers against carbon dioxide, oxygen and lipids, therefore the amount of absorbed oil can be decreased. Salep as a hydrocolloid source cultivated in western and northwestern Iran is known as a food and pharmaceutical substance. In the present research, Salep mucilage (SaM) was studied as a coating agent with the aim of declining oil absorption and increasing the amount of moisture of stuck-pot rice based on potato (SpP) by using a central-composite design. Salep mucilage concentration (0.75, 1 and 1.25% w/w), frying time (3, 4.5, 6 min) and frying temperature (160, 170 and 180°C) were the examined parameters of this research. The effects of frying oil type (Sunflower oil, corn oil, rice bran oil, canola oil, palm olein oil and hydrogenated vegetable oil as the frying media) and blanching (85°C, 3.5 min in hot water) were examined only at the optimum point. According to the results, optimal conditions for coating and frying processes obtained from RSM were 1.24% (w/w) SaM concentration, 3.6 min frying time at 162°C frying temperature. Salep mucilage can be used as a promising agent to coat deep-fat fried potatoes.

1. Introduction

Vegetable oils and fats as a nutritious foodstuff with a considerable consumption in the daily diet, have a key role in human health, such as in prostaglandins, blood pressure, cholesterol level and the reproductive system by providing the essential fatty acids (Askarpour et al., 2023; Eghbaljoo et al., 2023; A. Kamkar et al., 2014). The frying process refers to a dehydration treatment with mass and heat transfer. Protein denaturation, rapid water evaporation, starch gelatinization, oil absorption and surface browning are some of the changes during frying (Wang, Su, Wang, & Nie, 2019). The unbound water in the product is evaporated and oil is replaced by up to 40% affecting the quality properties of the product (Isik, Sahin, & Oztop, 2018). This is a concern–that results in adverse health effects such as heart disease and obesity. Different factors including porosity, frying temperature, food composition (protein, fat and moisture contents), the quality of the used oil and the pre-treatment process have impacts on oil absorption (Santos *et al.*, 2019). Various products like potato strips, chickpeas, cereal products, chicken nuggets and carrot slices go through different processes to decrease oil absorption when in deep-fat frying (Belkova *et al.*, 2018). Some studies showed that in moderate protein and high carbohydrate foods

such as Asian potatoes, higher levels of acrylamide have been formed under heating and frying conditions (A Kamkar et al., 2015). To achieve the goal, frying is done under special conditions at high temperatures and short time and benefits from pre-treatments like coating, blanching, immersing in an acidic solution, pulsed electric field and semi-drying in fried potatoes-based products (Ananey-Obiri *et al.*, 2018). In recent years, biodegradable coating has been used widely for different purposes such as in films and or improving food properties (Molaee Aghaee, Kamkar, Akhondzadeh Basti, Khanjari, & Kontominas, 2016). Coating hydrocolloids such as carbohydrates and plant gums are suitable barriers against carbon dioxide, oxygen and lipids, therefore they can play an acceptable role in decreasing the amount of absorbed oil (Eghbaljoo et al., 2022; Naghavi, Dehghannya, & Ghanbarzadeh, 2018a).

Salep as a new hydrocolloid source cultivated in western and northwestern Iran in two types (Branched and rounded) is known as a food and pharmaceutical substance. It contains starch (2.7%) ash (2.4%) and nitrogen compounds (5%) and can be used in different food formulations such as desserts and ice cream (Ekrami & Emam-Djomeh, 2014). Salep contains glucomannan (16-55%) so, the mucilage with viscoelastic properties is used as a gelling agent at low temperatures and also functions as an emulsifier and thickening agent, hence capable of forming edible films and batters to develop different kinds of biodegradable packaging materials (Farhoosh & Riazi, 2007; Kurt, 2019).

Decreasing the amount of linolenic acid via mixing or hydrogenating which means a change in the composition, leads to more stability in the frying process. Nowadays, genetic modification is a way to enhance the properties of products (Safaei, Aghaee, Khaniki, Afshari, & Rezaie, 2019) and alter the number of fatty acids (Uluata, McClements, & Decker, 2015). It has been proved that diminishing the levels of linolenic acid improves the stability of frying oils (Park & Kim, 2016). Oils with a high amount of oleic acid are accessible in the market. There is a great attempt in the agriculture sector to plant verities with high amounts of saturated fatty acids. Efforts to reduce linolenic acid and increase oleic and saturated acids look suitable, because these oils have some properties such as better frying stability, less polymerization, hydrolysis and oxidation. The impact of these alterations in fatty acid composition on foods fried in modified oils needs to be studied (Selani *et al.*, 2016). The vulnerability of fats and oils rich in omega (ω) fatty acids to thermal process effects, is a major concern in the food industry. Cooking oils provide a heat transfer medium which helps to improve the aroma and flavor of cooked food products. However, commercial cooking oils, rich in ω_6-fatty acids, often do not meet the thermal stability requirements and get rancid (Ghosh, Upadhyay, Mahato, & Mishra, 2019).

The chemical changes at high temperatures in fats and oils and their natural contaminants, result in polymerization, isomerization, oxidation, hydrolysis, or cyclisation reactions. The oxygen, moisture, trace elements and free radicals may promote these reactions. The amount of antioxidants in the oil may reduce, and products with lowered nutritional value and quality of the oil will be obtained (Quiles, Ramírez-Tortosa, Gomez, Huertas, & Mataix, 2002).

Considering rice as one of the major cultivated and consumed agro-products and a good source of carbohydrates and fibers, which almost provide the required calorie for a large population (Mohajer et al., 2024; Safaei et al., 2019), so, it is a relatively novel and essential approach to decrease oil absorption and increase the moisture content of stuck-pot rice. Therefore, this work aimed to use the Iranian Salep mucilage (SaM) as a new hydrocolloid source and coating agent for stuck-pot rice based on potato (SpP) and also study its effects during frying. Response surface methodology (RSM) was used to investigate the impacts of frying temperature, time and the SaM concentration on the properties of SpP. The impacts related to the type of oil during the frying process on the

stability and quality of stuck-pot rice based on potato were also studied.

