



Original Article

Texture-Modified Black Plum Peel Marmalade for Older Adults: RSM-Based Optimization of Chemical and Rheological Properties

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ABSTRACT

Background: This research was conducted with the aim of optimizing the formulation of black plum peel marmalade, in order to obtain a product with a modified texture suitable for consumption by the elderly. In this regard, the effect of independent variables of pectin and puree concentration on the chemical, and rheological properties of the formulation was investigated.

Methods: Formulation modeling and optimization was done using response surface method. Pectin and puree concentration as independent input variables and 7 indicators including pH, acidity, moisture content, ash, apparent viscosity, flow behavior index (n), consistency coefficient (K), were defined as response variables. Simultaneous optimization of responses was done using the desirability function.

Results: Numerical optimization identified the optimum formulation at coded levels $A = 0.45\%$ (pectin) and $B = 40.17\%$ (black plum peel puree) with overall desirability $D=0.70$. At this optimum point, the predicted values for pH, acidity, moisture content, apparent viscosity, flow behavior index, and consistency coefficient were 3.43, 0.30%, 33.88%, 210.559 Pa·s, 0.27, and 88.33 Pa·sⁿ, respectively. The regression models provided useful descriptions of several responses; however, some models showed limited predictive performance, as indicated by low or negative Pred-R² values.

Conclusion: The results showed that the optimized formulation of black plum peel marmalade provides suitable chemical characteristics and rheological properties for swallowing and consumption by the elderly. Therefore, the use of black plum peel is not only an efficient solution to reduce food industry waste and create added value, but can also be used as a practical raw material in the development of texture-modified products for target groups with swallowing limitations.

Introduction

Aging is associated with a set of physiological, functional and metabolic changes that can significantly affect the nutritional status of people. In the meantime, the occurrence of oral and swallowing disorders, reduced chewing ability, weakness of the muscles involved in swallowing, decreased saliva secretion and age-related sensory changes increase the risk of insufficient intake of nutrients in the elderly. One of the most important nutritional problems in this group is

dysphagia or swallowing disorder, which can lead to several consequences, including malnutrition, dehydration, reduced quality of life, increased risk of aspiration, and aspiration pneumonia. Therefore, it is very important to design foods that, in addition to the appropriate nutritional value, are compatible with the swallowing ability of this group in terms of consistency and texture (1-3).

In recent years, Texture-Modified Foods (TMF) have been considered as one of the main strategies in the nutrition management of people with dysphagia. These foods are



developed with the aim of facilitating bite formation, improving oral control, reducing the risk of choking and increasing swallowing safety. However, the preparation of such products is not only limited to softening the texture, but it is necessary to adjust their rheological and textural properties in such a way that while maintaining the nutritional quality and sensory acceptance, they also comply with the standards of ingestion safety. In this regard, the international IDDSI framework has been introduced as a standard system for classifying the texture of foods and the concentration of drinks in patients with dysphagia. In this system, level 4 includes pureed and very concentrated foods, which are considered suitable for many elderly people with swallowing disorders (2). Along with the safety of swallowing, the nutritional value of modified foods is also very important. Many of these products, although suitable in terms of consistency, may not be rich enough in terms of dietary fiber, bioactive compounds and antioxidants. Therefore, the use of vegetable and fruit raw materials rich in functional compounds can be an effective strategy in the development of special foods for the elderly. Plum (*Prunus domestica*) is one of the valuable fruits in this field, which has a high potential for use in the formulation of healthy products due to its dietary fiber, phenolic compounds, antioxidants, vitamins and minerals. Studies have shown that plum and its products can play a role in improving the function of the digestive system, reducing oxidative stress and promoting general health (4). In addition to fruit flesh, plum peel is also a rich source of fiber and phenolic compounds and can be used as a valuable component in the development of multipurpose food products. The use of plum peel, in addition to improving the nutritional and functional value of the product, can also be important in reducing food industry waste and better utilization of fruit processing by-products. In recent years, the use of fruit by-products in the design of innovative and functional foods, especially in the field of food sustainability, has attracted the attention of researchers.

To transfer these benefits to a suitable food format, it is very important to choose the type of product. Meanwhile, marmalade, as a semi-solid product made from fruit, sugar and pectin, can be a suitable option for designing foods with modified texture. This product, if properly formulated, has a uniform, homogeneous texture without coarse particles; a feature that is very important for people with swallowing disorders. In general, homogenous and puree-like fruit products can improve swallowing safety and sensory acceptance in people with dysphagia if textural and rheological properties are properly adjusted (2, 3)). Therefore, plum peel marmalade can be considered as a suitable platform for providing a safe, palatable nutritional product rich in bioactive compounds.

Despite the growing importance of foods with modified texture, there are still significant research gaps in the field of designing and optimizing fruit products for people with dysphagia. In particular, limited information is available on the use of plum peel in the production of a product with textural characteristics meeting the IDDSI Level 4 standard. On the other hand, the final characteristics of such a product depend on several factors, including raw material ratio, sugar amount, pectin level, and processing conditions, and the interaction of these variables can affect the texture, viscosity, and acceptance of the product. In such a situation, it is

necessary to use appropriate statistical methods to determine the optimal formulation conditions.

