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JUSTIFICATION OF THE OPTIMAL RATIO OF INGREDIENTS IN COOKED POULTRY SAUSAGES USING MATHEMATICAL PROCESSING METHODS

Abstract. This study determined optimal ingredient ratios in cooked turkey sausage using mathematical processing methods, focusing on apple pomace powder as a functional ingredient. A Design of Experiments approach used four factors: apple pomace powder (3-8%), turkey skin (20-30%), salt (1.6-2.5%), and cooking temperature (70-80°C). Responses included cooking yield, lightness, production cost, total microbial count, and sensory score. Statistical analysis used ANOVA, regression modeling, and contour plots. The factors significantly affected technological and quality parameters. Optimization predicted optimal conditions of 7.75% apple pomace powder, 30% turkey skin, 2.5% salt, and 70°C cooking temperature, yielding cooking yield 96.86%, lightness 77.63, texture 68.58, sensory score 6.92, and production cost 1588 tenge. Mathematical modeling effectively optimized sausage formulations, with apple pomace powder improving properties while maintaining quality and reducing costs.

Keywords: ingredient optimization; design of experiments (DOE); mathematical modeling; response surface methodology; regression analysis.

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Introduction. In modern food production, scientific approaches are increasingly used to optimize product formulations in order to improve quality, extend shelf life, and increase economic efficiency. Mathematical data processing plays an important role in both scientific research and industrial production because it allows objective evaluation of how different factors influence the final product. Mathematical modeling helps identify the most effective combination of ingredients, providing a balance between product quality and production cost while reducing subjectivity in manual evaluation. It also allows prediction of changes in product characteristics when technological parameters are modified, which

supports more efficient process management. Justifying the optimal ratio of ingredients is particularly important in the meat industry, as it directly affects product quality, safety, and consumer acceptance. In cooked poultry sausages, ingredient proportions influence technological properties such as texture, water-holding capacity, flavor, nutritional value, and shelf life. Proper optimization also supports economic efficiency by improving raw material utilization and reducing production costs. In addition, it helps producers meet food safety standards and respond to consumer demand for healthier and "clean-label" meat products containing fewer synthetic additives and more natural ingredients [1-5]. Mathematical processing methods, including experimental design and statistical software such as Minitab, are widely applied to optimize sausage formulations. These methods allow systematic variation of ingredient ratios, statistical evaluation of response variables, and the development of regression models that describe the relationship between formulation factors and product quality parameters. Such approaches have been successfully used to study the influence of various functional ingredients on technological and sensory properties of sausage products [6-8].

The aim of this study was to determine the optimal ratio of ingredients in a new formulation of cooked turkey sausage using mathematical analysis. Particular attention was given to the use of apple pomace powder as a functional ingredient that may improve the technological properties of the product while simultaneously reducing production cost.

Materials and methods. To investigate the quality characteristics of raw materials and food products, standard methods for determining the physicochemical composition were applied, including: yield of the finished product, lightness (color parameter), sensory evaluation, cost calculation, and microbiological analysis. Sensory evaluation of the products was carried out using a 9-point hedonic scale.

In order to produce cooked sausage from turkey meat, which is characterized by high nutritional and biological value, the influence of the amount of plant additive, turkey meat, and turkey skin on product yield, sensory characteristics, and shelf life was studied using the method of mathematical experimental design. Therefore, the development of an experimental design matrix was considered appropriate (Table 1).

To achieve the objectives of the study, an experimental design matrix was developed, including four factors, each studied at two levels:

X_1 – amount of apple pomace powder, % (low level: 3% and high level: 8%);

X_2 – amount of turkey skin, % (low level: 20% and high level: 30%);

X_3 – salt content, % (low level: 1.6% and high level: 2.5%);

X_4 – cooking temperature, °C (low level: 70°C and high level: 80°C)

The selection of two levels for each factor makes it possible to evaluate not only the main effects but also the interactions between factors. This approach allows a deeper understanding of how changes in one ingredient influence the effects of other components. In addition, it enables the investigation of the influence of each ingredient on different product characteristics such as product yield, redness, production cost, texture, and sensory attributes, as well as the identification of optimal ingredient ratios ensuring high product quality and economic efficiency.

Table 1

Experimental design matrix for cooked turkey sausage

Std Order	Run Order	X_1 Pomace	X_2 Skin	X_3 Salt	X_4 Temp	X_1	X_2	X_3	X_4
1	1	3	20	1.6	70	-1	-1	-1	-1
2	2	8	20	1.6	70	1	-1	-1	-1
3	3	3	30	1.6	70	-1	1	-1	-1
4	4	8	30	1.6	70	1	1	-1	-1
5	5	3	20	2.5	70	-1	-1	1	-1
6	6	8	20	2.5	70	1	-1	1	-1
7	7	3	30	2.5	70	-1	1	1	-1
8	8	8	30	2.5	70	1	1	1	-1
9	9	3	20	1.6	80	-1	-1	-1	1
10	10	8	20	1.6	80	1	-1	-1	1
11	11	3	30	1.6	80	-1	1	-1	1
12	12	8	30	1.6	80	1	1	-1	1
13	13	3	20	2.5	80	-1	-1	1	1
14	14	8	20	2.5	80	1	-1	1	1
15	15	3	30	2.5	80	-1	1	1	1
16	16	8	30	2.5	80	1	1	1	1

X_1 (apple pomace powder): Apple pomace powder is a source of dietary fiber, which may improve texture and extend shelf life. It is important to determine the optimal level at which this ingredient does not negatively affect the sensory properties of the product, and the use of apple pomace, a by-product of apple processing, may reduce production costs.