2. Materials and Methods

Salep was provided during the flowering season (July) 2022 from the northwest (East Azerbaijan province) and west (Kurdistan province) of Iran. Six commercial oil (refined, bleached and deodorized) oil including corn oil, sunflower oil, rice bran oil, canola oil and hydrogenated vegetable oil palm olein oil were prepared from the local market. All chemical materials were provided by Sigma (St. Louis, Mo., USA.).

2.1. Preparation of coating solution

The SaM extraction was performed by the method demonstrated in our previous procedure (Ekrami & Emam-Djomeh, 2014). Various concentrations of SaM solution were prepared and SpP were coated by them. A mixture of powdered SaM (the size of the particles was less than 100 µm) and deionized water was provided and the achieved solution was stirred during the night to assure that the dissolution had been done completely.

2.2. Coating deep fat frying of SpP procedure

The potato variety used in this research was Monona. After storage at 13°C for a week, they were kept at 9°C for 2 weeks and the relative humidity of the place where potatoes were kept was 93-95%. The coating process lasted 30 s and drained for 15 min, respectively. Domestic rice cookers with an aluminum vessel (260×192×348 mm of capacity) were used. For every type of oil, the vessel was filled with 20 g of potato slices (4 mm thickness) at the bottom, rice pre-cooked and 40 mL oil and heated. After 15 min, the cookers were switched off and the oil was allowed to cool to room temperature at the end of the experimental process. After frying, samples wrapped on absorbing tissue paper were allowed to cool and stored in a freezer at -20°C before analysis.

2.3. Analytical methods

2.3.1. Color analysis

A colorimeter (Minolta CR 300 Series, Osaka, Japan) with 3 scales (a, b and L) was used to estimate the color of the chips. The scales for the reference sample were a*=0.2, b*= -2.6 and L*= 98.1. Various parts of each sample were taken at room temperature and the average of five measurements was calculated. The total color difference (ΔE), whiteness index (WI), browning index (BI) and yellowness index (YI) were calculated as follows (Hassannia-Kolaee, Khodaiyan, Pourahmad, & Shahabi-Ghahfarrokhi, 2016):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

Where L, a, and b color values were averaged. Also, the results were expressed as ΔE values in comparison with the control sample before frying (L=82.1, a=−3.8 and b=17.1).

2.3.2. Oil and water content

For each ground sample (5 g) after frying and cooling, the oil content was determined and reported as a percentage of dry matter weight by n-hexane solvent extraction using the Soxhlet method.

The water content was determined as the percentage of the difference between control and dried samples at 105°C for 3 h in an oven according to the following equation:

$$W_C\% = \frac{S_i - S_f}{S_i} \times 100 \quad (2)$$

Where W_C is the whole water content (%), S_i is the initial weight (g), and S_f is the final dry weight (g). All tests were conducted in triplicates.

2.3.3. Total antioxidant capacity (TAC) determination

TAC was determined by spectrophotometry and the extraction procedure was adopted by Granato *et al.*, (2018). One mL potassium acetate and 0.5 mL copper (II) chloride were mixed with 1 mL sample absorbance measurement of the resulting cuprous-neocuproine complex which was performed at

450 nm against a reagent blank prepared from pure distilled water (Granato *et al.,* 2018).

2.3.4. Lipid oxidation (LO-T) determination

The LO-T test was conducted according to the thiobarbituric acid (TBA) method with the modification described by Zainol *et al.,* (2003). Two mL of sample (with chloroform) was added to the thiobarbituric acid solution (2 mL). The mixture was then placed in a boiling water bath at 40°C for 15 min. After cooling, it was then measured at 532 nm with a UV/Visible spectrophotometer (Zainol, Abd-Hamid, Yusof, & Muse, 2003).

2.3.5. Total flavonoid content (TFC) determination

The TFC was determined according to Ekrami *et al.,* 2019 with some modifications, using quercetin as a standard of the calibration curve. About 0.5 mL (1 mg sample dissolved in 10 mL - methanol) was mixed at room temperature for 30 min with 1.5 mL of 2% (w/v) aluminum chloride and 1 mL of distilled water. The absorbance of the samples was recorded at 430 nm with a UV/Visible spectrophotometer (Ekrami, Emam-Djomeh, Ghoreishy, Najari, & Shakoury, 2019).

2.3.6. Total carotenoid content (TCC) determination

The absorbance of TCC in methanol after appropriate dilution was measured at 470 nm using a UV/Visible spectrophotometer (Fullerton, CA, USA) according to García-López *et al.,* 2016. Total carotenoids concentration (astaxanthin) in the extracts was measured by external calibration with astaxanthin standards in the same solvent (García-López, Pérez-Martín, & Sotelo, 2016).

2.3.7. Sensory evaluation

The samples were prepared and displayed homogeneously. Overall ratings of texture, odor, color and appearance were used for estimating the acceptable sensory quality of SpP. The mean value of each parameter was measured followed by a ranking test including 40 females and 20 males with a range of 22-50 years old. To evaluate the samples, a nine-point hedonic scale was used, where score 1 stands for most disliked and score 9 represented most liked. Scores higher or equal to 5 were taken as acceptable.

2.3.8. Coating and frying processes optimized by RSM

Response surface methodology (RSM) design can quantify the relationships between the measured responses (dependent variables) and the significant input factors (independent variables). A desirable location in the design space was aimed to be found. In addition, estimating the coefficients of the mathematical model which expresses the relationship between dependent and independent variables is possible by this technique. The accuracy (validation) of the predicted optimum run and its corresponding response was assessed by experimental data. As it is clear in Table 1, the impact of coating and frying parameters on the amount of oil was estimated by a Central-composite design. X1, X2 and X3 were the three independent variables showing SaM concentration (0.75, 1 and 1.25% w/w), frying time (3, 4.5, 6 min), and frying temperature (160, 170 and 180°C) respectively. The design included 20 experiments which consisted of 6 center points. The operating conditions were conducted at 5 levels coded as -2 (-α), -1, 0, +1 and +2 (+α). To investigate the optimal conditions, a second-order polynomial function was fitted to the correlated relationship between the independent variables and the response. The relationship between four factors and the response was expressed by a second-order polynomial model:

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{4} \beta_{ii} x_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{4} \beta_{ij} x_i x_j \quad (3)$$

Where Y is the response, β0 is the constant coefficient, xi (i=1–3) are non-coded variables, βi, βii, and βij are the linear, quadratic, and second-order interaction coefficients, respectively.