Response Surface Methodology (RSM) is one of the efficient methods in the optimization of food formulations and processes, which allows the simultaneous investigation of the effect of several variables and interactions between them. This method can be very beneficial in the development of special food products for dysphagia, in order to achieve desirable rheological and textural characteristics (5). Based on this, the aim of this study is to optimize the formulation of marmalade prepared from black plum peel using the response surface method, in order to achieve appropriate texture and viscosity characteristics, in order to provide a safe, nutritious and acceptable product for the elderly with dysphagia.

Methods

Preparation of raw materials and marmalade production process

Black plum peel as the main raw material of this research was obtained from plum processing factories in Neyshabur, Iran. In order to remove physical impurities, the peels were manually cleaned, washed and crushed; then the samples were frozen and stored at -18°C until the test. To prepare the puree, the defrosted peels were mixed with an equal ratio of water and after homogenization using a high-speed blender, they were passed through a strainer to obtain a uniform puree.

The cooking process was based on the fact that first 75% of the formulation sugar was dissolved in water to prepare a solution with Brix 70%; Then plum puree was added to the solution. At the stage when the brix of the mixture reached 60%, a mixture including pectin, 25% remaining sugar and citric acid was added to the formulation. The heating operation continued until reaching the final brix of 65 to 70% and pH in the range of 2.8 to 3.5. After cooking, the marmalade was packed in glass containers and kept at room temperature ($25 \pm 2^{\circ}\text{C}$) for at least 24 hours to complete the gelling process. Figure 1 shows the production process of black plum peel marmalade. In this study, the effect of different concentrations of pectin (0.3, 0.45 and 0.6%) and different levels of plum puree (40, 50 and 60%) were evaluated. Table 1 shows the mean and standard deviation values of the different marmalade samples examined in this study.

Chemical evaluations

The chemical characteristics of the samples including pH, Brix, acidity, ash and moisture content were determined. Acidity was measured according to AOAC 942.15 method, Brix value was controlled by refractometer (RHBO_80, Fuzhou, China) and pH was measured using pH meter (Sartorius PB_11, Göttingen, Germany). The moisture content of the samples was determined in an oven at 70°C (Fan-Azma-Gostar, Iran at 70°C) and total ash at 550°C for 4 hours. All tests were performed in three repetitions at ambient temperature ($25 \pm 2^{\circ}\text{C}$).

Rheological properties



The rheological properties of marmalade were investigated using Bohlin Visco 88 rotary viscometer (equipped with cup and bob system) at a temperature of 25 ± 0.5 °C and over a shear rate range of 20–300 s⁻¹. The apparent

viscosity was reported at a shear rate of 40 s⁻¹. The Power law model was used to describe the time-independent flow curves of black plum peel marmalade (6, 7).

Table 1. Predicted values, experimental mean values, and individual desirability of the responses at the optimized formulation.

Response Variable	Mean $\pm$ SD	Individual Desirability	Predicted Value	Observed value
pH	3.47 $\pm$ 0.024	0.4752	3.4293	3.54
Acidity	0.311 $\pm$ 0.057	0.7593	0.3042	0.31
Moisture content (%)	33.181 $\pm$ 2.668	0.3340	33.875	34.12
Ash (%)	0.723 $\pm$ 0.621	0.7866	0.885	0.865
Consistency coefficient (Pa.s ⁿ)	56.212 $\pm$ 25.105	0.9137	88.33	84.01
Flow behavior index (n)	0.328 $\pm$ 0.091	0.4885	0.27	0.29
Apparent viscosity (Pa.s)	185.312 $\pm$ 60.106	0.6480	210.559	201.86

Statistical formulation optimization

In order to determine the optimal formulation, Response Surface Methodology and utility function were used using numerical optimization in Design-Expert software (Version 12). After fitting regression models for different responses, pectin concentration (A) and puree concentration (B) were included as independent variables in the optimization process. For each response, the individual utility function was defined in the range of zero to one, and the overall utility (D) was calculated from the geometric mean of the individual utilities. The optimization goals included the maximization of some rheological and textural properties, and the minimization of acidity and moisture content.

Results

Chemical properties

pH

Two-factor interactive model (2FI) was chosen to model pH changes. This model is statistically significant ($p=0.0056$). The value of the adjusted explanatory coefficient is equal to $\text{Adj-R}^2=0.6495$, which indicates the appropriate explanation of data changes. However, the predictive coefficient is low ($\text{Pred-R}^2=0.0635$) and the Lack of Fit test is reported to be significant ($p=0.0029$). The Adeq Precision value was 9.5883, indicating an adequate signal-to-noise ratio, which is greater than the base number of 4 and shows that the model has enough signal to guide the optimal design process (Table 2). The results showed that both pectin (A) with $p=0.0235$ and plum peel puree (B) with $p=0.0090$ have significant linear effects on pH. Also, their interaction (AB) is statistically significant ($p=0.0282$) (Table 3). Meanwhile, the effect of plum peel puree was negative (lowering pH) and the effect of pectin was positive (slightly increasing pH). The coded regression equation for the pH response was shown in Table 3. The negative coefficient of variable B shows that the pH of the system decreases with the increase of plum peel puree. A positive coefficient indicates the increasing effect of pectin on pH. The positive coefficient of the interaction term AB shows that the simultaneous effect of pectin and plum peel puree synergistically moderates the acidity and as a result the pH tends to higher values at high concentrations of