X_2 (turkey skin): Turkey skin contributes fat and collagen, which may improve juiciness and texture of cooked sausages. However, it is necessary to determine the optimal proportion in order to avoid excessive fat content. Moreover, turkey skin is generally less expensive than meat, which can contribute to lowering the production cost.

X_3 (salt): Salt directly affects the taste of meat products, microbiological stability, water-binding capacity, and overall texture. An insufficient amount of salt makes the product taste bland, while excessive amounts may negatively affect health and deteriorate organoleptic properties.

X_4 (temperature): Temperature is an important parameter of heat treatment and directly influences the thermal stability, microbiological safety, and yield of meat products.

These proportions were selected based on preliminary studies, consultations with food technologists, and existing formulations of similar products, ensuring the relevance and potential industrial applicability of the experimental results. The inclusion of these factors within the specified ranges allows achieving a balance between sensory characteristics, texture, nutritional value, and economic efficiency, which is essential for developing a competitive product for the market. The above considerations justify the selection of these factor levels in the experiment and allow obtaining reliable and practically significant results for the optimization of cooked turkey sausage formulation.

The optimization of turkey sausage formulation requires a detailed understanding of how various ingredients and processing conditions affect the final product. In this study, we utilized a Design of Experiments (DOE) approach to investigate the effects of four critical factors: apple pomace percentage, turkey skin percentage, salt concentration, and cooking temperature on the response variables.

The analysis was performed using Minitab software, and the results are presented in terms of coded coefficients for each factor.

The output parameters evaluated during the experiments included (Table 2):
Y_1 – cooking yield, %;
Y_2 –lightness;
Y_3 – production cost, tenge;
Y_4 – total microbial count;
Y_5 – sensory evaluation score.

Table 2

Factors and response variables used in the experimental design

Std Order	Run Order	X_1	X_2	X_3	X_4	Y_1 Yield	Y_2 Lightness	Y_3 Texture	Y_4 Sensory	Y_5 Price
1	2	3	4	5	6	7	8	9	10	11
1	1	-1	-1	-1	-1	96.5	79.18	70.1	7.2	1962
2	2	1	-1	-1	-1	95.3	76.5	68.5	6	1793
3	3	-1	1	-1	-1	97.3	80.3	65.5	7.5	1679
4	4	1	1	-1	-1	96.1	77.7	67.3	6.4	1510
5	5	-1	-1	1	-1	96.9	79.15	72.3	7.4	1932
6	6	1	-1	1	-1	95.8	76.3	69.8	6.6	1763
7	7	-1	1	1	-1	98	80.1	67.9	7.7	1649
8	8	1	1	1	-1	96.5	77.5	68.7	6.8	1480
9	9	-1	-1	-1	1	94.3	79	71.2	7	1962
10	10	1	-1	-1	1	94	76.7	69.1	5.8	1793
11	11	-1	1	-1	1	96.6	80.27	66.4	7.2	1679
12	12	1	1	-1	1	94.9	77.5	68	6	1510
13	13	-1	-1	1	1	95.8	79	73.2	7.1	1932
14	14	1	-1	1	1	94.3	76	70.1	6.5	1763
15	15	-1	1	1	1	97.2	80.05	68.5	7.5	1649
16	16	1	1	1	1	95.5	77.48	69.4	6.6	1480

Research results and discussion. The optimization of turkey sausage formulation requires a detailed understanding of how various ingredients and processing conditions affect the final product. In this study, we utilized a Design of Experiments (DOE) approach to investigate the effects of four critical factors: apple pomace percentage, turkey skin percentage, salt concentration, and cooking temperature on the cooking yield. The analysis was performed using Minitab Software, and the results are presented in terms of coded coefficients for each factor. Table 3 presents analysis of variance of four factor effects to Y_1-Y_5.

The model was statistically significant (p-value=0.000), showing the studied factors significantly affected cooking yield. The F-statistic of 44.36 exceeded the critical value, confirming factor significance.