Table 1. Experimental conditions of the Central-Composite design studying the effect of X1, X2 and X_3: SaM concentration, frying time and frying temperature, respectively

Run	Coded			Un-coded		
	X_1	X_2	X_3	SaM concentration (%w/w)	Frying time (min)	Frying temperature (°C)
1	0	+2	0	1	7	170
2	-1	-1	-1	0.75	3	160
3	-1	+1	+1	0.75	6	180
4	0	0	0	1	4.5	170
5	0	-2	0	1	2	170
6	0	0	0	1	4.5	170
7	0	0	+2	1	4.5	187
8	+1	-1	+1	1.25	3	180
9	0	0	0	1	4.5	170
10	0	0	0	1	4.5	170
11	+1	-1	-1	1.25	3	160
12	-1	+1	-1	0.75	6	160
13	+1	+1	+1	1.25	6	180
14	+1	+1	-1	1.25	6	160
15	-1	-1	+1	0.75	3	180
16	-2	0	0	0.58	4.5	170
17	+2	0	0	1.42	4.5	170
18	0	0	0	1	4.5	170
19	0	0	-2	1	4.5	153
20	0	0	0	1	4.5	170

All tests and analytical observations were conducted in triplicate. ANOVA was used to calculate the mean of each parameter. The p-value was less than 0.05, which means that differences between treatments at a 5% level ($p < 0.05$) were considered significant.

3. Results and discussion

3.1. Optimization of coating and frying condition

3.1.1. Fitting of models

Regression analysis was performed for the experimental data. Derived models for different response variables including water content, acceptable quality and color difference are given in Table 2. The goodness-of-fit of the models was evaluated by a lack-of-fit test and R^2 analysis. R^2 and Adj R^2 values of the model for all response variables were more than 0.99 indicating that a high proportion of variability can be explained by the data. The Adeq precision measures the signal-to-noise ratio was 310.6, 325.1, 537.8 and 2126.6 for oil content, water content, acceptable quality and color difference, respectively. A ratio greater than 4 was desirable. Our ratios indicated an adequate signal and models can be used to navigate the design space. The lack of fit test is a measure of the failure of a model to represent data in the experimental domain. The lack-of-fit test (F-values) for all the models was not-significant (Fcal < Ftab). The F value for oil content water content, acceptable quality and color difference (6600.7, 6710.1, 3.3×10^4 and 3.8×10^5) were significant at the 95% level. The coefficients of variation (CV) were less than 2.24% in all responses, which shows the experiments were performed with adequate precision.

3.2. Oil content

According to Fig. 1, the amount of absorbed fat is affected by the time and temperature of frying. There is a direct connection between the amount of absorbed oil and its temperature. The control SpP contained 25% oil content while the other samples had significantly lower oil content. Results revealed that by increasing the concentration of SaM, oil uptake declined noticeably by SpP.

The amount of oil consumed during frying after coating declined. Hydrocolloids can have a noticeable impact on the frying process by controlling oil uptake (Naghavi, Dehghannya, & Ghanbarzadeh, 2018b). Moreover, decreasing the amount of oil in different foods with the aim of producing low-fat and low-calorie foods can be another advantage of using hydrocolloids (Valiahdi, Asadollahi, & Hosseini, 2019).

In other words, a decrease in the amount of oil occurred up to 47% when SaM concentration increased to maximum. Coating by other hydrocolloids revealed a similar result. For instance, the addition of almond gum declined 34% of chips oil (Bouaziz *et al.*, 2016), 41% of stripes coated with guar gum (Kim, Lim, Bae, Lee, & Lee, 2011), and Gellan gum reduced the oil uptake of fried pastry dough by 55% (Albert & Mittal, 2002). A few broad punctures which were the result of the thermal gelation or crosslinking properties of gums with low capillary pressures in gum allowed less oil to enter the pores. Akdeniz *et al.*, 2006 demonstrated that the connection between oil uptake and moisture loss was inverse. In other words, coating foods with gums resulted in less oil uptake by keeping more moisture (Akdeniz, Sahin, & Sumnu, 2006). Kim *et al.*, 2011 agreed with this result in their research and reported water evaporation resulted from a frying process that made void spaces within the food and was filled with oil, thus increasing the oil content of fried foods (Kim *et al.*, 2011).

Table 2. Regression models and ANOVA for the experimental data of SpP

Quality Parameter	ANOVA					Model equations
	Model (F value)	Lack of fit (F value)	R^2	Adq Pre	CV%	
Oil content	6600.7*	3.8**	0.99	310.6	0.52	$Y_1=+14.9-2.9X_1+1.7X_2+3.7X_3-0.1X_1X_2+0.325X_1X_3+0.4X_2X_3+1.1X_1^2+0.2X_2^2-0.8X_3^2$
Water content	6710.1*	4.1**	0.98	325.1	0.33	$Y_2=+7.3+0.8X_1-0.7X_2-1X_3+0.1AX_2-0.2X_1X_3+0.2X_2X_3+0.1X_1^2-0.1X_2^2-0.5X_3^2$
Acceptable sensory quality	$3.3\times10^{4*}$	1**	0.99	537.8	0.28	$Y_3=+8.2-0.1X_1-0.7X_2-0.9X_3-0.3X_1X_2-0.1X_1X_3+0.1X_2X_3-0.5X_1^2-1.4X_2^2-1.6X_3^2$
Color difference	$3.8\times10^{5*}$	0.4**	0.95	2126.6	0.08	$Y_4=+17.5-4.6X_1+1.3X_2+6.4X_3-0.7X_1X_2+0.1X_1X_3+0.8X_2X_3+1.5X_1^2-0.2X_2^2+1.9X_3^2$