both factors. Figure 2a shows the effect of black plum peel puree and pectin concentration on the pH value of black plum peel marmalade. The decrease in pH due to the increase in puree of plum peel is due to the presence of weak and free organic acids in the fruit. Pectin, as a weak acid polymer (polygalacturonic acid) with different degrees of methoxylation, creates a specific buffering capacity in the system, which is modulated by the presence of the carboxyl group. Accurate pH control in the range of 3.2 to 3.5 is critical for the formation of a stable pectin gel network. In this interval, the negative electrical charges of pectin chains are reduced and the possibility of creating hydrogen bonds and junction zones is provided. Accurately adjusting the pH of marmalade prevents the growth of microorganisms and increases the shelf life of the product.

Acidity

Based on statistical analysis, quadratic model was chosen for acidity response (Table 2). The p-value of the model is reported as 0.0722, which is not significant at the 95% confidence level, but is considered as a trend close to significance. The value of adjusted explanatory coefficient $\text{Adj-R}^2=0.4968$ and predictive explanatory coefficient $\text{Pred-R}^2=-1.8250$. The negative R^2 indicates the poor ability of the model to predict data outside the test range. Also, the lack of fit test is completely significant ($p=0.0007$), which indicates that the quadratic model has not been able to cover all the changes in the system and there are probably non-linear factors or other interactions that are not included in the model. Therefore, the interpretation of the results of this model should be done with caution.

The regression equation based on the coded coefficients shows that the acidity is mainly controlled by the plum peel puree variable (Table 3). The positive sign of the linear coefficients indicates the increasing trend of acidity with the increase in the percentage of plum puree. However, due to the non-significance of the entire regression model at the 95% level, the exact numerical coefficients of pectin and interactions do not have high statistical reliability for industrial predictions and are used only to show the direction of influence (positive or negative).

From the point of view of food chemistry, the increase in acidity occurs with the addition of plum peel puree due to the release of free acids in the cell vacuoles of the fruit texture.



Maintaining a certain level of acidity is essential for the activation of commercial pectins (especially pectins with high methoxyl) to form a gel, because the presence of hydrogen ions neutralizes the negative charge of pectin carboxyl groups and allows the polymer chains to come together and form a three-dimensional network. For the elderly, the acidity should be adjusted in such a way that, in addition to ensuring the microbial stability of the product, it causes the proper secretion of saliva and facilitates swallowing, without causing a burning sensation or an unpleasant aftertaste in the mouth. However, the quadratic model for acidity was not statistically significant and showed

poor predictive performance, as indicated by the negative Pred-R² value (-1.8250) and significant lack of fit ($p = 0.0007$). Therefore, the model should not be used for reliable quantitative prediction or extrapolation beyond the experimental region. The observed changes in acidity may have been influenced by uncontrolled sources of variation, such as compositional heterogeneity of the plum peel puree, variability in organic acid content, and processing-related changes. Accordingly, the acidity results are discussed primarily as observed experimental trends rather than as a robust response surface prediction.

Table 2. Final integrated statistical summary of fitted response surface models for physicochemical, rheological, and textural properties of black plum peel marmalade

Response	Model Type	Model Significance	Model p-value	Lack of Fit	Lack of Fit p-value	R ²	Adj-R ²	Pred-R ²	Adeq. Precision	CV (%)	Remark
pH	Two-Factor Interaction	Significant	0.0056	Significant	0.0029	0.7371	0.6495	0.0635	9.5883	0.0506	Acceptable fit, but significant lack of fit
Acidity (%)	Quadratic	Not significant	0.0722	Significant	0.0007	0.7065	0.4968	-1.8250	6.152	13.10	Weak model
Moisture content (%)	Linear	Not significant	0.3975	Significant	0.0008	0.1685	0.0022	-0.7777	32738	7.35	Weak model with poor predictive ability
Ash content (%)	Quadratic	Significant	0.0077	Significant	<0.0001	0.8538	0.7494	-0.4740	10.2924	43.54	Good fit, but significant lack of fit
Consistency coefficient (Pa.sn)	Quadratic	Significant	0.0083	Significant	<0.0001	0.8508	0.7442	-0.0625	9.5208	21.91	Good fit, but significant lack of fit
Flow behavior index	Linear	Not significant	0.1918	Not significant	<0.0001	0.4511	0.2315	-0.4183	4.05	6.40	Weak model
Apparent viscosity (Pa.s)	Quadratic	Significant	0.0006	Significant	<0.0001	0.9319	0.8832	0.3554	14.5659	1.79	Excellent model adequacy, but significant lack of fit

