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# Evaluation of Physicochemical and Textural Properties of Low-Fat and Low Sodium Imitation Pizza Cheese

**M. Mehraban Sangatash[1]*, M. Dadras-Moghadam[2], S.A. Mortazavi[3], H. Yarabbi[4]**

1- Food Quality and Safety Research Department, Food Science and Technology Research Institute, ACECR, Razavi Khorasan Province, Mashhad, Iran
(*- Corresponding Author Email: mehraban@acecr.ac.ir)
2- Department of Food Science and Technology, Islamic Azad University of Sabzevar, Sabzevar, Iran
3 and 4- Department of Food Science and Technology, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

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## Abstract

The increasing growth of cardiovascular diseases, high blood pressure, and hardening of the vessel walls as well as obesity in many countries has made low-fat and low sodium pizza cheese one of the subjects of study all over the world. The effects of four important independent variables including inulin (0-0.025 %), pre-gelatinized starch (0-0.5 %), NaCl (0.35-1%), and KCl (0.35-1%) were studied. The fat content of imitation pizza cheese was significantly decreased to 11.91% with the increased levels of inulin and starch substitution ($p<0.05$). Also, its moisture and pH values were significantly different ($p < 0.05$). The increased levels of pre-gelatinized starch and inulin reduced hardness (from 5.04 to 3.55) and adhesiveness (from 4368.89% to 1640.54%), however, increased cohesiveness (from 0.365 to 0.43) and springiness (from 0.456 to 0.545). NaCl and KCl increased the hardness of the product. Inulin and starch led to decrease the a* value. The b* value decreases with the increase of inulin and increases with the increase of modified starch. The formulation containing 0.19% inulin, 0.4% pre-gelatinized starch, 0.35% NaCl, and 0.50% KCl was found as the optimal formulation for low-fat imitation cheese. Results of scanning electron microscope (SEM) images revealed that inulin crystals were accumulated in the continuous phase, which this can lead to important changes in the sensory and textural properties. The study concludes that inulin or starch can be used to replace up to 3.6% of fat in the imitation pizza cheese and 0.35% NaCl-0.50% KCl to lower the sodium content of the product.

**Keywords:** Imitation pizza cheese, Inulin, Optimization, Pre-gelatinized starch

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## Introduction

Fat consumption is directly related to various diseases such as obesity, diabetes, hardening of blood vessels and blood pressure. In recent years, the demand for low-fat products has increased dramatically. Hence, the food industry is interested in reducing the fat content and using fat substitutes. In addition, it is important to improve the organoleptic characteristics and shelf life of the products (Shehata *et al.*, 2022). The development of flavor, texture and appearance of cheese is largely influenced by fat. Imitation pizza cheese is a relatively high-fat product, containing 20-27% fat (Bi *et al.*, 2016). Therefore, there is potential for formulating low-fat versions of this product. However, the decrease of fat from cheese leads to defects in texture, yield and taste, such as rubbery texture, lack of taste, bitterness, bad taste, poor meltability and unfavorable color (Żbikowska *et al.*, 2020). It is not easy to produce low-fat cheese with desirable characteristics. The challenge of using fat substitutes in cheese while maintaining the same functional and organoleptic properties of cheeses has attracted a lot of attention (de Souza Paglarini *et al.*, 2021). Fat substitutes are compounds with a protein or carbohydrate structure that can replace all or part of the fat and mimic some of its functional properties. They include starch, inulin, polydextrose and carboxymethyl cellulose. Inulin is a plant storage carbohydrate that has a linear chain of fructose molecules linked by 1-20 β-fructosyl bonds (Ruiz-Moyano *et al.*, 2019). Inulin also acts as a prebiotic, enhancing the probiotic bacteria in the human gut's microbiota and improving immune functions and calcium absorption (Tsatsaragkou *et al.*, 2021). Some of the benefits of prebiotic food include normalizing intestinal movements, helping to maintain intestinal health, reducing cholesterol levels, helping to control blood sugar levels and helping to achieve a healthy weight (Rosa *et al.*, 2021). To date, inulin has been successfully used as a partial fat replacer in fermented sausages (Glisic *et al.*, 2019), yogurt (Żbikowska *et al.*, 2020), soft white cheese (Shehata *et al.*, 2022), rice muffin (Amorim *et al.*, 2021), sponge cake (Krupa-Kozak *et al.*, 2020), biscuits (Tsatsaragkou *et al.*, 2021), and cookie (da Silva & Conti-Silva, 2018).

High amounts of sodium increase the risk of heart attack and high blood pressure. Different types of emulsifying salts such as: phosphate, citrate, tartrate, ammonium or potassium are used in the production of imitation cheese. The problem of high blood pressure caused by high sodium consumption should be reduced by using potassium chloride in food as a substitute for sodium chloride (Ayyash *et al.*, 2011). Replacing sodium chloride with potassium chloride has a significant effect on sensory properties such as bitterness, saltiness, hardness in the process of cheese. The aim of this study was to investigate the physicochemical, textural and sensory characteristics of imitation pizza cheese as a result of replacing potassium chloride with sodium chloride and using different amounts of inulin and modified starch as a fat substitute.

## Materials and Methods

### Materials

Hydrogenated soybean oil was prepared from Behpak Co. (Behshahr, Iran). Pre-gelatinized starch was obtained from Food Science and Technology Research Institute, ACECR (Mashhad, Iran). Inulin, sodium caseinate (90% protein), and all the solvents used in this research were procured from Sigma-Aldrich (USA) and Merck (Germany) Chemical Companies.

### Preparation of low- fat and low sodium imitation pizza cheese

Imitation cheese was prepared using the method described by Hennelly *et al.* (2006) with some modification. Briefly, 52 % w/w water, 14 % w/w hydrogenated soybean oil and 7 % w/w canola oil were mixed at 50 °C. Sodium chloride, potassium chloride, potassium sorbate and sodium phosphate were added to the water and oil mixture and mixing was done at 50 rpm and 80 °C for 1 minute (the temperature and stirring speed remained constant until the end of the production process). Then 24.5 % w/w sodium caseinate was added to the mixture, and the agitation was continued for about 15 min. After producing a homogeneous mass, pre-gelatinized starch (0-0.5 % w/w) and inulin (0-0.25 % w/w) were added and the mixing process was continued for 2 min. Citric acid (0.5 % w/w) was added and the final mixing was performed for 2 min. The produced imitation pizza cheeses were packaged in polypropylene containers and stored at 4 °C. The Formulation of produced imitation cheese was based on 52 % water, 24.5 % sodium caseinate, 21 % oil, 0.2 % potassium sorbate, 1.3 % sodium chloride, 0.5 % citric acid, and 0.5 % disodium phosphate (without considering independent variables).

## Chemical analysis

### pH

pH value was measured using a pH-meter (Cole-Parmer, EW-35419-10, USA) on a homogenate cheese/water (1:1) slurry (AOAC, 2000).

### Dry matter (DM)

Imitation cheese samples were dried in oven and DM content was measured using the method described by Bermúdez-Aguirre & Barbosa-Cánovas (2012).

### Fat

Fat content of prepared imitation cheese was measured using Gerber method (Kleyn *et al*., 2001).

### Salt

Salt measurement was done by potentiometric titration method (AOAC, 2000).

### Color analysis

The color properties of prepared imitation cheese samples (L*, a* and b* values) were studied using the method developed by Cunha *et al*. (2010).

### Textural analysis

Textural parameters were measured using the method described by Kiziloz *et al*. (2009) with some modification. Briefly, the texture was evaluated by using TA Plus texture analyzer (QTS25, CNS FARANEL, UK) equipped with a computer programmed with NEXYGEN 3 software. A cylindrical probe (35 mm in diameter) was attached to a 5 Kg compression load, while the target value was set at 20 mm with the speed of 100 mm/min. The Samples (15×15×15 $mm^3$) were placed into cylindrical vessel. The probe was set to penetrate in the samples up to 50% of their initial height. The texture profile analysis (TPA) that used in this study was based on the evaluation of instrumental hardness (the peak force estimated during the first compression cycle), instrumental cohesiveness (the ratio of the positive force area during the second compression to that during the first compression), instrumental adhesiveness (the negative force area of the first compression cycle), and springiness (the height or deformation food that goes back to the previous state during the end of first compression cycle and starting the second cycle).

### Determining microstructure

Samples were prepared for SEM by treating with $OsO_4$ (2%) for 24 h and followed by trimming to a 1-mm in thickness. In order to dissolve lipids, the samples were washed using toluene and followed by drying for overnight. SEM Images were taken from surface of the samples coated with gold at x500 and x300 magnifications by scanning electronic microscopy (SEM) (Cambriidge S360, US) (Marcellino & Benson, 1992).

### Sensory evaluation

The sensory properties of the product were evaluated by 10 trained individuals in terms of color, flavor, sweetness, hardness, and overall acceptance on a 5-point hedonic scale. In this test, the excellent sample scored 5, good 4, average 3, bad 2, and very bad 1(Kiziloz *et al*., 2009).