* Significant ** Not-significant

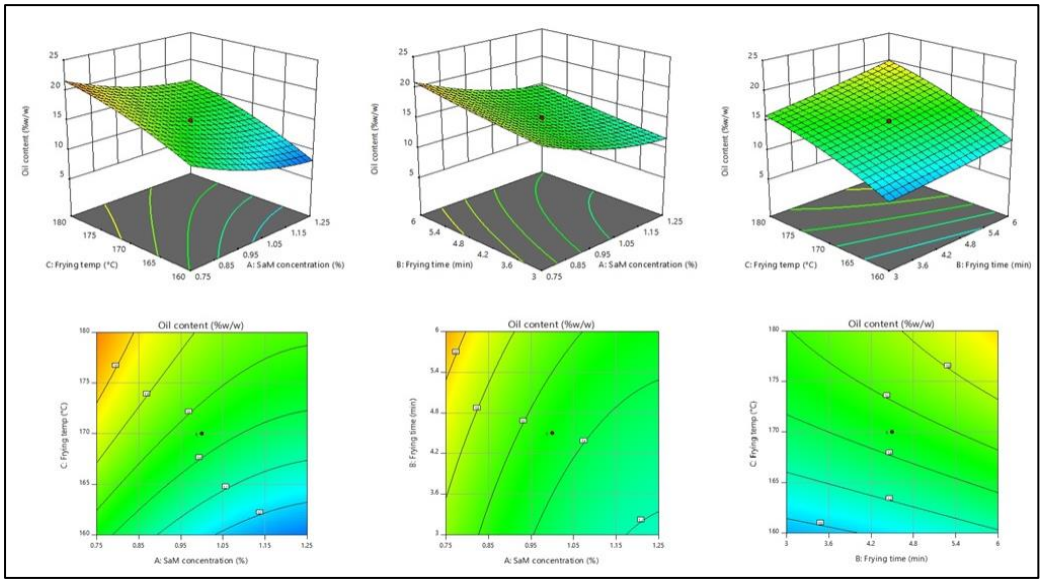

Figure 1. 3D surface/contour plots demonstrating the effect of SaM concentration, frying time and frying temperature on oil content of SpP

3.3. Water content

The frying process of SpP in which water loss occurs is classified into 3 steps: The first step consists of losing water at the cutting surface (heating potato). The second stage refers to producing water bubbles. As time passes during this step, the water content of the slices declines. The last step happens after crust production and prevents the movement of vapor bubbles which are produced by internal gas pressure (Mohammadalinejhad & Dehghannya, 2018).

According to Fig. 2 coated SpP kept a higher amount of moisture. This impact occurred because the capacity of water binding was high so, it did not allow moisture to be replaced with oil during the frying process (Ghaderi, Dehghannya, & Ghanbarzadeh, 2018).

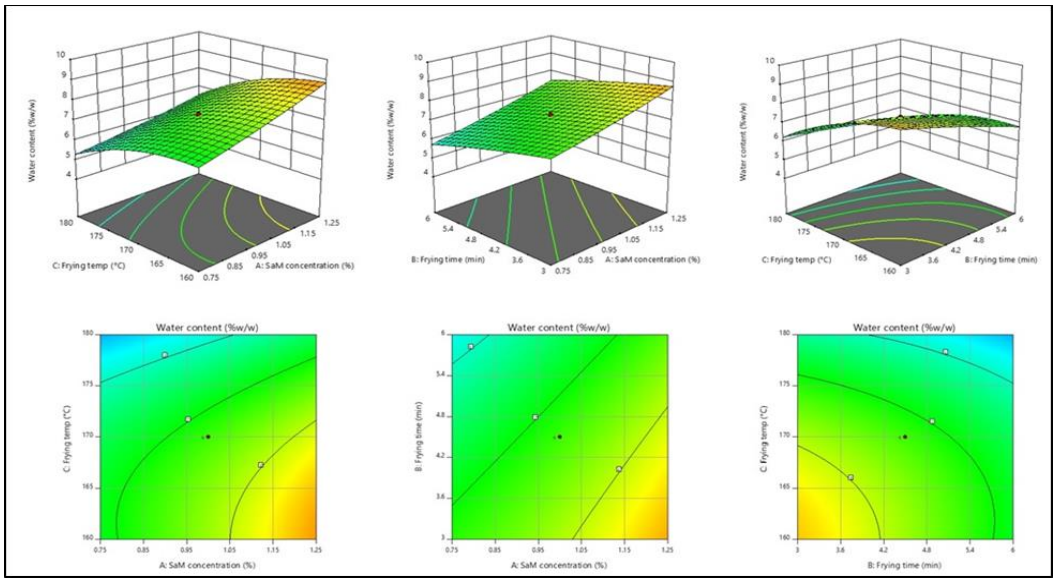

Figure 2. 3D surface/contour plots demonstrating the effect of SaM concentration, frying time and frying temperature on water content of SpP

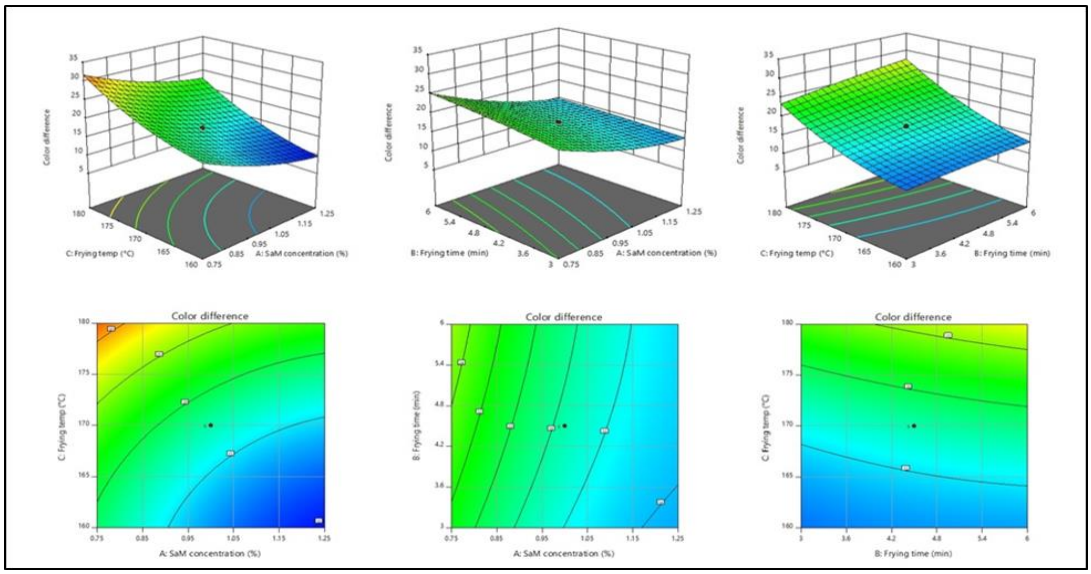

Figure 3. 3D surface/contour plots demonstrating the effect of SaM concentration, frying time and frying temperature on color difference of SpP