Moisture content

A linear model was proposed for the moisture content response (Table 2). This model is not statistically significant ($p=0.3975$) and its adjusted explanatory coefficient is very low (Adj-R²=0.0022). A negative predictive coefficient was reported (Pred-R²=-0.7777). Also, the Lack of Fit test is completely significant ($p=0.0008$). All these indicators show that the linear regression model is not able to describe the changes in the moisture content percentage of marmalade, and the moisture content fluctuations are dependent on other variables outside of this design (such as the time and temperature of the evaporation process or the fluctuations of the initial texture of the fruit). None of the independent variables of pectin (A) and plum peel puree (B) showed a significant effect on the final moisture content of marmalade in the investigated range (Table 3). The reason for this is the control and uniformity of the cooking and evaporation process at a certain level during the preparation of the samples, which caused no significant difference in the amount of remaining water in the samples.

Due to the lack of significance of the model and variables, the numerical values of the coefficients in the moisture content regression equation have no scientific predictive value and should not be used as the basis for statistical

optimization of the formulation. The moisture content of marmalade indicates the amount of free and bound liquid phase in the system. Although the formulation did not directly change the moisture content, the way the water was distributed (free water versus water bound with pectin and plum peel fibers) was the ultimate determinant of consistency. For the elderly, maintaining moisture content in an optimal range is very important to prevent syneresis; because the separation of the liquid phase from the solid in the mouth can increase the risk of premature bolus flow into the pharynx and aspiration and coughing (aspiration) in people with swallowing disorders. The linear model for moisture content was not significant and had limited predictive capability, as reflected by the negative Pred-R² value (-0.7777) and significant lack of fit ($p = 0.0008$). This result suggests that moisture variation was not sufficiently explained by the investigated formulation factors alone. Other variables, including heating intensity, evaporation time, endpoint temperature, initial moisture variability of the raw materials, and batch-to-batch processing variation, may have contributed to the observed moisture content. Therefore, this model should be interpreted with caution and should not be used as a predictive tool outside the experimental conditions evaluated in this study.



Ash content

Quadratic model was selected for ash response (Table 2). This model had a p-value equal to 0.0077, which indicates that the model is statistically significant. An acceptable adjusted explanatory coefficient is obtained ($\text{Adj-R}^2=0.7494$), but the predictive explanatory coefficient is negative ($\text{Pred-R}^2=-0.4740$). The lack of fit test is also reported to be very significant ($p<0.0001$). These conditions show that although the model describes the process of experimental changes of manufactured samples to some extent, its generalization to predict new formulations will be accompanied by errors.

The variable plum peel puree (B) shows a more positive effect on the amount of ash (Table 3). Since ash represents the total mineral content in the sample, the high concentration of mineral compounds in plum peel is the main reason for this increase. The pectin variable (A) had a linear and second-order effects. According to the values of the coefficients, the plum peel puree variable had a higher positive coefficient than pectin. This shows that the direction of movement of ash response is aligned and upward with the increase of plum peel puree. The quadratic sentences show a slight curvature in the response behavior that should be interpreted with caution due to the statistical limitation of the prediction model. Figure 2b shows the effect of the independent variables on ash content.

Ash indicates the total amount of salts and minerals (such as potassium, magnesium and calcium) in marmalade. Black plum peel is a rich source of these mineral elements, so increasing the proportion of plum peel puree directly leads to an increase in ash. From a practical point of view, the presence of rich minerals in the diet of the elderly is very important; minerals in plums, such as potassium, help regulate blood pressure, and calcium and magnesium help maintain bone health, so the high amount of natural ash in this product is considered a positive nutritional feature.

Rheological properties

Consistency coefficient

Quadratic model was proposed to model consistency coefficient. The model was statistically significant ($p=0.0083$) and shows a suitable adjusted explanatory coefficient ($\text{Adj-R}^2=0.7442$). However, the predictive explanatory coefficient was negative ($\text{Pred-R}^2=-0.0625$) and Lack of Fit was significant ($p<0.0001$). Therefore, this model is very useful for understanding the general process of system consistency changes, but it does not have absolute numerical prediction capability for new formulas (Table 2).

Figure 3a shows the effect of black plum peel puree and pectin concentration on the consistency coefficient of black plum peel marmalade. The concentration of pectin (A) was recognized as the main and positive factor influencing the consistency coefficient. The positive coefficients of variables A and B in the coded form indicate a direct increase in the consistency coefficient with the increase of these two components of the formulation. The quadratic effect of pectin is negative, which shows that the acceleration of consistency increase in high concentrations of pectin decreases due to the limitation of chain mobility (Table 3).

The consistency coefficient (K) based on the power law, indicates the physical resistance of the liquid at low shear rates. Increasing pectin with free water bonding and cross-linking between chains increases the apparent viscosity and initial consistency of the system. The fibers in plum peel puree also increase the strength of the pectin network. In the diet of the elderly, the high consistency coefficient prevents food from spreading uncontrollably in the mouth and makes bolus control easier for a person. Plum peel puree (B) had also played a positive linear contribution to consistency. The quadratic terms of the variables have had a significant role in the model, which indicates the curvature of changes in concentration versus consistency.