### Statistical analysis

A three level, four variables box behnken design was used to optimize with respect to four independent variables, namely inulin, starch, NaCl, and KCl. Table 1 shows the factors and their levels. The multiple regression equation was employed to fit the second-order polynomial equation based on the observed results as follows:

$$Y = \beta_{k0} + \sum_{i=1}^{4} \beta_{ki} x_i + \sum_{i=1}^{4} \beta_{kii} x_i^2 + \sum_{i<j=2}^{4} \beta_{kij} x_i x_j$$

Where $Y$ represents the predicted response; $\beta_{k0}, \beta_{ki}, \beta_{kii}$ and $\beta_{kij}$ represent regression coefficients; and $x_i$, $x_j$ are the coded independent factors. The models were compared based on $R^2$, $R^2$-adj, and $R^2$-pred. $R^2$ values closer to 1, indicate that the model is more accurate (Yolmeh & Najafzadeh, 2014). After selecting the most accurate model, the statistical significance of regression coefficients was investigated using the analysis of variance (ANOVA) by Dunkan's test at 95% confidence level. Surface plots were used to study the interactive effects of the independent variables (Yolmeh & Jafari, 2017).

The aim of the optimizing formulation of imitation cheese was to maximize the L*, b*, cohesiveness, springiness, and to minimize fat and adhesiveness with the same weight (w= 1). The validity of the optimum formulation was examined by the desirability values of the responses that ranged from 0 to 1. Values of desirability close to 1 indicate the most desirable and valid optimal formula (Ghorbannezhad *et al.*, 2016).

## Results and Discussion

### Fitting the response surface models

According to the design used in this study, 30 experiments were carried out and the observed results are shown in Table 1.

The values of $R^2$, $R^2$-adj and $R^2$-pred revealed that 2FI model was more adequate than other models for DM value of prepared imitation cheese samples; however, for fat and L* value, quadratic model was suitable. Cubic model had more accuracy on the other responses of prepared imitation cheese samples (Table 2). Lack-of-fit values of the selected models were insignificant (P>0.05) that shows suitability of the models to predict the responses (Table 3).

The significance of the selected models was evaluated through analysis of variance (ANOVA). A small P-value and a large F-value for each term in the models would show a much effect on the response (Esmaeili *et al.*, 2015). Therefore, quadratic term of NaCl ($C^2$), linear term of starch (B), ($C^2$), linear term of NaCl (C), interaction between starch and NaCl (BC), quadratic term of starch ($B^2$), interaction between quadratic term of inulin and KCl ($A^2D$), $A^2D$, $A^2D$, and $C^2$ had the most effect on pH, DM, fat, L*, a*, b* values, hardness, cohesiveness, springiness, and adhesiveness of low-fat imitation cheese, respectively (Table 3).

### Effects of independent variables on the responses

### pH

pH is an important characteristic that affects almost all quality parameters of cheese, including taste, texture, and appearance. So that the structure of cheese largely depends on the physicochemical state of the protein. It also depends on pH and ionic composition (Chatli *et al.*, 2019). Adding of dietary fiber like starch and inulin has a significant effect ($P < 0.05$) on various physicochemical parameters such as dry matter, fat, pH, texture and color (Fig. 1). pH value of low-fat imitation cheese was initially increased by adding starch up to 0.3%, but subsequently decreased to 5.66 (Fig. 1 (f)). On the other hand, the pH was increased to 5.7 by increasing NaCl content (Fig. 1 (a, c)).

**Table 1- The formulation and the experimental data for the responses**

| Formulation | Independent variables | | | | Dependent variables | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inulin (A) | Starch (B) | NaCl (C) | KCl (D) | pH | DM (%) | Fat (%) | L* | a* | b* | Hardness (N) | Cohesiveness | Springiness (mm) | Adhesiveness (Nm) |
| 1 | 0 | 0 | 0.675 | 0.675 | 5.6 | 50.3 | 22 | 76.7 | -2.4 | 17.2 | 1.611 | 0.410 | 0.5136 | 906.94 |
| 2 | 0.25 | 0 | 0.675 | 0.675 | 5.5 | 56.2 | 11 | 73.4 | -1.9 | 19.1 | 3.204 | 0.431 | 0.5311 | 1486.45 |
| 3 | 0.125 | 0.25 | 0.35 | 0.35 | 5.7 | 56.9 | 12 | 74.7 | -2.2 | 17.8 | 3.246 | 0.430 | 0.5351 | 1781.57 |
| 4 | 0.125 | 0.25 | 1 | 1 | 5.8 | 54.9 | 11 | 73.2 | -2.1 | 19.2 | 3.40 | 0.446 | 0.5544 | 1287.14 |
| 5 | 0.125 | 0.25 | 0.35 | 1 | 5.9 | 58.7 | 11 | 72.8 | -2.1 | 18.4 | 5.033 | 0.401 | 0.4905 | 4207.32 |
| 6 | 0.125 | 0.25 | 0.675 | 0.675 | 5.8 | 55.7 | 13 | 74.0 | -2.1 | 18.2 | 5.737 | 0.434 | 0.5356 | 4986.85 |
| 7 | 0.25 | 0.5 | 0.675 | 0.675 | 5.7 | 54.9 | 11 | 75.2 | -2.1 | 18.7 | 4.868 | 0.432 | 0.5456 | 2949.05 |
| 8 | 0 | 0.5 | 0.675 | 0.675 | 5.6 | 56 | 11 | 74.9 | -2.2 | 18.1 | 4.354 | 0.419 | 0.5302 | 3376.75 |
| 9 | 0.125 | 0.25 | 1 | 0.35 | 5.7 | 56.6 | 5.6 | 73.4 | -1.9 | 19.0 | 3.825 | 0.423 | 0.5317 | 2569.21 |
| 10 | 0.125 | 0.25 | 0.675 | 0.675 | 5.7 | 54.6 | 11 | 75.1 | -2.1 | 18.3 | 3.777 | 0.405 | 0.5065 | 1551.24 |
| 11 | 0 | 0.25 | 0.675 | 1 | 5.5 | 54.6 | 12 | 74.7 | -2.3 | 18.4 | 5.837 | 0.453 | 0.5545 | 3014.23 |
| 12 | 0.25 | 0.25 | 0.675 | 1 | 5.6 | 53.9 | 16 | 75.2 | -2.1 | 18.5 | 4.901 | 0.457 | 0.5683 | 2599.84 |
| 13 | 0.125 | 0 | 0.35 | 0.675 | 5.9 | 59.1 | 10 | 72.2 | -2.3 | 17.5 | 3.256 | 0.410 | 0.5106 | 1946.66 |
| 14 | 0.25 | 0.25 | 0.675 | 0.35 | 5.7 | 57.5 | 7.2 | 72.6 | -2.5 | 17.4 | 4.111 | 0.400 | 0.5023 | 3011.95 |
| 15 | 0 | 0.25 | 0.675 | 0.35 | 5.9 | 57.2 | 12 | 73.9 | -2.1 | 18.3 | 6.668 | 0.365 | 0.4556 | 5655.23 |
| 16 | 0.125 | 0 | 1 | 0.675 | 5.6 | 49.8 | 13 | 74.6 | -2.5 | 18.9 | 9.495 | 0.507 | 0.6337 | 4051.85 |
| 17 | 0.125 | 0.5 | 0.35 | 0.675 | 5.8 | 57.3 | 7.2 | 73.2 | -2.3 | 18.1 | 3.5033 | 0.411 | 0.5101 | 1811.50 |
| 18 | 0.125 | 0.25 | 0.675 | 0.675 | 5.6 | 52.1 | 10 | 72.7 | -2.4 | 18.3 | 6.085 | 0.446 | 0.5541 | 2630.29 |
| 19 | 0.125 | 0.25 | 0.675 | 0.675 | 5.4 | 53.9 | 7.2 | 73.5 | -2.4 | 18.2 | 7.162 | 0.443 | 0.5544 | 2429.96 |
| 20 | 0.125 | 0.5 | 1 | 0.675 | 5.6 | 54.5 | 12 | 73.5 | -2.4 | 18.5 | 4.742 | 0.478 | 0.6019 | 1803.64 |
| 21 | 0 | 0.25 | 1 | 0.675 | 5.6 | 52.3 | 13 | 72.5 | -2.5 | 18.2 | 5.689 | 0.441 | 0.5472 | 2616.72 |
| 22 | 0 | 0.25 | 0.35 | 0.675 | 5.8 | 52.6 | 4.8 | 71.1 | -2.3 | 19.3 | 5.379 | 0.464 | 0.5752 | 3059.71 |
| 23 | 0.125 | 0 | 0.675 | 1 | 5.6 | 53.2 | 12 | 74.3 | -2.4 | 18.4 | 9.960 | 0.476 | 0.5956 | 5958.05 |
| 24 | 0.125 | 0.25 | 0.675 | 0.675 | 5.9 | 57.4 | 6 | 74.3 | -2.2 | 17.8 | 2.328 | 0.381 | 0.4766 | 1239.42 |
| 25 | 0.25 | 0.25 | 1 | 0.675 | 5.7 | 52.8 | 9 | 73.5 | -2.6 | 18.1 | 4.445 | 0.448 | 0.5409 | 1614.61 |
| 26 | 0.125 | 0.25 | 0.675 | 0.675 | 5.7 | 57.8 | 14 | 73.5 | -2.3 | 17.4 | 1.355 | 0.359 | 0.4365 | 693.42 |
| 27 | 0.125 | 0 | 0.675 | 0.35 | 5.7 | 58.2 | 12 | 73.5 | -2.3 | 18.1 | 7.439 | 0.443 | 0.5571 | 6153.85 |
| 28 | 0.125 | 0.5 | 0.675 | 0.35 | 5.7 | 53.1 | 6.8 | 72.6 | -2.2 | 18.5 | 4.477 | 0.413 | 0.5111 | 1647.70 |
| 29 | 0.125 | 0.5 | 0.675 | 1 | 5.3 | 50.5 | 15 | 72.1 | -2.8 | 17.2 | 4.711 | 0.436 | 0.5468 | 1501.29 |
| 30 | 0.25 | 0.25 | 0.35 | 0.675 | 5.7 | 52.7 | 7.2 | 72.2 | -2.5 | 17.8 | 5.394 | 0.401 | 0.5012 | 3894.85 |