Table 3

Analysis of variance of four factors effects

Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	2	3	4	5	6
Cooking yield					
Model	4	19.358	4.8394	44.36	0.000
Linear	4	19.358	4.8394	44.36	0.000
Pomace	1	6.502	6.5025	59.61	0.000

Table 3 (continued)

1	2	3	4	5	6
Skin	1	5.290	5.2900	48.49	0.000
Salt	1	1.563	1.5625	14.32	0.003
Temp	1	6.002	6.0025	55.02	0.000
Error	11	1.200	0.1091		
Total	15	20.558			
Lightness					
Model	4	33.8712	8.4678	487.24	0.000
Linear	4	33.8712	8.4678	487.24	0.000
Pomace	1	28.5423	28.5423	1642.35	0.000
Skin	1	5.1416	5.1416	295.85	0.000
Salt	1	0.1541	0.1541	8.86	0.013
Temp	1	0.0333	0.0333	1.92	0.194
Error	11	0.1912	0.0174		
Total	15	34.0624			
Texture					
Model	6	60.8000	10.1333	364.80	0.000
Linear	4	46.0677	11.5169	414.61	0.000
Pomace	1	0.1402	0.1402	5.05	0.051
Skin	1	31.9225	31.9225	1149.21	0.000
Salt	1	11.9025	11.9025	428.49	0.000
Temp	1	2.1025	2.1025	75.69	0.000
2-Way Interactions	2	13.7700	6.8850	247.86	0.000
Pomace*Skin	1	12.9600	12.9600	466.56	0.000
Pomace*Salt	1	0.8100	0.8100	29.16	0.000
Error	9	0.2500	0.0278		
Total	15	61.0500			
Sensory properties					
Model	5	5.14313	1.02863	200.71	0.000
Linear	4	4.52923	1.13231	220.94	0.000
Pomace	1	3.42736	3.42736	668.75	0.000
Skin	1	0.27562	0.27562	53.78	0.000
Salt	1	0.60063	0.60063	117.20	0.000
Temp	1	0.22563	0.22563	44.02	0.000
2-Way Interactions	1	0.14062	0.14062	27.44	0.000
Pomace*Salt	1	0.14062	0.14062	27.44	0.000
Error	10	0.05125	0.00513		
Total	15	5.19438			
Price					
Model	4	517047	129262	101.00	0.000
Linear	4	517047	129262	101.00	0.000
Pomace	1	139708	139708	109.16	0.000
Skin	1	362133	362133	282.95	0.000
Salt	1	9024	9024	7.05	0.022
Temp	1	6182	6182	4.83	0.050
Error	11	14078	1280		
Total	15	531125			

All factors (apple pomace powder, turkey skin, salt, temperature) significantly influenced cooking yield ($p<0.05$), with temperature and apple

pomace powder showing strongest effects (F=59.61 and 55.02). Turkey skin contributed substantially (F=48.49), while salt showed the least influence (F=14.32). The addition of apple pomace to meat products often increases cooking yield due to the ability of dietary fibers to bind water and fat, thereby reducing losses during thermal processing. For example, in lamb patties, cooking yield increased to 97.90% with the addition of 15% apple pomace [9]. In goshtaba products, apple pomace improved water- and fat-holding capacity, which also increased cooking yield [10]. Chicken sausages with apple pomace demonstrated a similar increase in yield up to 102.1% with 6% addition [11]. In buffalo meat patties, yield increased to 98.17% with 8% apple pomace [12]. However, in low-fat chicken nuggets, an increase in apple pomace content resulted in a decrease in yield, which was associated with reduced sodium chloride levels [13].

Sausage product lightness is an important quality attribute affecting consumer acceptance. Analysis of variance showed all factors significantly influenced lightness. Apple pomace powder had the strongest effect (F=1642.35, $p<0.001$), followed by turkey skin (F=295.85, $p<0.001$). Salt had a less pronounced but significant influence (F=8.86, p=0.013), while temperature's effect was not significant (F=1.92, p 0.194) within the studied range. Different types of apple pomace contain pigments that influence the color of meat products such as salami, chicken sausages, and chicken nuggets. Variations in color coordinates are important because color is one of the primary factors influencing consumer choice [14]. The addition of apple pomace also leads to reduced lightness, making the products darker. For instance, the lightness of sausages with 8% apple pomace decreased from 57.74 to 52.02 [15]. In goshtaba products, lightness decreased from 47.09 to 31.14 in raw form and from 49.74 to 35.99 after cooking with 5% apple pomace addition [10].

ANOVA results showed turkey skin had the greatest influence on sausage texture (F=1149.21, $p<0.001$), indicating its crucial role in structural properties. Salt significantly affected texture (F=428.49, $p<0.001$), influencing firmness and elasticity. Temperature impacted texture formation (F=5.69, $p<0.001$). The interaction «apple pomace powder×turkey skin» showed the strongest synergistic effect (= 466.56, $p<0.001$), while «apple pomace powder×salt» was also significant (F=29.16, $p<0.001$). The addition of apple pomace to meat products such as chicken sausages, nuggets, patties, and goshtaba affects various texture attributes, including hardness, cohesiveness, chewiness, and adhesiveness. These effects depend on the type and level of pomace as well as the fat content of the product. For instance, in chicken nuggets with 9% apple pomace, hardness increased from 48.59 to 60.24 [16], while in sausages with 2% pomace, hardness increased from 2.35 kg to 2.55 kg [17]. Mixing apple pomace with wheat bran also increased hardness from 26.85 to 44.83 [15]. In buffalo meat patties, the addition of 8% apple pomace increased hardness from 47.85 to 109.54 [12]. In contrast, in lamb products, hardness decreased with 15% pomace addition, which was explained by increased moisture retention and reduced protein binding [9]. In goshtaba products, hardness decreased from 189.924 to 143.202, which was associated with reduced fat content [10].