Table 3. Final predictive regression equations in terms of coded factors for physicochemical and rheological properties

Response Variable	Final Equation (Coded Factors)	(A) p-value	(B) p-value	(AB) p-value	(A ²) p-value	(B ²) p-value
pH	$Y = 3.41 + 0.0192A - 0.0233B + 0.0225AB$	0.0235	0.0090	0.0282	-	-
Acidity (%)	$Y = 0.2814 - 0.04A + 0.0258B - 0.0175AB + 0.0282A^2 + 0.0507B^2$	0.0508	0.1723	0.4283	0.2978	0.0828
Moisture content (%)	$Y = 33.18 + 1.25A - 0.6675B$	0.2377	0.5179	-	-	-
Ash content (%)	$Y = 0.4655 - 0.4250A - 0.3667B + 0.5750AB + 0.4657A^2 + 0.0907B^2$	0.0129	0.0245	0.0081	0.0434	0.6464
Consistency coefficient (Pa.sn)	$Y = 64.61 + 16.64A - 2.44B + 0.1700AB - 39.29A^2 + 21.63B^2$	0.0132	0.6443	0.9788	0.0001	0.0228
Apparent viscosity (Pa.s)	$Y = 205.56 + 52.47A + 24.49B - 17.75AB - 74.26A^2 + 28.07B^2$	0.0003	0.0181	0.1122	0.0004	0.0485

A: Pectin concentration (%)

B: Puree concentration (%)

Y: represents the predicted response for each property.





Figure 1- Production process of black plum peel marmalade

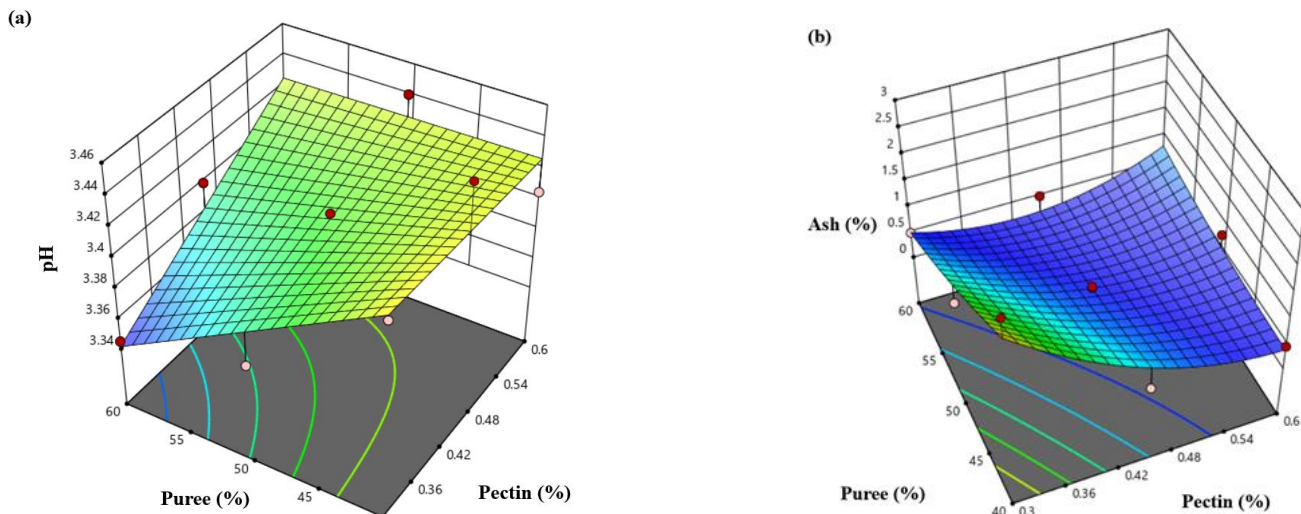


Figure 2. The effect of black plum peel puree and pectin concentration on the a) pH and b) ash content of black plum peel marmalade