**Table 2- The statistics of the four fitted models**

| Models | Statistics | Responses | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | DM | Fat | L* | a* | b* | Hardness | Cohesiveness | Springiness | Adhesiveness |
| Linear | | | | | | | | | | | |
| | $R^2$ | 71.76 | 46.09 | 26.74 | 30.74 | 40.14 | 26.69 | 19.31 | 19.71 | 35.24 | 30.35 |
| | $R^2$-adj | 62.11 | 35.31 | 17.26 | 19.08 | 28.79 | 18.46 | 12.63 | 12.62 | 26.73 | 16.15 |
| | $R^2$-pred | 46.75 | 31.62 | 9.02 | 10.12 | 10.33 | 7.68 | 5.58 | 4.22 | 19.27 | 7.45 |
| 2FI | | | | | | | | | | | |
| | $R^2$ | 62.21 | 84.69 | 42.94 | 38.51 | 61.84 | 42.19 | 57.57 | 44.71 | 47.71 | 35.61 |
| | $R^2$-adj | 46.12 | 76.25 | 37.08 | 27.98 | 55.25 | 36.65 | 42.76 | 31.57 | 39.57 | 21.08 |
| | $R^2$-pred | 13.80 | 57.50 | 23.32 | 13.55 | 35.11 | 24.41 | 29.61 | 20.67 | 11.80 | 9.24 |
| Quadratic | | | | | | | | | | | |
| | $R^2$ | 85.99 | 71.91 | 90.15 | 67.82 | 67.34 | 57.32 | 55.94 | 27.32 | 68.03 | 74.62 |
| | $R^2$-adj | 73.26 | 59.94 | 78.64 | 55.26 | 58.33 | 58.32 | 24.46 | 19.54 | 57.38 | 60.35 |
| | $R^2$-pred | 58.54 | 34.68 | 54.67 | 44.08 | 25.16 | 48.25 | 18.91 | 9.13 | 39.26 | 49.61 |
| Cubic | | | | | | | | | | | |
| | $R^2$ | 89.62 | 69.03 | 71.83 | 87.65 | 88.64 | 80.32 | 75.45 | 68.45 | 78.48 | 88.90 |
| | $R^2$-adj | 80.15 | 46.87 | 59.46 | 82.74 | 73.69 | 64.31 | 68.78 | 59.14 | 76.94 | 91.72 |
| | $R^2$-pred | 69.67 | 22.18 | 34.08 | 24.73 | 61.43 | 38.87 | 50.34 | 40.02 | 46.31 | 88.65 |

pH value of low-fat imitation cheese was initially increased by adding KCl. The pH value was gently increased and then decreased by increasing inulin content. Increasing the initial pH and decreasing the final pH could be related to the nature of inulin and hydrolysis of inulin, respectively (Fig. 1 (d)) (Mensink *et al.*, 2016). The results showed that lowest pH (5.2) and highest pH (5.39) were belonged to full fat cheese and higher concentration of inulin, respectively. Abbasi & Nateghi (2022) reported that the pH of low-fat pizza cheese decreased with increasing the amount of pregelatinized corn starch in the formulation, which could be related to the increase in the acidity of the cheese in these conditions. Shabani *et al.* (2013) showed that the addition of white cheese as a substitute in processed pizza cheese caused a significant decrease in pH. The reason was that white cheese had a lower pH than processed pizza cheese. The pH range of 5.1-6.6 is the best choice for processed cheese, as it promotes protein formation and hydration, emulsifier solubility, and calcium ion confinement. Similar research results show that cheese samples having higher concentration of fiber had less acidity due to increased pH. The pH values of low-fat cheeses were slightly higher than that of full-fat cheese throughout cheese ripening (Karahanal, 2011; Lashkari *et al.*, 2014).

**Table 3- Variance analysis of the responses**

| | pH | | | | DM | | | | Fat | | | | L* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **DF** | **Mean of squares (MS)** | **F** | **P** | **DF** | **MS** | **F** | **P** | **DF** | **MS** | **F** | **P** | **DF** | **MS** | **F** | **P** |
| Model | 22 | 0.012 | 6.23 | 0.0256 | 14 | 5.24 | 2.72 | 0.033 | 14 | 16.611 | 2.71 | 0.040 | 14 | 1.63 | 2.98 | 0.0283 |
| Inulin (A) | 1 | 0.003 | 1.57 | 0.2651 | 1 | 0.19 | 0.48 | 0.500 | 1 | 14.963 | 2.44 | 0.142 | 1 | 0.34 | 0.62 | 0.4466 |
| Starch (B) | 1 | 0.036 | 18.83 | 0.0074 | 1 | 17.3 | 9.00 | 0.008 | 1 | 24.083 | 3.93 | 0.069 | 1 | 0 | 0 | 1 |
| NaCl (C) | 1 | 0.036 | 18.83 | 0.0074 | 1 | 13.67 | 7.12 | 0.016 | 1 | 10.830 | 1.77 | 0.206 | 1 | 11.41 | 20.88 | 0.0005 |
| KCl (D) | 1 | 0.036 | 18.83 | 0.0074 | 1 | 9.74 | 5.07 | 0.038 | 1 | 38.163 | 6.23 | 0.026 | 1 | 0.6 | 1.1 | 0.3126 |
| $A^2$ | 1 | 0.039 | 20.44 | 0.0063 | 1 | – | – | – | 1 | 0.017 | 0.01 | 0.958 | 1 | 0.067 | 0.12 | 0.7321 |
| $B^2$ | 1 | 0.06 | 31.14 | 0.0025 | 1 | – | – | – | 1 | 4.388 | 0.71 | 0.413 | 1 | 2.45 | 4.48 | 0.0542 |
| $C^2$ | 1 | 0.062 | 32.21 | 0.0024 | 1 | – | – | – | 1 | 46.354 | 7.56 | 0.016 | 1 | 1.22 | 2.24 | 0.1584 |
| $D^2$ | 1 | 0.036 | 18.88 | 0.0074 | 1 | – | – | – | 1 | 1.7142 | 0.28 | 0.606 | 1 | 0.01 | 1.68 | 0.217 |
| AB | 1 | 0.054 | 28.31 | 0.0031 | 1 | 2.96 | 1.54 | 0.2316 | 1 | 30.25 | 4.93 | 0.045 | 1 | 0.053 | 0.097 | 0.7606 |
| AC | 1 | 0.046 | 24.03 | 0.0045 | 1 | 0.72 | 0.38 | 0.5479 | 1 | 10.240 | 1.67 | 0.219 | 1 | 1.03 | 1.89 | 0.193 |
| AD | 1 | 0.036 | 18.95 | 0.0073 | 1 | 2.48 | 1.29 | 0.2717 | 1 | 19.360 | 3.16 | 0.099 | 1 | 0 | 0 | 1 |
| BC | 1 | 0.037 | 19.04 | 0.0073 | 1 | 0.008 | 0.44 | 0.5181 | 1 | 0.810 | 0.13 | 0.722 | 1 | 0.02 | 0.39 | 0.5445 |
| BD | 1 | 0.037 | 19.15 | 0.0072 | 1 | 3.69 | 1.92 | 0.184 | 1 | 16.810 | 2.74 | 0.121 | 1 | 0.98 | 1.79 | 0.2034 |
| CD | 1 | 0.062 | 32.15 | 0.0024 | 1 | 0.044 | 0.023 | 0.8814 | 1 | 10.240 | 1.67 | 0.218 | 1 | 2.84 | 5.2 | 0.0402 |
| $A^2B$ | 1 | 0.039 | 20.18 | 0.0064 | – | – | – | – | – | – | – | – | – | – | – | – |
| $A^2C$ | 1 | 0.04 | 20.78 | 0.0061 | – | – | – | – | – | – | – | – | – | – | – | – |
| $A^2D$ | 1 | 0.045 | 23.22 | 0.0048 | – | – | – | – | – | – | – | – | – | – | – | – |
| $AB^2$ | 1 | 0.037 | 19 | 0.0073 | – | – | – | – | – | – | – | – | – | – | – | – |
| $AC^2$ | 1 | 0.037 | 19 | 0.0073 | – | – | – | – | – | – | – | – | – | – | – | – |
| $AD^2$ | 0 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $B^2C$ | 1 | 0.037 | 19 | 0.0073 | – | – | – | – | – | – | – | – | – | – | – | – |
| $B^2D$ | 1 | 0.037 | 19 | 0.0073 | – | – | – | – | – | – | – | – | – | – | – | – |
| $BC^2$ | 1 | 0.039 | 19 | 0.0073 | – | – | – | – | – | – | – | – | – | – | – | – |
| $BD^2$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $C^2D$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $CD^2$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $A^3$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $B^3$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Residual error | 5 | 0.002 | – | – | 17 | 1.92 | – | – | 13 | 6.128 | – | – | 13 | 0.55 | – | – |
| Lack of fit | 2 | 0.002 | 1.14 | 0.427 | 14 | 0.001 | 0.37 | 0.914 | 10 | 7.017 | 2.21 | 0.278 | 10 | 0.65 | 3.47 | 0.167 |
| Pure error | 3 | 0.002 | – | – | 3 | 3.99 | – | – | 3 | 3.166 | – | – | 3 | 0.19 | – | – |
| Total | 29 | – | – | – | 29 | -– | – | – | 29 | – | – | – | 29 | – | – | – |