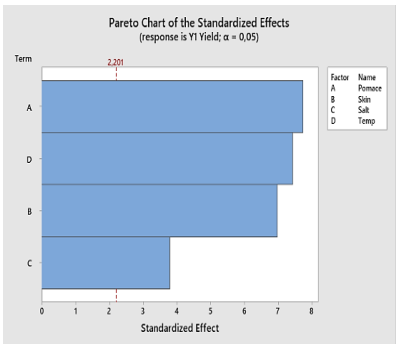
Apple pomace powder showed the strongest influence on sausage sensory properties (F=668.75), significantly affecting taste and texture. Turkey skin (F=53.78) and salt (F=117.20) were also important factors, while temperature had moderate influence (F=44.02). The interaction between apple pomace powder and salt (F=27.44) was notable. Thus, apple pomace powder most strongly affects sausage sensory characteristics by modifying flavor and texture, with salt and

turkey skin playing important roles. The addition of apple pomace generally improves color characteristics of meat products. In particular, the presence of apple peel in pomace enhances red color intensity, making sausages visually more attractive. Pollini et al. [14] reported improved color intensity in beef burgers with apple pomace, and similar findings were reported in chicken nuggets and sausages, where dried apple pomace enhanced redness [11,13]. Overall acceptability tends to decrease with increasing pomace content. Sausages containing moderate levels of apple pomace (up to 3%) received higher acceptability scores, indicating that lower inclusion levels are preferable for maintaining sensory quality. A similar trend was observed by Younis and Ahmad [12] in buffalo meat patties, where 6% apple pomace powder provided the highest overall acceptability. Higher pomace levels typically reduce acceptability due to negative effects on flavor and texture [10,18].

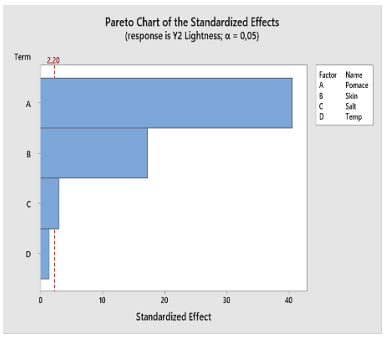
Apple pomace powder significantly influenced production cost, as shown by high adjusted sum of squares (139,708) and F-value (109.16, p=0.000), indicating substantial cost reduction potential. Turkey skin had the strongest effect (Adj SS=362,133; F=82.95; p=0.000), reducing costs due to its lower price compared to meat. Salt showed moderate cost impact (F=7.05, p=0.022), while temperature had the lowest but still significant effect (F=4.83, p=0.050) on production costs.

After completing the analysis of variance (ANOVA), the software calculated the effects of individual factors as well as their interaction effects. Pareto charts were used to visualize these effects and to determine which factors (or their interactions) were statistically significant. Figure 1 presents the Pareto charts of standardized effects of the factors influencing the response variables of cooked sausage (Y_1-Y_5). The charts display the standardized effect values for each factor: apple pomace powder (A), turkey skin (B), salt (C), and cooking temperature (D).

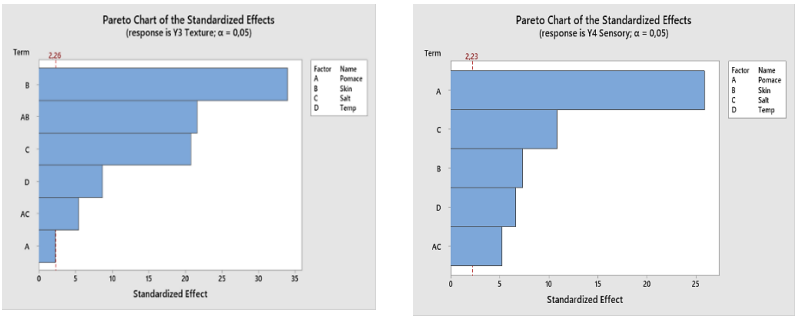
The red dashed line (α=0.05) represents the threshold of statistical significance. Factors whose effects exceed this line are considered statistically significant. Thus, using Pareto charts, the main factors influencing the yield of the finished product were identified. Among them, particular attention should be paid to those factors that are most important when optimizing the technology of cooked turkey sausage enriched with apple pomace powder. Optimization of the production process of cooked sausage products is a comprehensive approach aimed at improving product quality, yield, and economic efficiency through the effective selection of technological parameters and formulation composition.



a)

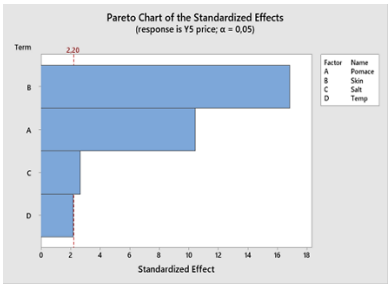


b)



c)

d)



e)

Fig. 1. Pareto charts of standardized effects of factors influencing the response variables (Y_1-Y_5) of cooked sausage: (a) yield of finished product; (b) lightness of cooked sausage; (c) texture of cooked sausage; (d) sensory characteristics of cooked sausage; (e) production cost of cooked sausage

The coded coefficients describing the influence of four factors on the response variables of cooked sausage products are presented in Table 4.