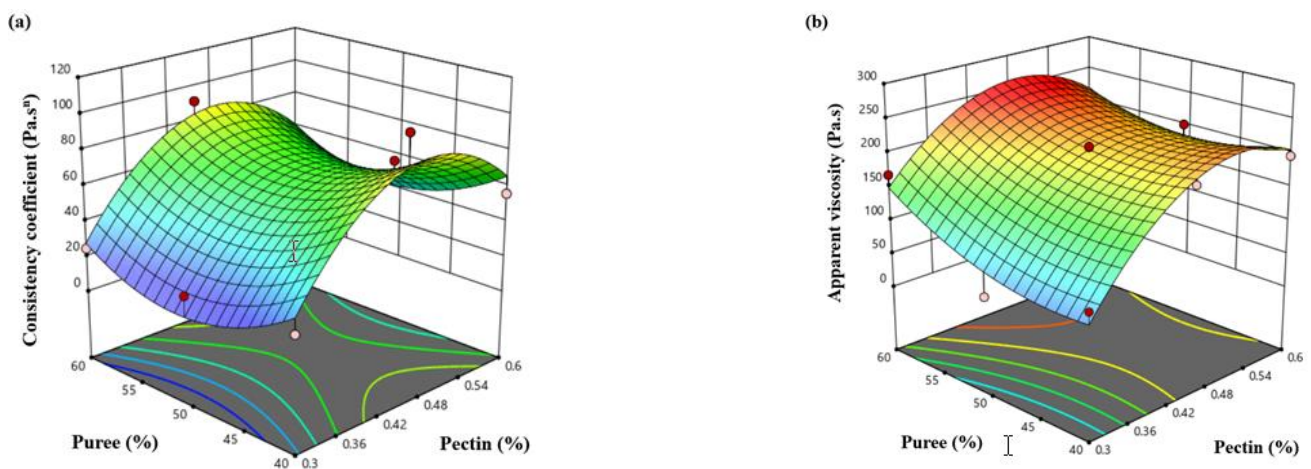


Figure 3. The effect of black plum peel puree and pectin concentration on the a) consistency coefficient and b) apparent viscosity of black plum peel marmalade



Flow behavior index

Linear model was chosen for flow behavior index (n). This model was not statistically significant ($p=0.1918$). The adjusted explanatory coefficient was extremely low ($\text{Adj-R}^2=0.1375$) and the negative predictive coefficient was reported ($\text{Pred-R}^2=-0.5911$). Also, the Lack of Fit test was significant ($p<0.0001$). These statistical results show that the linear model cannot reliably describe the non-Newtonian behavior of the system based on independent input variables (Table 2).

The variables of pectin and plum peel puree did not show a significant effect on the flow behavior index at the linear level and within the investigated range. The experimental values obtained for n indicate the pseudoplastic behavior of the samples ($n<1$), but the intensity of this behavior did not change significantly with the concentration of factors in this model. Due to the non-significance of the statistical model, the interpretation of the coefficients of the regression equation for the flow behavior index is omitted in order to avoid statistical misinterpretations.

The values obtained for the flow behavior index were all less than one, which indicates the shear-thinning behavior of the marmalades. This feature is caused by the orientation of pectin polymer chains in the direction of applying shear

force. From the practical point of view for the elderly, pseudo-plastic behavior is considered a great advantage; because the product maintains its consistency in a stationary state (in a spoon or plate) and has a coherent structure, but as soon as a mild shearing force is applied during swallowing in the mouth, its viscosity decreases and it easily passes through the throat. Although all formulations exhibited flow behavior index values lower than 1, indicating pseudoplastic or shear-thinning behavior, the linear model for n was not statistically significant and showed poor predictive performance ($\text{Pred-R}^2 = -0.5911$;

lack of fit, $p < 0.0001$). Thus, the observed shear-thinning behavior can be described qualitatively for the tested formulations, but the fitted model cannot reliably predict changes in n as a function of the formulation variables. This limitation may be related to the complex interactions among pectin, soluble solids, peel particles, and water within the marmalade matrix, which may not be adequately represented by the selected linear model.

Apparent viscosity

Quadratic model was chosen as the optimal model for viscosity. This model is statistically significant ($p=0.0006$). The fit values of the model in the final ANOVA fit are excellent ($R^2=0.9319$ and $\text{Adj-R}^2=0.8832$). The value of Adeq Precision is equal to 14.5659, which indicates the high accuracy of the model in separating signal from noise. The value of $\text{Pred-R}^2=0.3554$ and the significance of Lack of Fit ($p<0.0001$) show that the prediction of exact viscosity values outside the boundaries of the test design should be done with caution (Table 2).

Figure 3b and Table 3 shows the effect of black plum peel puree and pectin concentration on the apparent viscosity of black plum peel marmalade. Pectin variable (A) has a very strong linear positive effect ($p=0.0003$). Plum peel puree (B) also has a significant positive linear effect ($p=0.0181$). The

interactive effect of AB is not significant ($p=0.1122$). However, the quadratic effects of pectin (A^2) with $p=0.0004$ and plum puree (B^2) with $p=0.0485$ are very significant and justify the shape of the response surface curve.

Table 3 shows the coded regression equation of apparent viscosity of black plum peel marmalade. The large coefficient of pectin (52.47) compared to plum peel puree (24.49) indicates the dominant role of pectin in increasing viscosity. The negative sign of the coefficient A^2 indicates that the viscosity increased with the increase of pectin up to an optimal concentration and then reached saturation, while the positive coefficient B^2 indicates the acceleration of the increase in viscosity at very high concentrations of plum peel puree. The increase in apparent viscosity caused by pectin is due to the water coating of polymer chains and the formation of a three-dimensional physical network that limits the mobility of the aqueous phase. Due to the presence of insoluble cellulose fibers and hemicelluloses, plum peel puree acts as a filler in this matrix and increases apparent viscosity. In the discussion of dysphagia of the elderly, apparent viscosity should be optimized in such a way that it conforms to the physical codes of international standards (such as IDDSI Level 4) so that swallowing can be done without the risk of suffocation.