Table 3- Variance analysis of the responses (Continued)

| | a* | | | | b* | | | | Hardness | | | | Cohesiveness | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | DF | MS | F | P | DF | MS | F | P | DF | MS | F | P | DF | MS | F | P |
| Model | 22 | 0.024 | 5.46 | 0.034 | 22 | 0.23 | 18.24 | 0.0022 | 22 | 1.3 | 6.73 | 0.0217 | 22 | 0.028 | 5.1 | 0.0393 |
| Inulin (A) | 1 | 0.005 | 1.28 | 0.31 | 1 | 0.260 | 20.21 | 0.0064 | 1 | 0.04 | 2.27 | 0.1921 | 1 | 0.057 | 25.29 | 0.004 |
| Starch (B) | 1 | 0.065 | 14.72 | 0.0122 | 1 | 0.76 | 59.99 | 0.0006 | 1 | 4.71 | 24.33 | 0.0044 | 1 | 0.280 | 39.07 | 0.0015 |
| NaCl (C) | 1 | 0.065 | 14.72 | 0.0122 | 1 | 0.76 | 59.99 | 0.0006 | 1 | 0.004 | 24.33 | 0.0044 | 1 | 0.440 | 39.07 | 0.0015 |
| KCl (D) | 1 | 0.065 | 14.72 | 0.0122 | 1 | 0.76 | 59.99 | 0.0006 | 1 | 0.004 | 24.33 | 0.0044 | 1 | 0.440 | 39.07 | 0.0015 |
| $A^2$ | 1 | 0.160 | 35.88 | 0.0019 | 1 | 0.79 | 62.56 | 0.0005 | 1 | 4.73 | 24.43 | 0.0043 | 1 | 0.440 | 47.43 | 0.001 |
| $B^2$ | 1 | 0.067 | 15.24 | 0.0114 | 1 | 1.46 | 116.07 | 0.0001 | 1 | 0.006 | 32.62 | 0.0023 | 1 | 0.530 | 39.21 | 0.0015 |
| $C^2$ | 1 | 0.065 | 14.72 | 0.0122 | 1 | 0.79 | 62.75 | 0.0005 | 1 | 0.004 | 24.33 | 0.0043 | 1 | 0.440 | 44.45 | 0.0011 |
| $D^2$ | 1 | 0.200 | 43.41 | 0.0012 | 1 | 0.850 | 67.65 | 0.0004 | 1 | 0.005 | 24.94 | 0.0041 | 1 | 0.500 | 39.09 | 0.0015 |
| AB | 1 | 0.067 | 15.18 | 0.0115 | 1 | 1.12 | 88.52 | 0.0002 | 1 | 4.96 | 25.63 | 0.0039 | 1 | 0.440 | 42.1 | 0.0013 |
| AC | 1 | 0.073 | 16.55 | 0.0096 | 1 | 1.27 | 100.5 | 0.0002 | 1 | 6.18 | 31.91 | 0.0024 | 1 | 0.470 | 39.36 | 0.0015 |
| AD | 1 | 0.076 | 17.22 | 0.0089 | 1 | 0.93 | 73.64 | 0.0004 | 1 | 7.8 | 40.29 | 0.0014 | 1 | 0.440 | 46.91 | 0.001 |
| BC | 1 | 0.016 | 37.22 | 0.0017 | 1 | 0.78 | 61.54 | 0.0005 | 1 | 0.005 | 25.68 | 0.0039 | 1 | 0.530 | 41.22 | 0.0014 |
| BD | 1 | 0.065 | 14.72 | 0.0122 | 1 | 0.79 | 62.28 | 0.0005 | 1 | 4.72 | 24.36 | 0.0043 | 1 | 0.460 | 39.55 | 0.0015 |
| CD | 1 | 0.066 | 14.86 | 0.012 | 1 | 0.89 | 70.55 | 0.0004 | 1 | 6.97 | 35.98 | 0.0018 | 1 | 0.440 | 39.51 | 0.0015 |
| $A^2B$ | 1 | 0.066 | 15.06 | 0.0116 | 1 | 1.11 | 88.14 | 0.0002 | 1 | 8.09 | 41.77 | 0.0013 | 1 | 0.440 | 41.61 | 0.0013 |
| $A^2C$ | 1 | 0.076 | 17.27 | 0.0089 | 1 | 1.24 | 97.93 | 0.0002 | 1 | 6.32 | 32.64 | 0.0023 | 1 | 0.470 | 40.06 | 0.0015 |
| $A^2D$ | 1 | 0.085 | 19.21 | 0.0071 | 1 | 0.84 | 66.74 | 0.0004 | 1 | 10.02 | 51.72 | 0.0008 | 1 | 0.450 | 62.15 | 0.0005 |
| $AB^2$ | 1 | 0.066 | 14.93 | 0.0118 | 1 | 1.04 | 82.31 | 0.0003 | 1 | 4.72 | 24.35 | 0.0043 | 1 | 0.700 | 39.96 | 0.0015 |
| $AC^2$ | 1 | 0.066 | 14.93 | 0.0118 | 1 | 1.04 | 82.31 | 0.0003 | 1 | 4.72 | 24.35 | 0.0043 | 1 | 0.450 | 39.96 | 0.0015 |
| $AD^2$ | 0 | – | – | – | 0 | – | – | – | 0 | – | – | – | 0 | – | – | – |
| $B^2C$ | 1 | 0.066 | 14.93 | 0.0118 | 1 | 1.04 | 82.31 | 0.0003 | 1 | 4.72 | 24.35 | 0.0043 | 1 | 0.450 | 39.96 | 0.0015 |
| $B^2D$ | 1 | 0.066 | 14.93 | 0.0118 | 1 | 1.04 | 82.31 | 0.0003 | 1 | 4.72 | 24.35 | 0.0043 | 1 | 0.450 | 39.96 | 0.0015 |
| $BC^2$ | 1 | 0.066 | 14.93 | 0.0118 | 1 | 1.04 | 82.31 | 0.0003 | 1 | 4.72 | 24.35 | 0.0043 | 1 | 0.450 | 39.96 | 0.0015 |
| $BD^2$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $C^2D$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $CD^2$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $A^3$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| $B^3$ | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Residual error | 5 | 0.0044 | – | – | 5 | 0.013 | – | – | 5 | 0.190 | – | – | 5 | 0.011 | – | – |
| Lack of fit | 2 | 0.0021 | 0.36 | 0.725 | 2 | 0.020 | 4.98 | 0.111 | 2 | 0.056 | 1.79 | 0.308 | 2 | 0.011 | 0.99 | 0.466 |
| Pure error | 3 | – | – | – | 3 | 0.005 | – | – | 3 | 0.150 | – | – | 3 | 0.011 | – | – |
| Total | 29 | – | – | – | 29 | – | – | – | 29 | – | – | – | 29 | – | – | – |

Table 3- Variance analysis of the responses (Continued)