Table 4

Coded coefficients of the influence of four factors on the response variables of cooked sausage products

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
1	2	3	4	5	6	7
Cooking yield						
Constant		95.7292	0.0992	964.63	0.000	
Pomace	-1.2750	-0.6375	0.0826	-7.72	0.000	1.00
Skin	1.1500	0.5750	0.0826	6.96	0.000	1.00
Salt	1.042	0.521	0.138	3.78	0.003	1.00
Temp	-1.2250	-0.6125	0.0826	-7.42	0.000	1.00
Lightness						
Constant		78.3610	0.0396	1978.33	0.000	
Pomace	-2.6712	-1.3356	0.0330	-40.53	0.000	1.00
Skin	1.1337	0.5669	0.0330	17.20	0.000	1.00
Salt	-0.3271	-0.1635	0.0549	-2.98	0.013	1.00
Temp	-0.0913	-0.0456	0.0330	-1.38	0.194	1.00
Texture						
Constant		68.5500	0.0501	1368.89	0.000	
Pomace	-0.2250	-0.1125	0.0501	-2.25	0.051	1.44
Skin	-2.8250	-1.4125	0.0417	-33.90	0.000	1.00
Salt	2.8750	1.4375	0.0694	20.70	0.000	1.00
Temp	0.7250	0.3625	0.0417	8.70	0.000	1.00

Table 4 (continued)

1	2	3	4	5	6	7
Pomace*skin	1.8000	0.9000	0.0417	21.60	0.000	1.00
Pomace*salt	-0.7500	-0.3750	0.0694	-5.40	0.000	1.44
Sensory properties						
Constant		6.7021	0.0215	311.58	0.000	
Pomace	-1.1125	-0.5563	0.0215	-25.86	0.000	1.44
Skin	0.2625	0.1313	0.0179	7.33	0.000	1.00
Salt	0.6458	0.3229	0.0298	10.83	0.000	1.00
Temp	-0.2375	-0.1188	0.0179	-6.64	0.000	1.00
Pomace*salt	0.3125	0.1562	0.0298	5.24	0.000	1.44
Price						
Constant		1842.4	10.7	171.40	0.000	
Pomace	-186.89	-93.44	8.94	-10.45	0.000	1.00
Skin	-300.89	-150.44	8.94	-16.82	0.000	1.00
Salt	-79.2	-39.6	14.9	-2.66	0.022	1.00
Temp	-39.31	-19.66	8.94	-2.20	0.050	1.00

Multiple regression is described by Equations (1) and (2):

a) for the case of two factors:

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\varepsilon, \quad (1)$$

b) for the case of several factors:

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_nx_n+\varepsilon, \quad (2)$$

where: y – dependent variable (model output or response); x_1, x_2, …, x_n – independent variables (factors); β_0 – intercept (constant term); β_1, β_2, …, β_n – regression coefficients; ε – random error (residual).

n multiple regression analysis, interaction effects are often described by Equation (3).

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_{12}(x_1\times x_2)+\cdots+\varepsilon. \quad (3)$$

In this equation, terms such as $x_i \times x_j$ (interaction terms) represent the combined influence of factors on each other.

To describe the influence of each factor on the response variables of cooked sausage products, regression equations in uncoded units were used. In this model, each of the regression equations presented below describes the relationship between the four factors (apple pomace powder, turkey skin, salt, and cooking temperature) and the corresponding response parameter of the cooked sausage product.

1) The yield of the finished product (Y_1) was determined using Equation (4):

$$Y_1=95{,}7292 - 0{,}6375\,X_{pomace} + 0{,}5750\,X_{skin} + 0{,}521\,X_{salt} - 0{,}6125\,X_{temp}, \quad (4)$$

where: Y_1 – cooking yield, %. X_{pomace}, X_{skin}, X_{salt}, X_{temp} – coded means of factors (-1-1-1 low level, +1+1+1 high level).