3.5. Sensory evaluation

Fig. 4 reveals a sensorial evaluation of coated SpP by using the ranking test mentioned above. Ordinal data were obtained from this experiment and there was proof regarding the difference between samples. A significant difference in sensory quality was observed. However, SpP coated by lower SaM was much preferable in terms of taste, appearance and crispiness (taste). The weak structure of the middle lamella matrix and the concomitant loss of intercellular adhesion, as well as the weakness of the cell walls during frying, may be the reason for the low crispiness of the control sample. Moreover, the existence of cross-linking and gel-forming agents in coated samples resulted in an increase in crispiness followed by an increase in the resistance of the film on the surface of potato (Troncoso, Pedreschi, & Zúñiga, 2009).

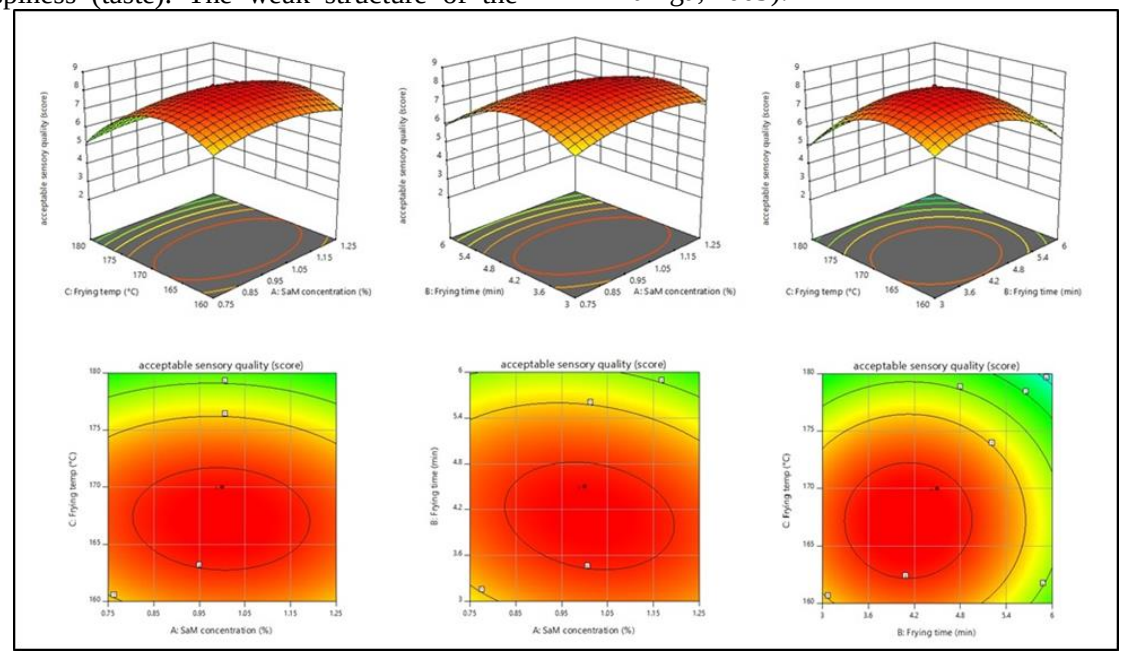

Figure 4. 3D surface/contour plots demonstrating the effect of SaM concentration, frying time and frying temperature on acceptable sensory quality (score) of SpP

3.6. Optimization

Optimized processing conditions for SpP were achieved by the numerical optimization tool of a Design expert with experimental data shown in Fig 5. The target values of the dependent variables were set in the program. The oil content and color variation were minimized, while the sensory evaluation and water content values were maximized. Therefore, the optimum conditions of the experimental data resulting in lower oil content and desirable physicochemical properties were 1.24% (w/w) SaM concentration, 3.6 min frying time at 162 °C frying temperature, resulting in oil content of 8.9%, water content of 9.2%, and a color difference of 10.5 and acceptable sensory quality score of 7.6. The optimum conditions and the corresponding predicted responses are listed in Table 3. For the validation of the optimum conditions, duplicate confirmatory experiments were performed. The measured values are closely related to the predicted data as shown in Table 3

Table 3. Constraints and criteria for optimum conditions, predicted and experimental values of responses of SpP

Factor		Limits	Weights	Predicted condition	Experimental condition	Correction (%)
Name	Code					
Salep mucilage concentration (%)	X_1	0.75-1.25	1	1.246	1.25	+0.32
Frying time (min)	X_2	3-6	1	3.622	3.7	+2.15

Frying temperature (°C)		X_3	160-180	1	162.393	165	+1.60
Response		Goal	Limits	Importance	Predicted value	Validated value	Variation (%)
Name	Code						
Oil content	Y_1	Minimize	6.3-23.9	3	8.91	9.05	+1.57
Water content	Y_2	Maximize	4.3-9.7	3	9.23	8.56	-7.82
Acceptable sensory quality	Y_3	Maximize	5-8.3	3	7.57	7.12	-5.94
Color difference	Y_4	Minimize	9.4-34.2	3	10.49	11.07	+5.52