Optimization of formulation

In order to determine the optimal formulation, Response Surface Methodology and utility function were used using numerical optimization in Design-Expert software. After fitting regression models for different responses, pectin concentration (A), and puree concentration (B) were entered as independent variables in the optimization process. For each answer, the individual utility function was defined in the range of zero to one and the overall utility (D). It was calculated from the geometric mean of individual preferences. The optimization goals included the maximization of some rheological properties, and the minimization of acidity and moisture content. Based on the results, the optimal point in the coded values $A=0.45$ and $B=40.17$ with overall desirability $D=0.70$ was obtained. Table 1 shows the predicted values, experimental mean values, and individual desirability of the responses at the optimized formulation.

Discussion

The results of this research showed that the change in the levels of pectin and black plum peel puree had a significant effect on a significant part of the chemical and rheological characteristics of marmalade. Based on the obtained models, apparent viscosity and consistency coefficient showed the most dependence on formulation changes; while for some indicators such as moisture content and flow behavior index, the selected models had lower predictive power. This shows that the mentioned responses were probably influenced by factors beyond the two independent variables examined; factors such as the thermal conditions of the process, the intensity of evaporation, the natural changes of the raw material and the complex interactions between the components of the food matrix.

In terms of titratable pH and acidity, increasing the level



of black plum peel puree decreased the pH and increased the acidity of the product. This result can be attributed to the presence of natural organic acids and acidic phenolic compounds in plum peel. Such a pattern has been previously reported in studies related to the enrichment of fruit products with peel or other secondary components of the fruit, so that the increase of these components usually leads to a more acidic food system (8, 9). This change is important not only from the point of view of the chemical characteristics of the product, but also from the point of view of gel technology, because the efficiency of pectin in forming the gel network is highly dependent on the acidic conditions of the environment. According to the report of Thakur et al. (1997), in the appropriate pH range, the reduction of electrostatic repulsion between pectin chains provides the conditions for more effective interaction and the formation of a stable gel structure. Therefore, the decrease in pH caused by the presence of plum peel can be considered as a factor consistent with the improvement of some structural characteristics of the product, although the quantitative interpretation of this response should be done with caution due to the statistical limitation of the model (10).

In the case of ash, the increasing trend of this index in response to the increase in the level of plum peel puree indicates the role of this raw material in improving the mineral load of the product. This finding is consistent with previous studies on the use of waste and by-products of fruits in food formulation, because the peel and pumice of fruits are usually rich in minerals and dietary fibers and can increase the total ash of the product (11). In terms of nutrition, this feature can be especially important in the design of targeted foods for the elderly, because this age group is at greater risk of insufficient intake of some micronutrients, and the use of raw materials with a higher nutritional density can help improve the quality of their diet.

The investigation of rheological characteristics showed that the increase of pectin and plum peel puree in general caused an increase in the apparent viscosity and consistency coefficient. This behavior can be seen as the result of two complementary mechanisms: first, the role of pectin in water absorption, swelling, and gel network formation; and second, the role of fibrous particles and structural components of plum peel in increasing the effective solid phase and strengthening the semi-solid matrix. Such an effect has also been reported in studies related to the use of fruit fibers in gel and semi-solid systems (12-14). The important point is that the values of flow behavior index n in all formulations were less than 1, which indicates pseudoplastic or shear-thinning behavior. This feature is considered desirable in puree and gel products, because the product has sufficient consistency in a stationary state, but becomes more fluid under the application of shear force. Previous studies have also reported similar behavior for concentrated foods and systems designed for dysphagia (12, 15).

From a practical point of view, the pseudo-plastic behavior observed in the samples of this research is considered a potential advantage for product development for the elderly and people with swallowing disorders. Based on the IDDSI framework, suitable foods for dysphagic patients should have a balance between consistency, coherence and flowability during swallowing; in such a way that while maintaining the integrity of the bolus, they also support its

safe movement in the oral cavity and pharynx (12). In this study, the increase in apparent viscosity and consistency along with the remaining shear-thinning behavior indicates that this food system theoretically has a favorable capacity to be placed in the group of semi-solid products suitable for swallowing disorders. This finding is consistent with the reports of Steele et al. (2015) and Cichero et al. (2017) who showed that targeted modification of the rheological properties of food can help reduce the risk of aspiration and improve bolus control (3, 12).

In general, the results of optimization and analysis of variance showed that the regression models obtained for most of the investigated responses, especially apparent viscosity and consistency coefficient (K), had high accuracy and predictive power and with high values of R^2 and Adj- R^2 and Adeq Precision, showed a suitable ability to describe the behavior of the system and predict the changes of responses in the range of process variables. Also, although the Lack of Fit test was significant in some responses such as pH, ash, and apparent viscosity, due to the adequacy of the fit indices, the models were still considered acceptable for analyzing the overall trend of the data. On the other hand, the models related to moisture content, flow behavior index (n) and to some extent acidity had less statistical strength and should be interpreted with more caution. In sum, the results of this research showed that the RSM method is a suitable tool for modeling, evaluating and optimizing the chemical and rheological characteristics of the product and can lead to determining the optimal process conditions to achieve better quality and suitable performance responses.