2) The lightness of the cooked sausage product (Y_2) was determined using Equation (5).

$$Y_2=78,3610 - 1,3356\,X_{pomace} + 0,5669\,X_{skin} - 0,1635\,X_{salt} - 0,0456\,X_{temp} \quad (5)$$

3) The texture of the cooked sausage product (Y_3) was determined using Equation (6). In this model, the interaction effects «apple pomace×skin» and «apple pomace×salt» were included.

$$Y_3= 68,5500 - 0,1125\,X_{pomace} - 1,4125\,X_{skin}+ 1,4375\,X_{salt} + 0,3625\,X_{temp}+ 0,9000\,(X_{pomace}\times X_{skin}) - 0,3750\,(X_{pomace}\times X_{salt}. \quad (6)$$

4) The sensory characteristics of the cooked sausage product (Y_4) were determined using Equation (7). In this model, the interaction «apple pomace×salt» was included.

$$Y_4= 6,7021 - 0,5563\,X_{pomace} + 0,1313\,X_{salt}+ 0,3229\,X_{salt} - 0,1188\,X_{temp} + 0,1562\,(X_{pomace}\times X_{salt}). \quad (7)$$

5) The production cost of the cooked sausage product (Y_5) was determined using Equation (8).

$$Y_5=1842,4 - 93,44\,X_{pomace} - 150,44\,X_{skin}- 39,60\,X_{salt} - 19,66\,X_{temp} \quad (8)$$

Figure 2 presents contour plots illustrating the effects of four factors (apple pomace powder, turkey skin, salt, and temperature) on the response variables (Y_1–Y_5) of cooked sausage products. In these diagrams, the values of the remaining variables are fixed at a certain level, while the responses are plotted as a function of variations in two factors. The color scale in the diagrams represents the range of finished product yield from below 94.5% (light green area) to above 96.5% (dark green area).

These contour plots were generated based on the regression equations obtained for coded variables after analysis of variance (ANOVA). The program calculated the response values (Y_1–Y_5) for each pair of factors while keeping the other factors at their average levels and displayed the trends graphically.

Cooking yield (Y_1): Increasing the amount of apple pomace powder and increasing the temperature leads to a decrease in the cooking yield of the finished product. Increasing the concentration of turkey skin and salt leads to an increase in the cooking yield of the finished product.

Lightness (Y_2): Increasing the amount of apple pomace powder significantly reduces the lightness of the sausage, while increasing the proportion of turkey skin enhances it. Salt slightly decreases the lightness of the sausage, whereas temperature does not have a significant effect on this parameter.

Texture (Y_3): Apple pomace powder shows a slight negative effect that is not statistically significant. Turkey skin significantly deteriorates the texture. Salt, on the contrary, improves the texture. The influence of temperature is relatively small.

Sensory characteristics (Y_4): Increasing the amount of apple pomace powder significantly decreases the sensory characteristics of the product. Turkey skin and salt significantly improve the sensory characteristics. Increasing the temperature negatively affects the taste and aroma of the product.

