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Optimization of Functional Properties of Sesame Seed Protein Products by Thermal Denaturation

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Abstract — **The aim of the study is the optimization of the functional properties of sesame seed protein. In the course of studies, functional properties (water- and fat-holding capacities, fat emulsifying capacity) of a sesame seed protein product – the protein concentrate - were determined. The obtained data was analyzed using the MathCAD and Statistica software's; the optimal thermal denaturation parameters were established in order to regulate functional properties of protein products. When the protein concentrate is heated for 20 minutes at a temperature of 60 ^{0}C we established a value increasing of water-holding and fat-holding capacities; the maximum value of fat emulsifying capacity is observed at a temperature of 35.5 ^{0}C.**

Keywords—protein concentrate, thermal denaturation, sesame seed protein, water-holding capacity and fat-holding capacity, fat-emulsifying capacity.

I. Introduction

Currently, there is a high level of protein deficiency. In solving this problem, the rational and complex use of protein-containing plant materials is of great importance, as well as the creation of protein-based food products on its basis. Vegetable proteins (full-fat flour, protein concentrates and isolates) have a number of functional properties: emulsifying, stabilizing, water-binding, texture-forming ability, absorption of fat from water, etc. They contribute to the formation and stabilization of emulsions, and their gel-forming ability significantly affects the consistency of products, which is of great importance in the confectionery industry in the manufacture of sugar whipped confectionery, such as soufflé, marshmallows, marshmallows, nougat, whipped candies [1, 2, 3]. Vegetable proteins are also used in flour confectionery and bakery products as moisture-retaining components, which can improve the structure, enrich with useful substances and keep freshness longer.

One of the most promising modern methods of modifying protein products is thermal denaturation. Thermal denaturation of proteins is widely used to regulate the functional properties of proteins [4,5], primarily to reduce the solubility of proteins during their isolation and purification. Recently, interest in protein thermal denaturation has increased due to the possibility of obtaining soluble products with new functional properties. These primarily include the surface properties of the protein, its ability to stabilize emulsions and foams, as well as the rheological properties and ability to form gels. With protein thermal denaturation in dilute solutions below the critical gelation concentration, it is possible to obtain soluble denatured forms in the form of aggregates of unfolded macromolecules or fragments of macromolecule subunits. In this case, not only the sizes of denatured protein particles change, but also the nature of their interaction between themselves and the solvent.

One of the little-studied potential sources of protein is sesame, since its complex has a balanced amount of essential amino acids in relation to the physiologically necessary norm (standard). In the preparation of various formulations with the addition of sesame protein products and other plant materials due to the effect of mutual enrichment of proteins limited by various amino acids, the biological value of the final product can be significantly increased [6,7]. A comparative study of the functional properties of protein products showed that protein concentrate has the best properties.

Heat treatment of seeds is accompanied by deep structural changes in their protein complex, the effect on seeds leads to increased attackability of proteins, and, consequently, to increase nutritional value [8].

Therefore, the study of the effect of thermal denaturation on sesame seed proteins in order to regulate their functional properties remains relevant.

II. Research Methodology

The object of research is a protein concentrate from sesame seeds, which is a finely ground fat-free seeds with a protein content of up to 70 %.

Sesame seeds of type I (white) type (humidity 5.20 %), moistened to a given moisture content (6 %), were subjected to thermal denaturation. During the modification, the heating temperature of the studied sesame seeds was varied. Technological modes of the process of thermal modification of sesame seed proteins are presented in table 1.

TABLE I. TECHNOLOGICAL MODES OF THE PROCESS OF THERMAL MODIFICATION OF SESAME SEED PROTEINS

Name of the technological stage and technological mode	The value of the technological mode
1. Humidification of seeds to critical humidity:	
1.1 The introduction of water and shaking seeds:	
time, min	1-2
1.2 Seed temperature control:	
time, min	60
temperature, ºC	20
2. Thermal denaturation of moistened sesame seeds:	
temperature, ºC	40, 60
time, min	20
3. Obtaining a protein product from sesame seeds - full-fat flour (FFF):	
3.1 Grinding heated sesame seeds without separating the shells:	
particle size, mm	1
4. Obtaining a protein product from sesame seeds - protein concentrate (PC):	
4.1 Lipid extraction of grinded sesame seeds with hexane:	
water module (ratio of grinded sesame seeds: hexane)	1:3
temperature, ºC	4-6
number of infusions, times	3-4
4.2 Drying fat-free grinded seeds:	
solvent content (hexane), %	0
4.3 Grinding fat-free shredded seeds:	
particle size, mm	0,25

To determine the effective heat treatment parameters (t, ºC) of sesame seeds at their different oil content (M, %) with the aim of regulating the functional properties (WHC, FHC, FEC) of the protein concentrate (PC), a quadratic regression model was used. It allows you to determine the points of extremum and to build it you need at least 3 levels of variation by factors:

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2 \qquad (1)$$

where b_0, b_1, b_2, b_{12} are the regression coefficients;

x_1 – factor 1, temperature t, ^{0}C;

x_2 – factor 2, oiliness M, %;

y – response function, investigated functional property (WHC, FHC or FEC, %).