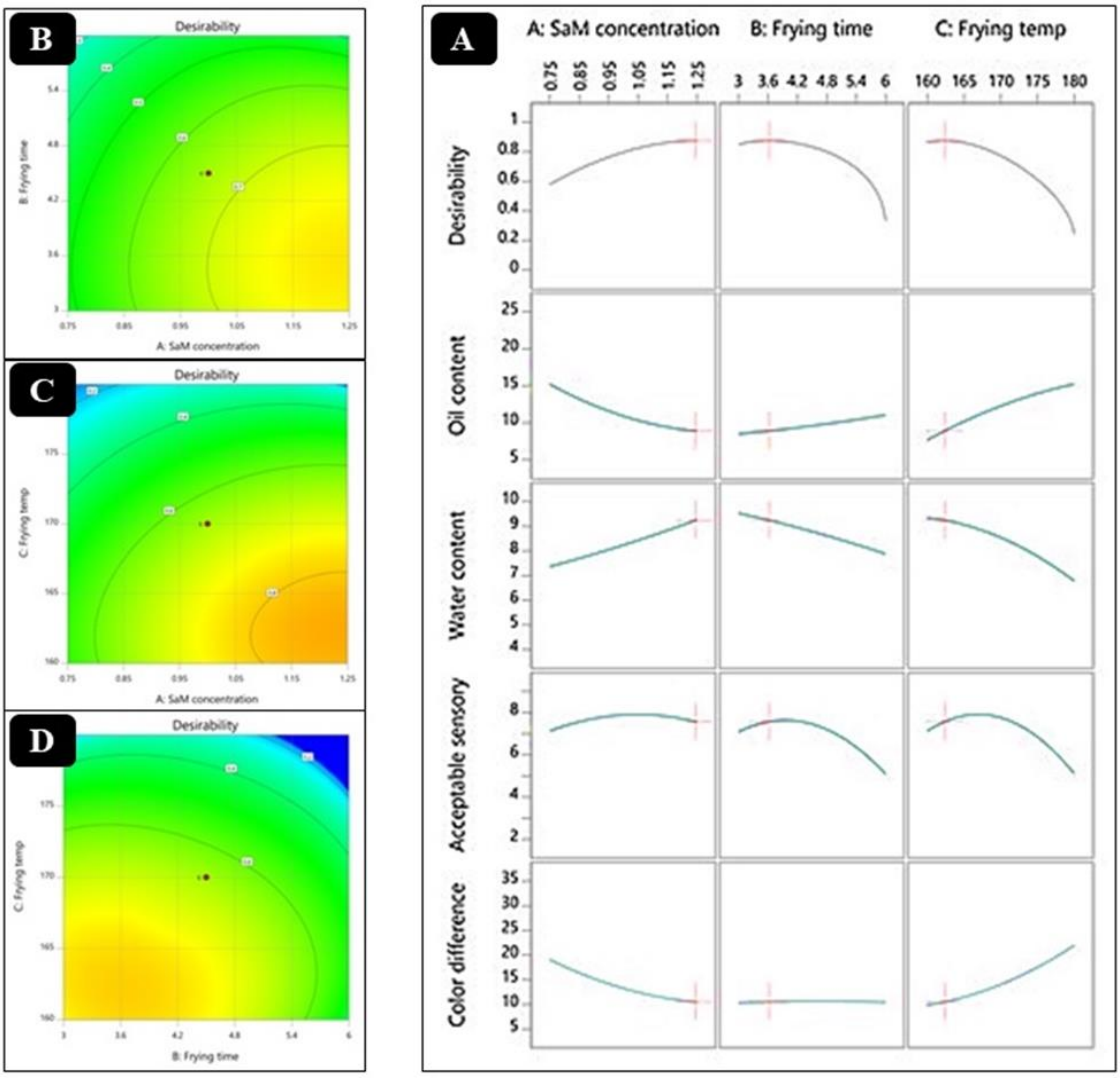

Figure 5. Optimization plot (A) and effect of SaM concentration and frying time (B), SaM concentration and frying temperature (C), frying time and frying temperature on desirability of SpP

3.7. Effect of frying oil type

TAC, LO-T, TFC and TCC measurement was the way to analyze the hydrolysis and polymerization of the frying oils. There was a direct relationship between C18:1 and FFA. According to this relationship, FFA displayed an increasing trend when the amount of C18:1 was increased. As it is shown in Table 4, the hydrogenated oil sample did not follow this rule. After using oil for 15 min, the lowest and the highest amount of TAC are referred to are hydrogenated vegetable oil (~ 35.9) and palm olein oil (~13.4) respectively.

Table 4. Total antioxidant capacity (TAC), lipid oxidation (LO-T), total flavonoid content (TFC) and total carotenoid content (TCC) of stuck-pot rice based on potato cooked with six types of oil

Type of oil	TAC (%)	LO-T (mg MDA/kg)	TFC (mg/kg)	TCC (mg/kg)
Sunflower oil	19.2±6.6	10.4±1.3	35.7±17.2	20.3±0.6
Corn oil	16.6±5.7	8.3±1.4	15.7±2.3	19.3±0.6
Rice bran oil	15.3±3.2	4.2±0.2	42.3±6.0	18.3±1.2
Canola oil	19.0±9.2	1.9±0.1	23.0±2.0	21.7±1.2
Palm olein oil	13.4±2.1	6.2±0.3	30.0±7.0	22.0±1.0
Hydrogenated vegetable oil	35.9±4.9	7.7±0.2	42.0±13.8	14.0±2.0

Except for rice bran oil (~42.3) and hydrogenated vegetable oil (~ 42), the amount of TFC was noticeably different for all types after using oil for 15 min. The range of LO-T in frying oils which were measured after using for 15 min was shown in Table 1 (1.9-10.4). The formation of lipid oxidation compounds, which shows oil deterioration, is strongly attributed to the primary and secondary oxidation that occurs during frying. When the amounts of LO-Ts reach, oil is thermally degraded and fresh oil must be used. LO-Ts during the deep fat frying process are given in Table 1. The amount of LO-Ts in sunflower oil was higher than in other samples. At the end of 15 min frying time, LO-Ts in all oils analyzed were found to be lower than 11 (mg MDA/kg) level. These results indicated that all of the oils could be used for frying potato chips for up to 15 min frying period. Khazaei *et al.* reported that the amount of LO-Ts in shrimp samples before and after the deep-fat frying process were 0.4 and 1 % respectively (mg MDA/kg) (Khazaei, Esmaiili, & Emam-Djomeh, 2016).

The TAC decreased during frying, which is the same pattern for antioxidant capacity in most deep-fat frying studies (Nsabimana, Powers, Chew, Mattinson, & Baik, 2018; Park & Kim, 2016). Antioxidants are unstable under deep fat frying conditions and may break down in the presence of high temperature, airflow, and light exposure as can be expected in deep fat frying operations (Wong *et al.*, 2019). The results of this study showed that in hydrogenated vegetable oil, the total antioxidant capacity decreases slowly.