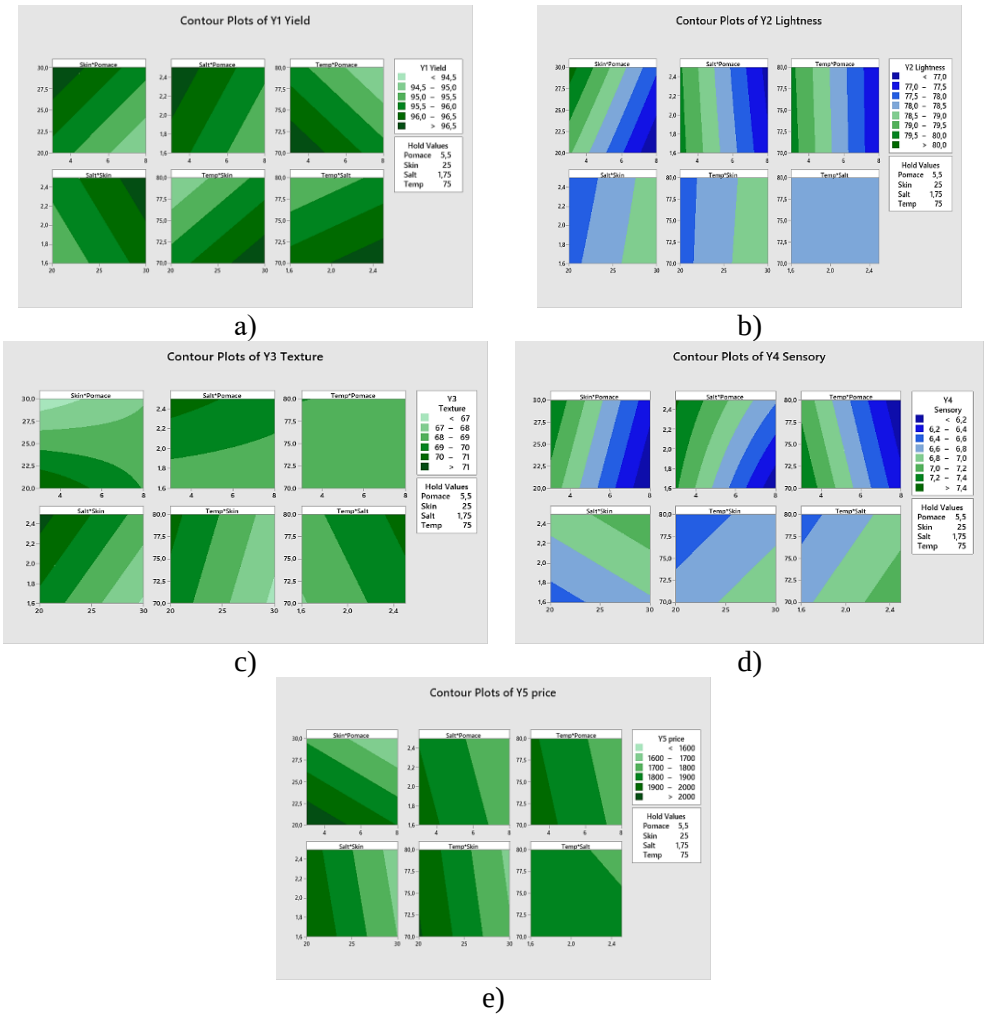


Fig. 2. Contour plots: (a) Y_1 (cooking yield); (b) Y_2 (lightness); (c) Y_3 (texture); (d) Y_4 (sensory characteristics); (e) Y_5 (production cost)

Price (Y_5): Both apple pomace powder and turkey skin significantly reduce the production cost of the finished product, with turkey skin having the strongest effect. Salt also slightly reduces the production cost. Temperature within the studied range has virtually no effect on the production cost.

The multiple response optimization (Table 5) shows that incorporating approximately 7.75% apple pomace powder together with 30% turkey skin, 2.5% salt, and a cooking temperature of 70°C provides a balanced formulation of cooked turkey sausage. Under these conditions, the product achieves high cooking yield, stable texture, acceptable sensory quality, appropriate color characteristics, and a reasonable production cost.

Thus, the mathematical optimization (Figure 3) approach effectively identifies formulation parameters that simultaneously satisfy technological, sensory, and economic criteria for cooked poultry sausage production.

Table 5

Multiple response prediction

Response	Fit	SE Fit	95% CI	95% PI
Y5 price	1588,0	19,6	(1544,8; 1631,2)	(1498,2; 1677,8)
Y4 Sensory	6,9154	0,0424	(6,8209; 7,0099)	(6,7300; 7,1008)
Y3 Texture	68,583	0,106	(68,344; 68,822)	(68,137; 69,030)
Y2 Lightness	77,63	*	(*; *)	(*; *)
Y1 Yield	96,864	0,181	(96,466; 97,263)	(96,035; 97,693)

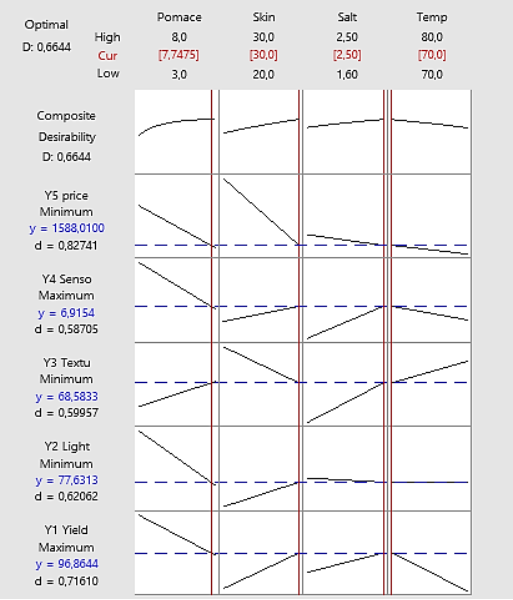


Fig. 3. Response optimization

Apple pomace powder is an inexpensive component that reduces the production cost, but it negatively affects the yield, lightness, and sensory characteristics of the finished product. Therefore, the optimal level of 7.75% was selected. Turkey skin was also shown to significantly reduce the production cost of cooked sausage products, while simultaneously increasing yield and lightness and improving flavor characteristics.However, it was found to have a negative effect on texture. Therefore, the optimal level of 30% was selected. Salt in 2.5% improves yield, texture, and sensory properties, although it slightly darkens the color of the finished product. At the same time, it is important to comply with technological and regulatory limits for salt content. As temperature increases, the yield and sensory characteristics of the finished product decrease, while its effect on color and texture is relatively small. Considering the juiciness and safety of the product, it became necessary to select an optimal range (70°C) of thermal processing.

Conclusion. Mathematical processing methods effectively optimize cooked poultry sausage formulation. Design of Experiments, regression analysis, ANOVA, and graphical tools enabled objective evaluation of technological and formulation factors on product quality. Apple pomace powder content, turkey skin level, salt concentration, and cooking temperature significantly affect cooking yield, lightness, texture, sensory quality, and cost. Optimal conditions were: 7.75% apple pomace powder, 30% turkey skin, 2.5% salt, and 70°C cooking temperature. These yielded 96.86% cooking yield, 77.63 lightness, 68.58 texture, 6.92 sensory score,

and 1588 tenge production cost. Results show apple pomace powder improves technological properties while maintaining sensory quality and reducing costs. Mathematical modeling proves reliable for optimizing meat product formulations.