To determine the parameters of the regression model (1), a two-level experimental design was constructed [9,10] (table 2).

TABLE II. EXPERIMENT PLAN

Component parts OCCP	No. test	Factor 1 – temperature	Factor 2 – oiliness	Number of points
		x_1	x_2	
Core of the plan - PFE 2^k	1	–1	–1	2^k=4
	2	+1	–1	
	3	–1	+1	
	4	+1	+1	
“Star” points	5	–1	0	2k=4
	6	+1	0	
	7	0	–1	
	8	0	+1	
Center points	9	0	0	N_0=1

Each of these factors has three levels of variation.

1) Temperature variation levels x1: x1min = level -1 = 20 ^{0}C, x1c = level 0 = 40 ºC, x1max = level +1 = 60 ^{0}C

2) Oil variation levels x2: x2min = level -1 = 38,60 %, x2c = level 0 = 39,41 %, x2max = level +1 = 41,86 %.

In carrying out the research, standard methods were used to determine the functional properties of protein products (water-holding capacity (WHC), fat-holding capacity (FHC) and fat-emulsifying (FEC) capacity).

III. RESULTS

To determine the effective heat treatment parameters, the functional properties of the protein concentrate modified by thermal denaturation were determined (table 3).

TABLE III. THE EFFECT OF THERMAL DENATURATION ON THE FUNCTIONAL PROPERTIES OF PROTEIN CONCENTRATE FROM SESAME SEEDS

No. Test	Factor 1 – temperature	Factor 2 – oiliness	The value of functional properties, %		
	x_1, ^{0}C	*x_2, %*	*WHC*	*FHC*	*FEC*
1	20	38.60	231.23	172.87	63.63
2	60	38.60	204.33	156.83	76.19
3	20	41.86	216.57	181.37	79.55
4	60	41.86	224.63	160.50	76.19
5	20	39.41	239.30	212.00	63.64
6	60	39.41	184.30	178.53	72.50
7	40	38.60	206.17	190.73	70.73
8	40	41.86	223.50	152.00	83.33
9	40	39.41	195.27	146.27	75.00

A regression analysis was performed using the Statistica v.12 software package of experimental data (Table 3) to obtain the dependences of functional properties (WHC, FHC, FEC) on temperature (x_1 = t, ^{0}C) and oil content (x_2 = M, %) (2-4).

$$WHC = 8497.1 + (-16.497) \cdot t + (-397.95) \cdot M + 0.35535 \cdot t \cdot M + 0.021033 \cdot t^2 + 4.79841 \cdot M^2 \qquad (2)$$

$$FHC = (-5883.3) + (-3.4425) \cdot t + 307.656 \cdot M + 0.001317 \cdot t \cdot M + 0.035042 \cdot t^2 + (-3.8581) \cdot M^2 \qquad (3)$$

$$FEC = 1503.93 + 5.93353 \cdot t + (-79.971) \cdot M + (-0.12269) \cdot t \cdot M + (-0.01101) \cdot t^2 + 1.09117 \cdot M^2 \qquad (4)$$

The correlation index of the functional properties of protein concentrate is presented in the table 4.

Regression models and surface graphs of the dependence of a given indicator on T and M for PC are presented on figure 1.

TABLE IV. THE CORRELATION INDEX OF THE FUNCTIONAL PROPERTIES OF PROTEIN CONCENTRATE IS PRESENTED IN THE TABLE PC

Name of functional property	Correlation index, R
WHC	0,88
FHC	0,66
FEC	0,98

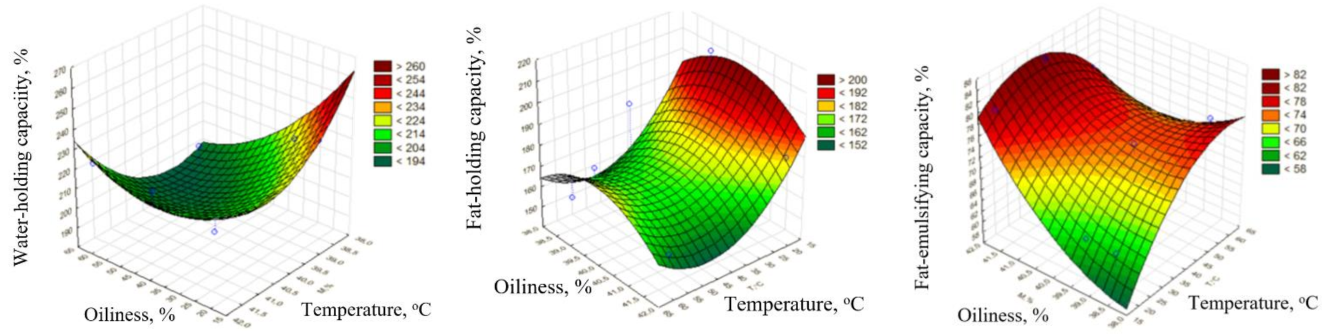

Fig. 1. Regression models and surface graphs of the dependence of a given indicator on T and M for PC

The obtained regression coefficients are presented in table 5.