A limitation of the present study is that direct compliance with the IDDSI framework was not verified using standardized IDDSI testing methods, such as the Spoon Tilt Test and Fork Drip Test. Although the measured rheological and textural characteristics provide useful information for the formulation of texture-modified foods, they cannot alone confirm classification at a specific IDDSI level. Therefore, the present findings should be interpreted as formulation data relevant to IDDSI Level 4 characteristics rather than definitive evidence of IDDSI Level 4 compliance. Future studies should confirm the suitability of the optimized product using standardized IDDSI tests and, where appropriate, sensory and swallowing-safety evaluations.

Overall, the response surface methodology was useful for exploring the effects of formulation variables on several quality attributes of black plum peel marmalade. Nevertheless, the predictive performance differed among responses. Models with satisfactory statistical adequacy may be useful for optimization within the studied experimental range, whereas the models for acidity, moisture content, and flow behavior index had limited predictive value because of negative Pred- R^2 values and significant lack of fit. Consequently, these latter models should be interpreted as descriptive of the observed experimental data rather than as robust predictive equations. Future work should include additional experimental runs, tighter control of processing conditions, and potentially alternative model forms to improve predictive accuracy.

Strengths and Limitations

One of the main strengths of this study was the valuable



use of black plum peel, as a by-product of the food industry, to produce marmalade with a modified texture. Also, the use of the response surface method and the simultaneous optimization of several chemical and rheological properties made it possible to determine a specific formulation with the ability to develop applications. However, some models had low or negative Pred-R² values and the Lack of Fit test was significant, which indicates the limitation of their predictive power and the impossibility of generalizing the results outside the scope of the experiment. This study included only the investigated concentrations of pectin and black plum peel puree, and other factors affecting the process and storage were not investigated. Also, direct compliance with a specific level of the IDDSI standard, sensory acceptance, stability during storage and clinical evaluation of swallowing was not performed. Therefore, it is necessary to conduct independent IDDSI tests, sensory evaluation, durability studies, and clinical investigations in future research.

Conclusion

The present findings demonstrate that the formulation variables influenced the physicochemical and rheological characteristics of black plum peel marmalade in different ways. Rather than exerting isolated effects, pectin concentration, plum peel puree level, and soluble solids likely interacted to determine water binding, gel network formation, structural strength, and flow properties. From a practical perspective, the formulation should provide sufficient structural integrity for spoon handling while maintaining a smooth, cohesive, and easily manageable consistency for older adults.

The results of this research showed that the use of pectin and black plum peel puree in the formulation of marmalade has a significant effect on the chemical and rheological characteristics of the product and can effectively improve its quality and functional value. Among the examined responses, apparent viscosity and consistency coefficient showed the most influence from formulation changes. In particular, increasing the level of black plum peel puree significantly increased ash, which indicates the role of this raw material as a rich source of minerals.

The statistical summary showed that most of the responses were adequately described by linear or quadratic models, so that quadratic models showed the best performance for acidity, apparent viscosity, consistency coefficient. Among all responses, apparent viscosity and consistency coefficient (K), had the highest model adequacy, which was confirmed by high values of R², Adj-R², Pred-R², and Adeq Precision. On the other hand, moisture content and flow behavior index (n) showed a weaker performance in terms of predictive power, which indicates that these responses were probably influenced by other uncontrolled factors in addition to the studied formulation variables.

On the other hand, pectin played an essential role in forming and strengthening the gel network, increasing viscosity of marmalade. Observing the pseudo-plastic behavior in all the formulations also showed that the produced system has a favorable characteristic from the rheological point of view, which can be valuable for the development of semi-solid foods suitable for the elderly and people with dysphagia.

Based on these findings, it can be concluded that black plum peel is not only a low-value by-product, but a material with high potential for the production of useful products and capable of being used in the design of special foods for the elderly. The use of this component in the formulation of marmalade, in addition to improving the properties of the product, is also in line with the principles of sustainable development and reducing waste in the food industry.

It is suggested that in future studies, evaluation of antioxidant activity, texture properties, sensory acceptance, direct compliance with IDDSI standard tests, stability of phenolic compounds during storage, investigation of microstructure and consumer tests in the elderly group will be carried out in order to enable more accurate determination of the optimal formulation and industrial development of this product.

Overall, the findings of this study showed that the combination of pectin and black plum peel puree can simultaneously improve the structural and functional characteristics of marmalade. While pectin was mainly responsible for developing the gel network and improving the rheological properties, plum peel puree contributed the most to increasing the nutritional value of the product. This synergy provides the possibility of designing a semi-solid product with application potential in the nutrition of the elderly, as well as a sustainable approach in the exploitation of the by-products of the food industry.

The optimized formulation showed promising chemical and rheological properties for the development of a texture-modified marmalade for older adults. However, its classification as an IDDSI Level 4 food requires confirmation through standardized IDDSI testing procedures.

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Ethical Approval

This study was approved by the Neyshabur University of Medical Sciences Ethics Committee (Project number 204).

Conflict of Interests

The authors declare that they do not have any conflict of interest.

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