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МАТЕМАТИКАЛЫҚ ӨҢДЕУ ӘДІСТЕРІН ҚОЛДАНА ОТЫРЫП ҚҰС ЕТІНЕН ДАЙЫНДАЛҒАН ПІСІРІЛГЕН ШҰЖЫҚТАҒЫ ИНГРЕДИЕНТТЕРДІҢ ОҢТАЙЛЫ ҚАТЫНАСЫН НЕГІЗДЕУ

Аңдатпа. Бұл зерттеуде математикалық өңдеу әдістерін қолдана отырып күркетауық етінен дайындалған пісірілген шұжық құрамындағы ингредиенттердің оңтайлы қатынасы анықталды. Зерттеуде функционалды ингредиент ретінде алма сығындысының ұнтағына ерекше назар аударылды. Эксперименттерді жоспарлау әдісі (Design of Experiments) қолданылып, төрт фактор зерттелді: алма сығындысының ұнтағы (3–8%), күркетауық терісі (20–30%), тұз (1,6–2,5%) және пісіру температурасы (70–80°C). Бағаланған көрсеткіштерге пісіру шығымы, ашықтық (L*), өндірістік өзіндік құны, микроорганизмдердің жалпы саны және сенсорлық бағалау нәтижелері кірді. Статистикалық талдау дисперсиялық талдау (ANOVA), регрессиялық модельдеу және контурлық графиктерді қолдану арқылы жүргізілді. Зерттелген факторлар пісірілген күркетауық шұжығының технологиялық және сапалық көрсеткіштеріне айтарлықтай әсер ететіні анықталды. Оңтайландыру нәтижесінде келесі оптималды шарттар анықталды: алма сығындысының ұнтағы – 7,75%, күркетауық терісі – 30%, тұз – 2,5% және пісіру температурасы – 70°C. Осы жағдайда болжамды нәтижелер: пісіру шығымы – 96,86%, ашықтық – 77,63, текстура – 68,58, сенсорлық бағалау – 6,92 балл және өндірістік өзіндік құны – 1588 теңге. Математикалық модельдеу шұжық өнімдерінің рецептурасын тиімді оңтайландыруға мүмкіндік беретіні анықталды. Алма сығындысының ұнтағын

қолдану өнімнің технологиялық қасиеттерін жақсартып, сапасын сақтай отырып өндіріс шығындарын азайтуға мүмкіндік береді.

Тірек сөздер: ингредиенттерді оңтайландыру; эксперименттерді жоспарлау (DOE); математикалық модельдеу; жауап беті әдістемесі; регрессиялық талдау.

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ОБОСНОВАНИЕ ОПТИМАЛЬНОГО СООТНОШЕНИЯ ИНГРЕДИЕНТОВ В ВАРЁНЫХ КОЛБАСАХ ИЗ МЯСА ПТИЦЫ С ИСПОЛЬЗОВАНИЕМ МЕТОДОВ МАТЕМАТИЧЕСКОЙ ОБРАБОТКИ

Аннотация. Оптимизация соотношения ингредиентов является важным условием повышения качества мясных продуктов и их экономической эффективности. Целью данного исследования было определение оптимального соотношения ингредиентов в варёной колбасе из мяса индейки с использованием методов математической обработки. Особое внимание было уделено применению порошка яблочных выжимок в качестве функционального ингредиента для улучшения свойств продукта и снижения его себестоимости. Для проведения исследования был применён метод планирования эксперимента (Design of Experiments, DOE), включающий четыре фактора на двух уровнях: порошок яблочных выжимок (3–8%), кожа индейки (20–30%), соль (1,6–2,5%) и температура варки (70–80°C). В качестве откликов рассматривались выход при тепловой обработке, светлота (L*), себестоимость производства, общее количество микроорганизмов и сенсорная оценка. Статистический анализ включал дисперсионный анализ (ANOVA), диаграммы Парето, регрессионное моделирование и построение контурных графиков. Результаты показали, что исследуемые факторы существенно влияют на технологические и качественные показатели варёной колбасы из индейки. Оптимизация по нескольким откликам позволила определить следующие оптимальные условия: 7,75% порошка яблочных выжимок, 30% кожи индейки, 2,5% соли и температура варки 70°C. При этих условиях прогнозируемые показатели составили: выход при тепловой обработке – 96,86%, светлота – 77,63, текстура – 68,58, сенсорная оценка – 6,92 балла, а себестоимость производства – 1588 тенге. Полученные результаты показывают, что математическое моделирование является эффективным инструментом для оптимизации рецептур колбасных изделий. Использование порошка яблочных выжимок способствует улучшению технологических свойств продукта при сохранении приемлемых сенсорных характеристик и снижении производственных затрат.

Ключевые слова: оптимизация ингредиентов; планирование эксперимента (DOE); математическое моделирование; метод поверхности отклика; регрессионный анализ.