| | Springiness | | | | Adhesiveness | | | |
|---|---|---|---|---|---|---|---|---|
| Source | DF | MS | F | P | DF | MS | F | P |
| Model | 22 | 0.0020 | 14.15 | 0.004 | 22 | 0.00003 | 24.37 | 0.0011 |
| Inulin (A) | 1 | 0.0034 | 24.56 | 0.0043 | 1 | 0.000002 | 0.29 | 0.611 |
| Starch (B) | 1 | 0.0088 | 63.19 | 0.0005 | 1 | 0.0003 | 228.48 | < 0.0001 |
| NaCl (C) | 1 | 0.0088 | 63.19 | 0.0005 | 1 | 0.0000002 | 228.48 | < 0.0001 |
| KCl (D) | 1 | 0.0088 | 63.19 | 0.0005 | 1 | 0.0000002 | 228.48 | < 0.0001 |
| $A^2$ | 1 | 0.0096 | 68.22 | 0.0004 | 1 | 0.0000002 | 229.54 | < 0.0001 |
| $B^2$ | 1 | 0.0120 | 85.3 | 0.0002 | 1 | 0.0000003 | 292.91 | < 0.0001 |
| $C^2$ | 1 | 0.0110 | 81.81 | 0.0003 | 1 | 0.0000003 | 321.4 | < 0.0001 |
| $D^2$ | 1 | 0.0100 | 72.2 | 0.0004 | 1 | 0.0000002 | 234.43 | < 0.0001 |
| AB | 1 | 0.0100 | 70.61 | 0.0004 | 1 | 0.0000002 | 236.45 | < 0.0001 |
| AC | 1 | 0.0100 | 71.12 | 0.0004 | 1 | 0.0000002 | 229.47 | < 0.0001 |
| AD | 1 | 0.0090 | 64.09 | 0.0005 | 1 | 0.0000002 | 238.58 | < 0.0001 |
| BC | 1 | 0.0120 | 88.78 | 0.0002 | 1 | 0.0000002 | 241.99 | < 0.0001 |
| BD | 1 | 0.0089 | 63.33 | 0.0005 | 1 | 0.0000002 | 255.95 | < 0.0001 |
| CD | 1 | 0.0089 | 63.65 | 0.0005 | 1 | 0.0000002 | 229.76 | < 0.0001 |
| $A^2B$ | 1 | 0.0094 | 66.96 | 0.0004 | 1 | 0.0000002 | – | – |
| $A^2C$ | 1 | 0.0160 | 114.48 | 0.0001 | 1 | 0.0000002 | – | – |
| $A^2D$ | 1 | 0.0160 | 116.44 | 0.0001 | 1 | 0.0000003 | – | – |
| $AB^2$ | 1 | 0.0095 | 68.05 | 0.0004 | 1 | 0.0000002 | – | – |
| $AC^2$ | 1 | 0.0095 | 68.05 | 0.0004 | 1 | 0.0000002 | – | – |
| $B^2C$ | 1 | 0.0095 | 68.05 | 0.0004 | 1 | 0.0000002 | – | – |
| $B^2D$ | 1 | 0.0095 | 68.05 | 0.0004 | 1 | 0.0000002 | – | – |
| $BC^2$ | 1 | 0.0095 | 68.05 | 0.0004 | 1 | 0.0000002 | – | – |
| $BD^2$ | – | – | – | – | – | – | – | – |
| $C^2D$ | – | – | – | – | – | – | – | – |
| $CD^2$ | – | – | – | – | – | – | – | – |
| $A^3$ | – | – | – | – | – | – | – | – |
| $B^3$ | – | – | – | – | – | – | – | – |
| Residual error | 5 | 0.0007 | – | – | 5 | 0.00001 | – | – |
| Lack of fit | 2 | – | 4.16 | 0.087 | 2 | 0.00094 | 0.84 | 0.514 |
| Pure error | 3 | – | – | – | 3 | 0.00001 | – | – |
| Total | 29 | – | – | – | 29 | – | – | – |

## Dry matter (DM)

With the increase of starch, the DM of low-fat imitation cheese decreased from 56.7673 to 54.7% (Fig. 2 (a) and (b)). Moghise *et al.* (2022) reported that DM of Feta cheese was decreased by adding inulin/kefiran to it, which was due to increasing moisture content. However, Rafiei *et al.* (2022) observed that moisture content of Mozzarella cheese was decreased by adding rice starch hydrocolloid to it. de Souza Paglarini *et al.* (2021) shows that cheese samples with dietary fiber and low fat have a higher percentage of dry matter. Abbasi & Nateghi (2022) and Świąder *et al.* (2021) reported similar results in the production of functional low-fat yogurt.

## Fat

Fat is responsible for sensory attributes including aroma, texture, and flavor of cheese. Fat affects the cheese texture by filling the interstitial spaces in the protein and mineral matrix (Lashkari *et al*., 2014). The lowest and highest amount of fat (5.6 % and 22%) was detected in samples containing 0.13 % inulin and without inulin and starch dietary fibers, respectively. As the concentration of starch and sodium chloride increased, the fat content of imitation pizza cheese decreased.

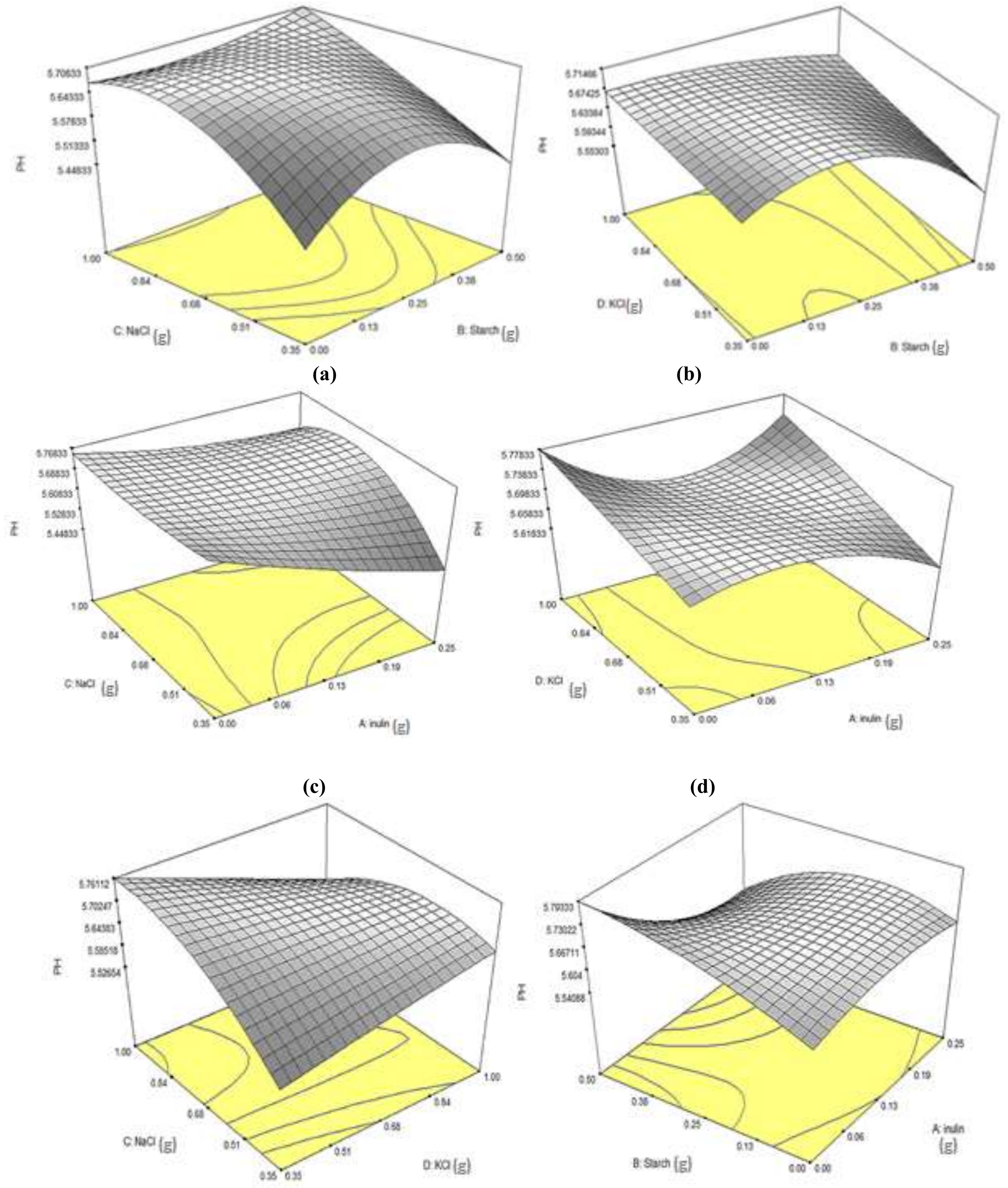
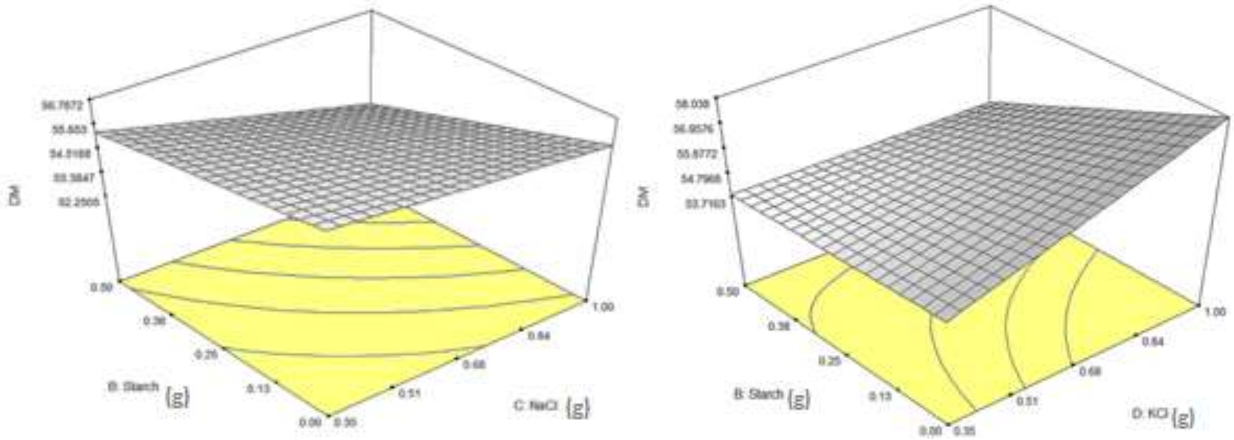