4. Conclusions

According to the findings of the current study, Salep mucilage can be used as a promising agent to coat deep-fat fried potatoes. One of the advantages of the aforementioned mucilage was decreasing the oil absorption of SpP, which can reduce the cost of large-scale production due to the price of frying vegetable oils. On the other hand, more studies are required to investigate the impact of the combined use of this mucilage along with emerging nonconventional technologies (i.e. pulsed electric fields) to improve the quality of the products, while reducing the costs. Therefore, Salep can be introduced as a coating agent for food products.

5. References

Akdeniz, N., Sahin, S., & Sumnu, G. (2006). Functionality of batters containing different gums for deep-fat frying of carrot slices. *Journal of Food Engineering, 75*(4), 522-526.

Albert, S., & Mittal, G. S. (2002). Comparative evaluation of edible coatings to reduce fat uptake in a deep-fried cereal product. *Food Research International, 35*(5), 445-458.

Ananey-Obiri, D., Matthews, L., Azahrani, M. H., Ibrahim, S. A., Galanakis, C. M., & Tahergorabi, R. (2018). Application of protein-based edible coatings for fat uptake reduction in deep-fat fried foods with an emphasis on muscle food proteins. *Trends in Food Science & Technology, 80*, 167-174.

Askarpour, S. A., Molaee-Aghaee, E., Ghaderi-Ghahfarokhi, M., Shariatifar, N., Mahmudiono, T., Sadighara, P., & Fakhri, Y. (2023). Potentially Toxic Elements (PTEs) in refined and cold-pressed vegetable oils distributed in Ahvaz, Iran: a probabilistic health risk assessment. *Biological Trace Element Research, 201*(9), 4567-4575.

Belkova, B., Hradecky, J., Hurkova, K., Forstova, V., Vaclavik, L., & Hajslova, J. (2018). Impact of vacuum frying on quality of potato crisps and frying oil. *Food chemistry, 241*, 51-59.

Bouaziz, F., Koubaa, M., Neifar, M., Zouari-Ellouzi, S., Besbes, S., Chaari, F., . . . Ghorbel, R. E. (2016). Feasibility of using almond gum as coating agent to improve the quality of fried potato chips: Evaluation of sensorial properties. *LWT-Food Science and Technology, 65*, 800-807.

Eghbaljoo, H., Ghalhari, M. R., Shariatifar, N., Khaniki, G. J., Aghaee, E. M., Sani, M. A., . . . Arabameri, M. (2023). Analysis of polychlorinated biphenyls (PCBs) in edible oils using the QuEChERS/GC-MS method: A health risk assessment study. *Heliyon, 9*(11).

Eghbaljoo, H., Sani, I. K., Sani, M. A., Rahati, S., Mansouri, E., Molaee-Aghaee, E., . . . Sarabandi, K. (2022). Advances in plant gum polysaccharides; Sources, techno-functional properties, and applications in the food industry-A review. *International journal of biological macromolecules, 222*, 2327-2340.

Ekrami, M., Emam-Djomeh, Z., Ghoreishy, S. A., Najari, Z., & Shakoury, N. (2019). Characterization of a high-performance edible film based on Salep mucilage functionalized with pennyroyal (Mentha pulegium). *International journal of biological macromolecules, 133*, 529-537.

Ekrami, M., & Emam-Djomeh, Z. (2014). Water Vapor Permeability, Optical and Mechanical Properties of Salep-Based Edible Film. *Journal of Food Processing and Preservation, 38*(4), 1812-1820.

Farhoosh, R., & Riazi, A. (2007). A compositional study on two current types of salep in Iran and their rheological properties as a function of concentration and temperature. *Food Hydrocolloids, 21*(4), 660-666.

García-López, M., Pérez-Martín, R. I., & Sotelo, C. G. (2016). Carotenoid pigments composition of two commonly discarded decapod crustaceans in grand sole and the Galician-Northern Portugal coast fisheries. *Journal of Aquatic Food Product Technology, 25*(1), 114-121.

Ghaderi, A., Dehghannya, J., & Ghanbarzadeh, B. (2018). Momentum, heat and mass transfer enhancement during deep-fat frying process of potato strips: Influence of convective oil temperature. *International Journal of Thermal Sciences, 134*, 485-499.

Ghosh, M., Upadhyay, R., Mahato, D. K., & Mishra, H. N. (2019). Kinetics of lipid oxidation in omega fatty acids rich blends of sunflower and sesame oils using Rancimat. *Food chemistry, 272*, 471-477.

Granato, D., Shahidi, F., Wrolstad, R., Kilmartin, P., Melton, L. D., Hidalgo, F. J., . . . Ismail, A. B. (2018). Antioxidant activity, total phenolics and flavonoids contents: Should we ban in vitro screening methods? *Food chemistry, 264*, 471-475.

Hassannia-Kolaee, M., Khodaiyan, F., Pourahmad, R., & Shahabi-Ghahfarrokhi, I. J. I. j. o. b. m. (2016). Development of ecofriendly bionanocomposite: Whey protein isolate/pullulan films with nano-SiO2. *86*, 139-144.

Isik, B., Sahin, S., & Oztop, M. H. (2018). Determination of oil and moisture distribution in fried potatoes using magnetic resonance imaging. *Journal of food process engineering, 41*(6), e12814.

Kamkar, A., Qajarbeygi, P., Jannat, B., Haj Hosseini Babaei, A., Misaghi, A., & Molaee Aghaee, E. (2015). The inhibitory role of autolysed yeast of Saccharomyces cerevisiae, vitamins B3 and B6 on acrylamide formation in potato chips. *Toxin*

Reviews, 34(1), 1-5. doi:10.3109/15569543.2014.974765

Kamkar, A., Tooriyan, F., Jafari, M., Bagherzade, M., Saadatjou, S., & Molaee Aghaee, E. (2014). Antioxidant Activity of Methanol and Ethanol Extracts of Satureja hortensis L. in Soybean Oil. *Journal of Food Quality and Hazards Control, 1*(4), 113-119. Retrieved from http://jfqhc.ssu.ac.ir/article-1-97-en.html

Khazaei, N., Esmaiili, M., & Emam-Djomeh, Z. (2016). Effect of active edible coatings made by basil seed gum and thymol on oil uptake and oxidation in shrimp during deep-fat frying. *Carbohydrate polymers, 137*, 249-254.