TABLE V. REGRESSION COEFFICIENTS AND THEIR STATISTICAL SIGNIFICANCE FOR WHC, FHC, FEC%

Coefficient designations	**Name of functional properties**					
	WHC		***FHC***		***FEC***	
	Regression coefficients	***Significance level***	***Regression coefficients***	***Significance level***	***Regression coefficients***	***Significance level***
b0	8497.097	0.37	-5883.337	0.73	1503.929	0.33
b1	-16.497	0.14	-3.442	0.84	5.934	0.02
b2	-397.945	0.40	307.656	0.72	-79,971	0.30
b12	0.355	0.17	0.001	1.00	-0.123	0.03
b11	0.021	0.45	0.035	0.50	-0.011	0.06
b22	4.798	0.41	-3.858	0.71	1.091	0.26

The task of optimization is set (5):

$$\begin{aligned} &WHC(t, M)\rightarrow max,\\ &FHC(t, M)\rightarrow max, \quad (5)\\ &FEC(t, M)\rightarrow max \end{aligned}$$

$$\text{by } 20\le t\le 60;\ 38\le M\le 42 \quad (6)$$

The values of temperature (t, °C) and oiliness (M,%) were determined under which conditions (5) and (6) are satisfied.

The problem (5) - (6) of vector optimization is solved by means of the MathCAD v.15 package by linear convolution of criteria and mathematical programming methods. A linear weighted convolution of criteria K was applied, normalized to the maximum values of each of the criteria separately. By maximizing K, we achieve a consistent maximization of all three criteria (WHC, FHC, FEC).

$$K(t,M) = 100 \cdot \frac{\frac{WHC(t,M)}{WHC_{max}} + \frac{FHC(t,M)}{FHC_{max}} + \frac{FEC(t,M)}{FEC_{max}}}{3} \quad (7)$$

where WHC_{max}, FHC_{max}, FEC_{max} is the maximum possible value of WHC, FHC, FEC with the restrictions (6), which are presented in Table 6 for protein concentrate.

TABLE VI. THE MAXIMUM POSSIBLE VALUE OF THE FUNCTIONAL PROPERTIES OF PROTEIN CONCENTRATE MODIFIED BY THERMAL DENATURATION

Name of indicator	**Indicator value, %**	**Thermal modification parameters**	
	max	***temperature, °C***	***oiliness, %***
WHC	228,98	60,0	42,0
FHC	173,00	60,0	39,9
FEC	83,81	35,5	42,0

The solution to the optimization problem (6)-(7) for protein concentrate modified by thermal denaturation is presented in table 7.

TABLE VII. THERMAL MODIFICATION PARAMETERS OF PROTEIN CONCENTRATE

Name of indicator	**Indicator value, %**	**Thermal modification parameters**	
	max	***temperature, °C***	***oiliness, %***
K	86,91	60	42
WHC	228,98		
FHC	155,65		
FEC	77,17		

IV. THE DISCUSSION OF THE RESULTS

It has been established that when the protein concentrate is heated for 20 minutes at a temperature of 60 °C, it increases the WHC and FHC; the maximum value of the Emu is observed at 35.5 °C. Complex regulation of the functional properties of protein products from sesame seeds is observed upon heating for 20 min at a temperature of 60 °C and oil content of 42 %.

V. CONCLUSION

As a result, functional properties of protein are increased, which play a large role in formation of organoleptic properties and biological value of flour culinary and confectionary products, main hot dishes, etc., which include thermal modified protein products of sesame seeds (Table 7).

Heat treatment of seeds is accompanied by deep structural changes in their protein complex. As a result of loosening caused by thermal exposure, proteins become more accessible to proteolytic enzymes. Loosening of the structure is associated with an increase in the protein globule, as a result of which the viscosity of the solutions of the globule increases. As a result, the functional properties of the protein are increased, which play a large role in the formation of the organoleptic properties and biological value of flour culinary and confectionery products, main hot dishes, etc., which include thermal modified protein products of sesame seeds (table 8).

TABLE VIII. RECOMMENDATIONS FOR THE USE OF PROTEIN PRODUCTS FROM SESAME SEEDS

Protein product	Functional property	Efficient use
Full fat flour	Viscosity Emulsification Color control	Soups, sauces Sausages, cakes, ice cream Bakery products
Protein concentrate	Gelation Foaming ability	Meat, cottage cheese, cheeses, jelly Whipped creams, whipped protein desserts

The use of vegetable protein is advantageous in the manufacture of food products, as it increases the economic efficiency of production due to the low cost of plant components.

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