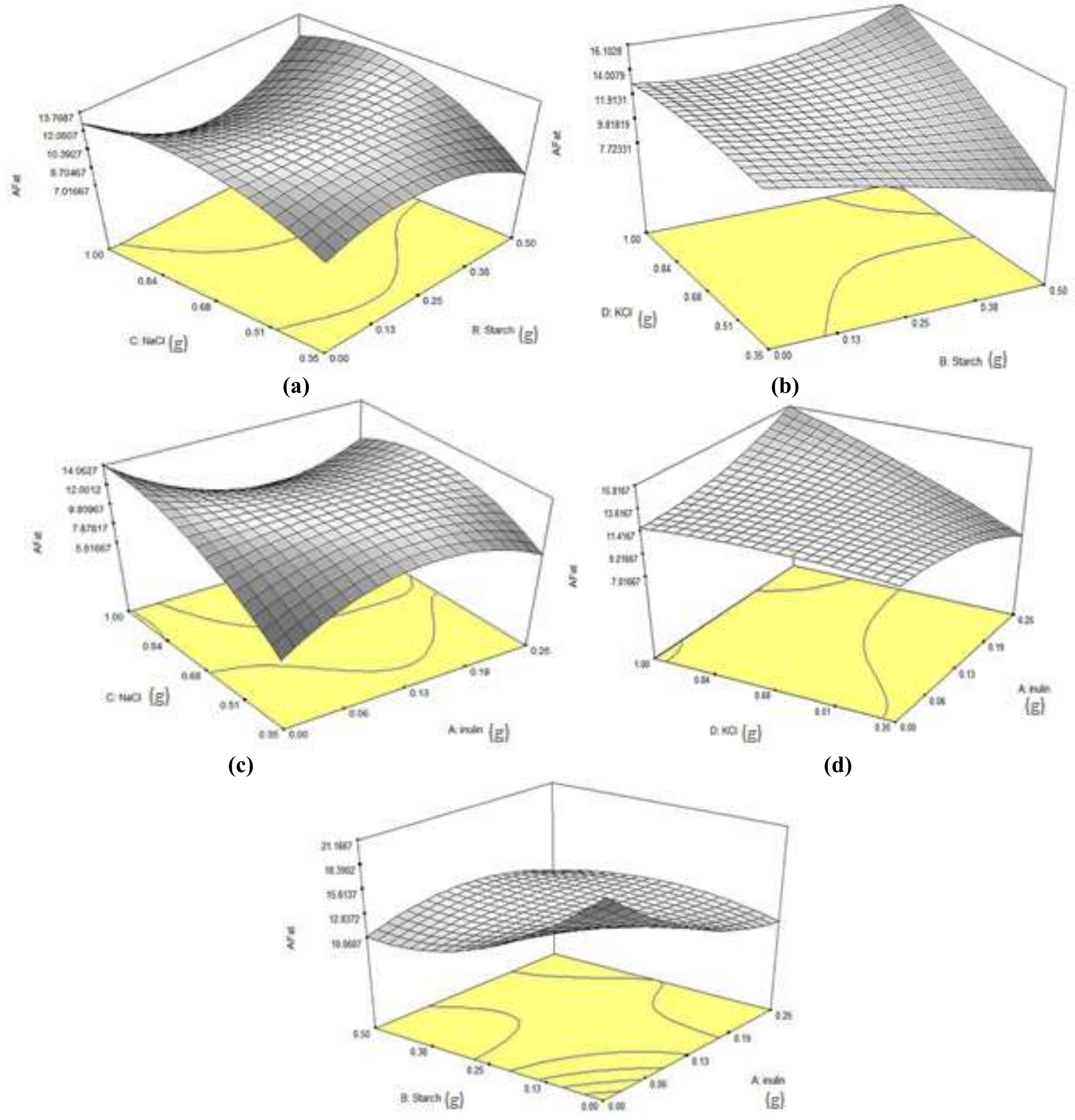

**Fig. 1. Effect of starch and NaCl (a), starch and KCl (b), inulin and NaCl (c), inulin and KCl (d), NaCl and KCl (e), starch and inulin (f) on the pH of imitation cheese**




(a) (b)

**Fig. 2. Effect of starch and NaCl (a), starch and KCl (b) on the DM of imitation cheese**

An increase in starch and potassium chloride variables resulted in a decrease in cheese fat. The increase in inulin and starch caused an increase (13.7627%) and then a decrease in fat content (11.91117%). Fig. 3 (c) shows that the increase in inulin (0.13%) resulted in an 11.9117% increase in fat and then decreased. The increase in sodium chloride (1%) resulted in an increase in the fat content. In general, decreasing NaCl levels resulted in a decrease in fat, protein, ash, sodium and pH, and an increase in moisture and l-lactic acid. As moisture increases, fat and protein decrease due to a dilution effect (Rulikowska *et al*., 2013). Results obtained from the effect of inulin and potassium chloride showed that the increase of each of these two parameters led to the decrease of fat content. With the simultaneous increase of inulin and potassium chloride, the fat content decreased. The reduction of fat with the increase of inulin is attributed to the replacement of inulin with sodium caseinate in the product. The reason for the reduction of fat with the increase of starch is the presence of pectin in the structure of starch, which replaces fat in imitation cheese (Hennelly *et al*., 2006). Mounsey & O'Riordan (2008) studied the influence of pre-gelatinized maize starch on the rheology; microstructure and processing of imitation cheese, and reported that this replacement caused a decrease in protein and increase the stability of fat globules. Fadaei *et al*. (2012) studied the chemical characteristics of low-fat wheyless cream cheese containing inulin as fat replacer. The results showed that it is possible to make a wheyless cream cheese with lower fat content and desirable attributes using inulin (10%) as fat replacer, and that inulin and stabilizers can improve chemical properties of low-fat whey less cream cheese. The results of Borges *et al*. (2019) showed that reduced-fat Frescal sheep milk cheese containing 5 %w/w inulin (as fat replacer) has sensory and textural attributes. Lashkari *et al*. (2014) investigated the effect of fat replacement with tapioca starch on the structure and sensory characteristics of Feta cheese. The results showed that the percentage of hardness increased with the reduction of cheese fat. Abbasi & Nateghi (2022) used pre-gelatinized corn starch to improve the sensory and physicochemical properties of low-fat pizza cheese. The results showed 67.56% of low-fat milk powder, 27.93% of fat and 4.5% of starch were the optimal quantities in the formulation. Melt ability, acidity, elasticity, firmness, total soil matters, flavor, texture and total acceptance were 4.08, 0.46, 13.91, 14.11, 49.68, 3.85, 4.26 and 3.78 respectively. The optimal formulation showed the highest acceptance rate among the treatments.




(e)

**Fig. 3. Effect of starch and NaCl (a), starch and KCl (b), inulin and NaCl (c), inulin and KCl (d), starch and inulin (e) on the fat percentage of imitation pizza cheese**

## Salt

In cheese, salt reduction is still a challenging task, because sodium chloride has multiple and essential functions such as increasing the flavor and aroma of cheese, adjusting the final pH, water activity and texture of the product, as well as affecting microbial growth (Lavasani, 2022). The increase of potassium chloride resulted in a significant decrease in the amount of salt in the product ($p<0.05$), while the salt content of the product increased with the increase in sodium chloride. Fig.3 shows the simultaneous effect of two variables (sodium chloride and potassium chloride) on the amount of salt in the product. The percentage of salt in imitation pizza cheese was reduced ($p<0.05$) by the combination of sodium chloride and potassium chloride. Dorosti *et al.* (2010) evaluated the effect of partial replacement of NaCl with KCl on the characteristics of Iranian white cheese. They showed that reducing sodium chloride by 50% has no significant effect on cheese quality. The partial replacement of NaCl with KCl is not able to significantly change the acid number and textural characteristics of the cheese samples. Rulikowska *et al.* (2013) evaluated the effect of reducing sodium chloride on Cheddar cheese quality. The results showed that salt reduction has an adverse effect on the taste and texture of cheddar. Salt reduction led to a simultaneous decrease in pH, a slight decrease in buffering capacity, and an increase in water activity and the growth of starter and non-starter lactic acid bacteria, which led to an increase in proteolysis. Mohammadzadeh (2020) analyzed the impact of replacing sodium chloride with potassium chloride on certain quality indices of fish sauce from Caspian Sea fish. Between two replacement concentrations of KCl, 50% has better quality than 25% in terms of total nitrogen, formaldehyde nitrogen, and amino nitrogen. Lavasani (2022) studied the quality and composition of Iranian low-salt UF-white cheese. The results showed that KCl did not significantly affect the moisture, dry matter, fat, total nitrogen/dry matter, and water soluble nitrogen of cheeses. Sensory evaluation showed that as the concentration of KCl increased, the cheese gradually became less acceptable. Treatments contained more potassium chloride were crumblier and less firm. The aroma evaluation of cheese samples revealed that acetaldehyde, ethanol, acetoin, and diacetyl had a significant decrease in their amounts during storage. According to the results, reducing sodium by up to 50% did not have a significant impact on the quality and composition of Iranian low-salt UF-white cheese.