Kim, D. N., Lim, J., Bae, I. Y., Lee, H. G., & Lee, S. (2011). Effect of hydrocolloid coatings on the heat transfer and oil uptake during frying of potato strips. *Journal of Food Engineering, 102*(4), 317-320.

Kurt, A. (2019). Development of a water-resistant salep glucomannan film via chemical modification. *Carbohydrate polymers, 213*, 286-295.

Mohajer, A., Safaei, P., Sleman Ali, H., Sarwar Karim, H., Sadighara, P., Molaee-Aghaee, E., & Ghanati, K. (2024). The association between toxic metals (As, Pb and Cd) exposure and rice cooking methods: A systematic review and meta-analysis. *International Journal of Environmental Health Research, 34*(2), 839-850.

Mohammadalinejhad, S., & Dehghannya, J. (2018). Effects of ultrasound frequency and application time prior to deep-fat frying on quality aspects of fried potato strips. *Innovative food science & emerging technologies, 47*, 493-503.

Molaee Aghaee, E., Kamkar, A., Akhondzadeh Basti, A., Khanjari, A., & Kontominas, M. (2016). Antimicrobial effect of garlic essential oil (Allium sativum L.) in combination with chitosan biodegradable coating films. *Journal of Medicinal Plants, 15*(58), 141-150.

Naghavi, E.-A., Dehghannya, J., & Ghanbarzadeh, B. (2018a). 3D computational simulation for the prediction of coupled momentum, heat and mass transfer during deep-fat frying of potato strips coated with different concentrations of alginate. *Journal of Food Engineering, 235*, 64-78.

Naghavi, E.-A., Dehghannya, J., & Ghanbarzadeh, B. (2018b). Effect of hydrocolloid type on transfer phenomena during deep-fat frying of coated potato strips: Numerical modeling and experimental analysis. *Computers and electronics in agriculture, 154*, 382-399.

Nsabimana, P., Powers, J. R., Chew, B., Mattinson, S., & Baik, B. K. (2018). Effects of deep-fat frying temperature on antioxidant properties of whole wheat doughnuts. *International journal of food science & technology, 53*(3), 665-675.

Park, J.-M., & Kim, J.-M. (2016). Monitoring of Used Frying Oils and Frying Times for Frying Chicken Nuggets Using Peroxide Value and Acid Value. *Korean journal for food science of animal resources, 36*(5), 612.

Quiles, J. L., Ramírez-Tortosa, M. C., Gomez, J. A., Huertas, J. R., & Mataix, J. (2002). Role of vitamin E and phenolic compounds in the antioxidant capacity, measured by ESR, of virgin olive, olive and sunflower oils after frying. *Food chemistry, 76*(4), 461-468.

Safaei, P., Aghaee, E. M., Khaniki, G. J., Afshari, S. A. K., & Rezaie, S. (2019). A simple and accurate PCR method for detection of genetically modified rice. *Journal of environmental health science & engineering, 17*(2), 847-851. doi:10.1007/s40201-019-00401-x

Santos, C. S., García, L. M., Cruz, R., Cunha, S. C., Fernandes, J. O., & Casal, S. (2019). Impact of potatoes deep-frying on common monounsaturated-rich vegetable oils: a comparative study. *Journal of food science and technology, 56*(1), 290-301.

Selani, M. M., Shirado, G. A., Margiotta, G. B., Rasera, M. L., Marabesi, A. C., Piedade, S. M., . . . Canniatti-Brazaca, S. G. (2016). Pineapple by-product and canola oil as

partial fat replacers in low-fat beef burger: Effects on oxidative stability, cholesterol content and fatty acid profile. *Meat science, 115*, 9-15.

Troncoso, E., Pedreschi, F., & Zúñiga, R. N. (2009). Comparative study of physical and sensory properties of pre-treated potato slices during vacuum and atmospheric frying. *LWT-Food Science and Technology, 42*(1), 187-195.

Uluata, S., McClements, D. J., & Decker, E. A. (2015). How the multiple antioxidant properties of ascorbic acid affect lipid oxidation in oil-in-water emulsions. *Journal of agricultural and food chemistry, 63*(6), 1819-1824.

Valiahdi, S. A., Asadollahi, S., & Hosseini, E. (2019). Effect of Edible Coatings (Xanthan gum and Carob gum) on the Physicochemical and Sensory Properties of French Fries Potatoes. *Malaysian Journal of Applied Sciences, 4*(1), 48-59.

Wang, C., Su, G., Wang, X., & Nie, S. (2019). Rapid Assessment of Deep Frying Oil Quality as Well as Water and Fat Contents in French Fries by Low-Field Nuclear Magnetic Resonance. *Journal of agricultural and food chemistry, 67*(8), 2361-2368.

Wong, Y. H., Goh, K. M., Nyam, K. L., Nehdi, I. A., Sbihi, H. M., & Tan, C. P. (2019). Effects of natural and synthetic antioxidants on changes in 3-MCPD esters and glycidyl ester in palm olein during deep-fat frying. *Food control, 96*, 488-493.

Zainol, M., Abd-Hamid, A., Yusof, S., & Muse, R. (2003). Antioxidative activity and total phenolic compounds of leaf, root and petiole of four accessions of Centella asiatica (L.) Urban. *Food chemistry, 81*(4), 575-581.

Acknowledgments

The authors are grateful to the Tehran University of Medical Sciences.

Authors' contributions

Mahmood-babooi, Kosar; Data curation, Methodology, Writing – original draft. Ekrami, Mohammad; Data curation, Methodology. Sadighara, Parisa; Data curation, Investigation, Methodology. Rostami, Mohammad reza; Conceptualization (Supporting), Writing – review & editing. Molaee-Aghaee, Ebrahim (Corresponding Author); Project administration, Supervision, Writing – review & editing, Methodology,

Funding

This study did not receive any funding by any institute.

Availability of data and materials

All data generated during this study are included in this published article.

Code availability

Not applicable.

Declaration ethics approval and consent to participate

All participants declare their consent to participate in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.