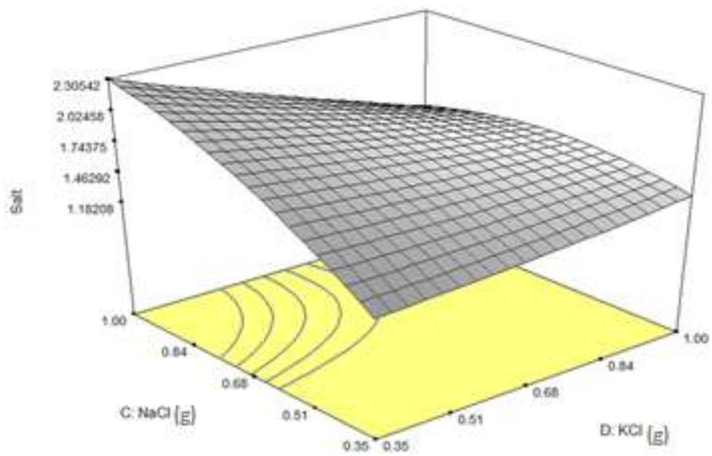
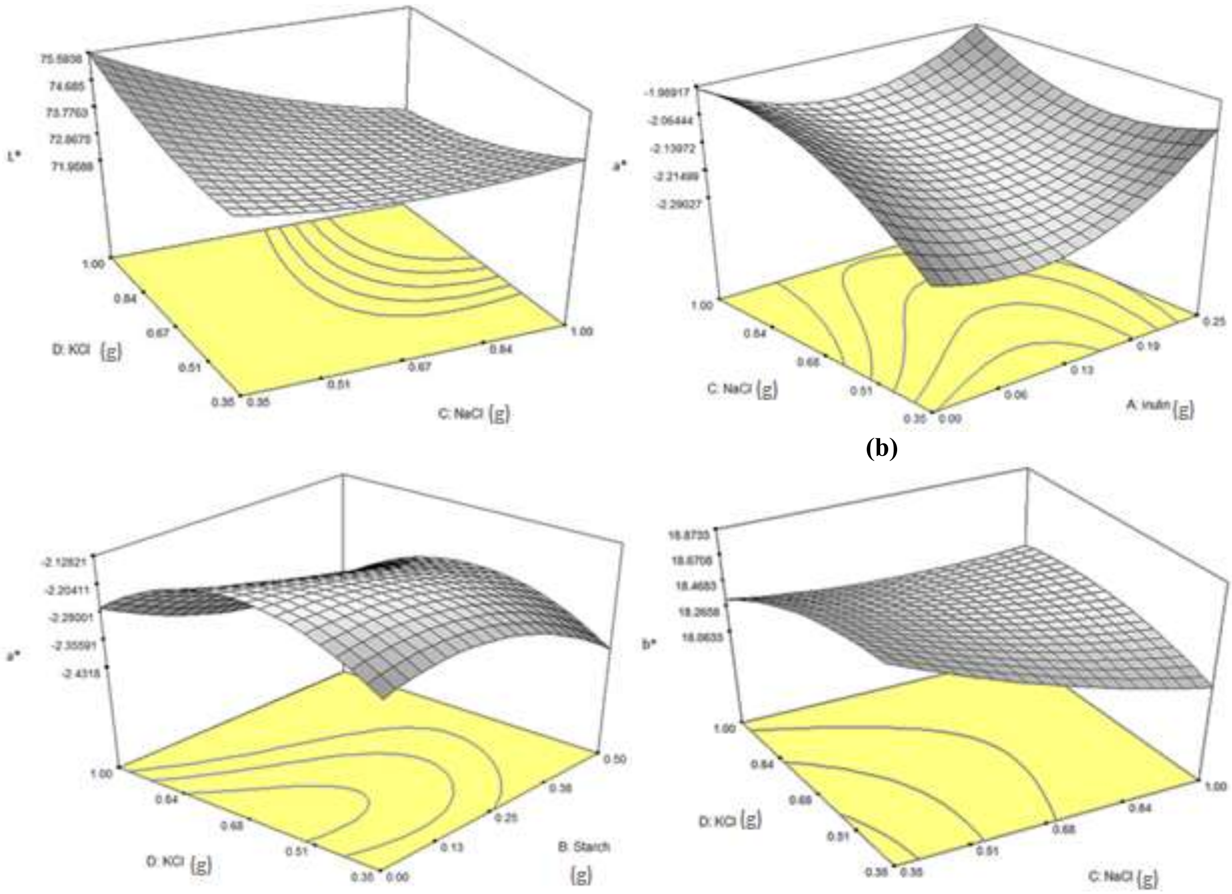



**Fig. 4. Effect of two variables (NaCl and KCl) on the salt of imitation pizza cheese**

## Color parameters

Increasing NaCl content led to reduce L* value of low-fat imitation cheese samples (Fig. 1 (g)). On the other hand, the L* value was gently increased by increasing KCl content at low levels of NaCl contents. However, at the higher content of NaCl, the L* value significantly decreased. This is attributed to natural color of sodium caseinate (yellow to opaque) and KCl (white) (Hogan *et al.*, 2001). Fig. 5 (h) shows the interactive effect of inulin and NaCl on the redness of low-fat imitation cheese. The a* value was initially decreased by increasing inulin content and followed by significant increase. On the other hand, the redness was increased by adding NaCl. According to Fig. 1 (i), the a* value was initially increased by increasing starch and KCl content, but subsequently reduced. Juan *et al.* (2013) reported that low-fat cheeses showed less lightness than full-fat cheeses, with inulin cheese having the lowest amount. In 6 days of storage, inulin cheeses showed the highest yellowness values. However, these instrumental color differences were not recognized by the panelists. Jayarathna *et al.* (2022) showed that sausages containing 2% inulin had lower lightness (L*) values than the control ($p<0.05$). During storage, the value of L*, pH, and water holding capacity decreased and the values of redness (a*) and yellowness (b*) increased in all samples. Fig. 1 (k) shows the interactive effect of NaCl and KCl on b* value of low-fat imitation cheese. The b* value was increased by decreasing NaCl and KCL content (Fig. 1 (k)). Due to its particulate nature, inulin can act as light scattering centers and increase the turbidity of cheeses. High-fat cheeses had less redness and yellowness than low-fat cheeses.




(b)

(c) (d)

**Fig. 5. Effects of the independent variables on color parameters of imitation pizza cheese (a: L* value; b and c: a* value; d: b* value)**

## Textural properties

### Hardness

Hardness of low-fat imitation pizza cheese was initially increased by decreasing starch content to 0.25%, and then remained constant. On the other hand, the hardness was decreased by adding inulin at low concentration of starch (Fig. 6 (a)). As is shown in Fig. 6 (b), the hardness was increased by increasing KCl and NaCl content. The hardness is attributed to the stability of emulsion, so that each emulsion-weakening agent caused in the reducing hardness (Hennelly *et al.*, 2006). Similarly, the increasing hardness was observed for mozzarella cheeses containing fat replacers reported by Rafiei *et al.* (2022) and Moghise *et al.* (2022), respectively. Borges *et al.* (2019) reported that the hardness of Frescal sheep milk cheese increased significantly with the addition of inulin ($p<0.05$). A higher ratio of moisture to protein reduces the bond between fat and casein. Diamantino *et al.* (2019) showed that by increasing the level of starch, cheese became harder and the maximum hardness was observed in cheese with higher concentration of starch. Cheese containing starch has more hardness as compared to other treatments due to crystal formation. The increase in the hardness of cheese containing starch is due to the change in protein matrix compactness, because the addition of starch increased the water-binding capacity of protein matrix. In a similar study, Sołowiej *et al.* (2015) used inulin and whey protein polymers in low -fat cheese and found that hardness increases with increasing level of inulin. Inulin can probably act as a stabilizer because of its ability to water binding. Therefore, the water molecules become immobilized and cannot move freely among the other molecules in the mixture. This improves the consistency of the mixture and thus increases the hardness.

### Cohesiveness

Fig. 6 (c) shows the interactive effect between inulin and NaCl content on cohesiveness of imitation cheese. The cohesiveness was initially increased by adding NaCl up to about 0.7%, but subsequently reduced. However, this trend was reversed at higher inulin content. On the other hand, the cohesiveness of imitation cheese was increased by adding inulin. Juan *et al.* (2013) reported that the mean amount of cohesiveness and chewiness of low-fat fresh cheeses was higher than that of high-fat cheeses. As is shown in Fig. 6 (d), the cohesiveness was remarkably increased by increasing starch and NaCl content. Butt *et al.* (2020) found that imitation cheese replaced with pregelatinized starches was more cohesive with improved melting properties compared to the control. It corresponded to the results of Moghiseh *et al.* (2021), and Diamantino *et al.* (2019) in Mozzarella, and cheddar reduced-fat cheeses, respectively.

### Springiness

Fig. 6 (e) shows the interactive effect between inulin and starch content on springiness of imitation cheese. The springiness was increased by increasing inulin content at low content of starch. However, the opposite is true when increasing inulin content at high levels of starch. Moghiseh *et al.* (2021) reported that Less springiness and greater cohesiveness of mozzarella cheese at high level of inulin can be due to the increase in moisture and protein content, which lead to the hydration phenomenon of caseins and the formation of a firm and less plastic structure. The springiness was increased by increasing starch content (Fig. 6 (e)). Juan *et al.* (2013) found that reduced-fat cheeses have a higher value of springiness than full-fat cheese. According to Fig. 6 (f), springiness of imitation cheese was increased by increasing NaCl and decreasing KCl content. This result was in agreement with Koca & Metin (2004) for low-fat fresh kashar cheese. Kiziloz *et al.*, (2009) studied development of the structure of an imitation cheese with low protein content, and reported that hardness; cohesiveness and springiness of the cheese were affected positively by κ-carrageenan and negatively by α-amylase.

### Adhesiveness

As shown in Fig. 6 (g), adhesiveness of low-fat imitation cheese was increased by increasing NaCl content. At low levels of NaCl, the adhesiveness was initially decreased by increasing inulin content, but subsequently increased. However, it was unlike at high levels of NaCl by increasing inulin content (Fig. 6 (g)). The adhesiveness was increased by adding starch and KCl (Fig. 6 (h)). Fat reduction with incorporated fat mimetics can increase protein-water interactions and increase cheese adhesiveness. As a result, by reducing the cheese fat, its hardness, springiness, consistency and chewiness increased.

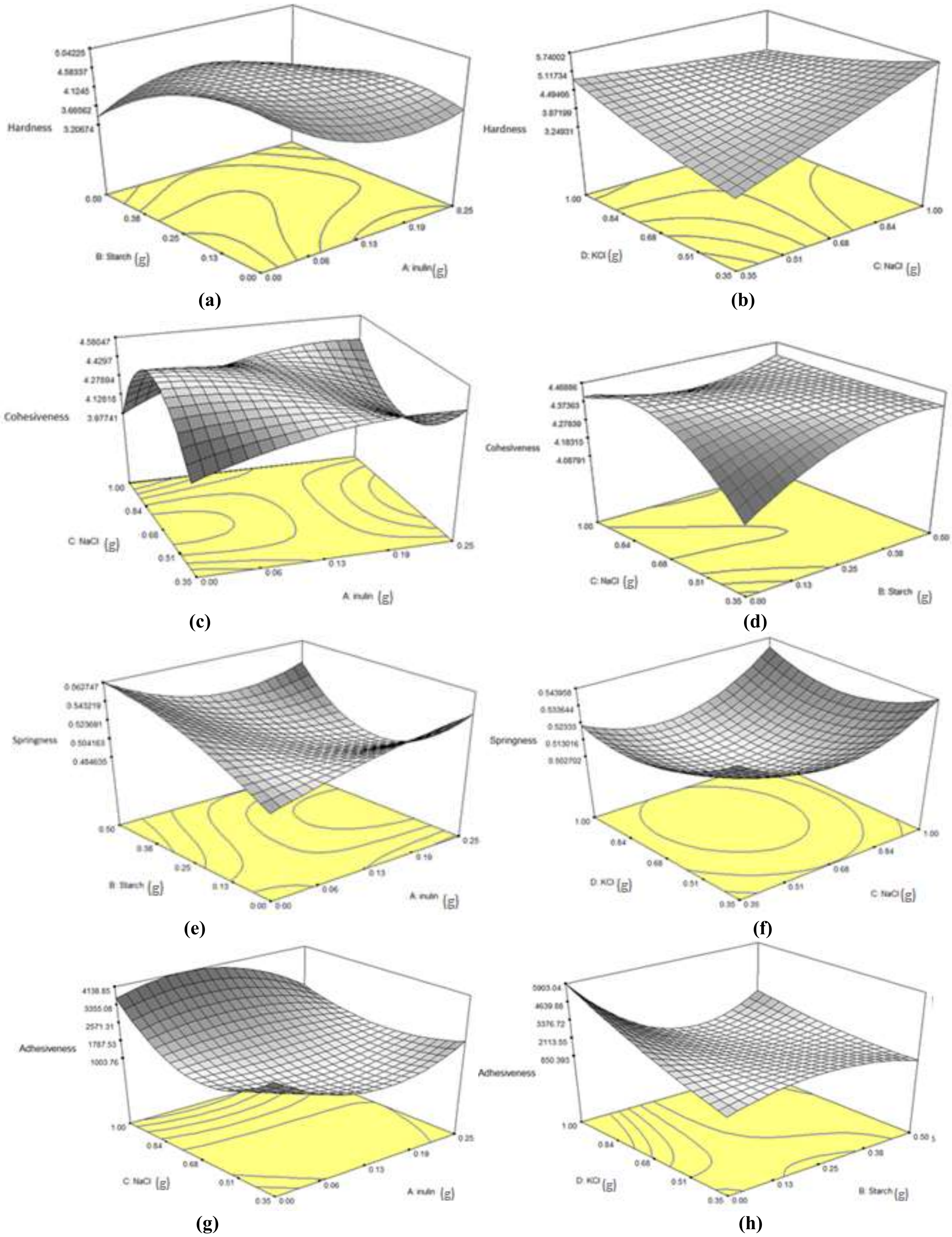



**Fig. 6. Effects of the independent variables on textural properties of imitation pizza cheese**

Diamantino *et al.* (2019) stated that the role of fat is so important that even if moisture is higher in low-fat cheddar cheese, the texture will be hard due to the denser protein matrix with less open spaces. Oliveira *et al.* (2011) found that when the starch level in Edam green cheese increases, the intermolecular interaction also increases, resulting in a denser three-dimensional matrix that affects the textural properties of low-fat cheese.

## Sensory evaluation

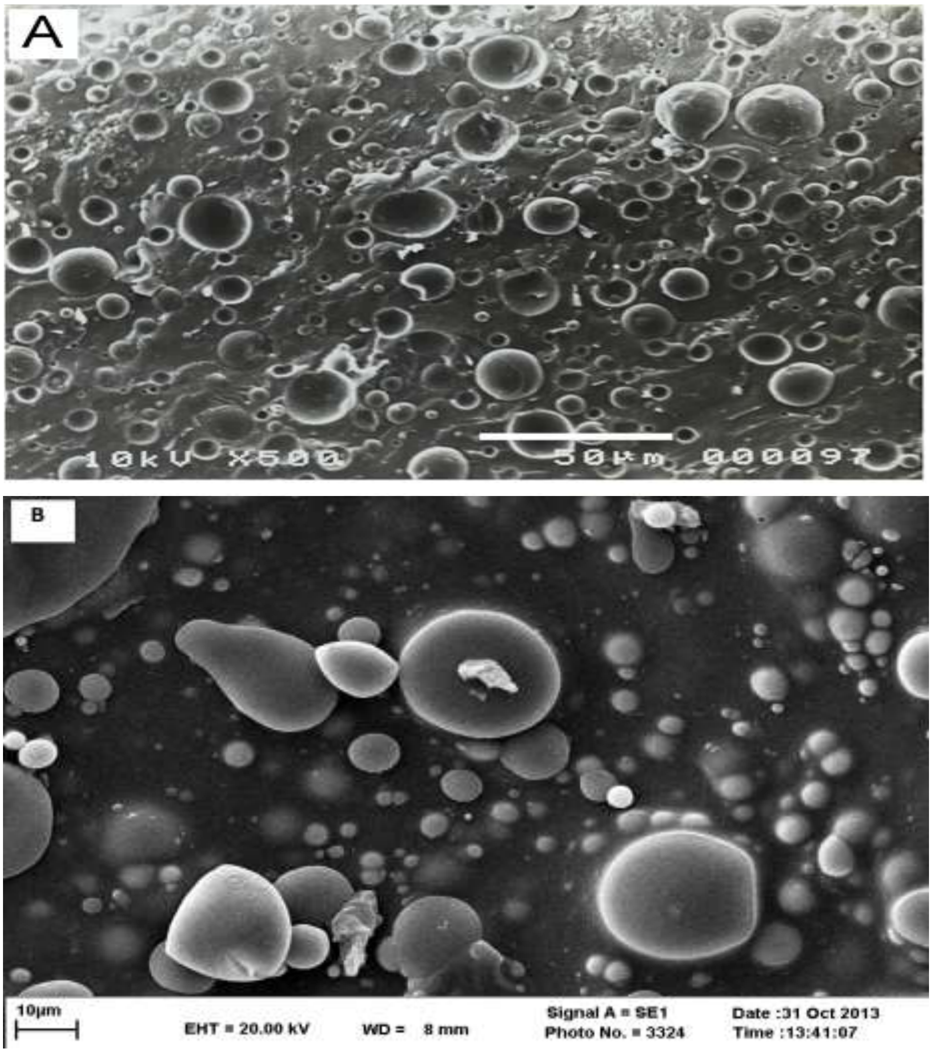
The aroma of imitation pizza cheese increased significantly from 6.14 to 7.39, with an increase in inulin content. The amount of aroma increased and then decreased as starch content increased (Fig. 7(a)). The results showed that the simultaneous effect of starch and sodium chloride reduced the aroma of imitation pizza cheese. Also, the aroma of imitation cheese decreased with the increase of starch and potassium chloride. When potassium chloride alone increased, there is an increase in aroma, but when sodium chloride alone increased, there is a decrease in aroma the imitation cheese texture decreased from 7.81 to 7.09-7.27% as inulin or starch increased. The texture score was significantly affected by reducing fat and increasing inulin and modified gelatin starch. The texture of the imitation pizza cheese containing inulin and starch was harder than that of the control cheese. The treatments with the lowest and highest amount of fat were scored lower. Some of the examined samples were found to be too soft or have an unfavorable hardness, according to the panelists. The sensory evaluation revealed that the increase in inulin resulted in a decrease in color index of imitation cheese. The color did not change significantly due to the increase of sodium chloride. Based on the results, the increase in starch caused a decrease in the color index. Cheeses with less potassium chloride are more palatable because they have more sodium (NaCl). The taste of salts is influenced by the nature of their cations and anions. The salts become bitter as their molecular weight increases for cation and anion. The aroma and taste scores differ between treatments due to the concentration of potassium chloride in combination with sodium chloride. Potassium chloride has an inherent bitterness due to the presence of potassium ions, the higher concentration, the more noticeable this bitterness will be. Mazaheri Nasab *et al.* (2012) reported that partial substitution of fat by carrageen and whey concentrate in low fat mozzarella cheese could produce a low fat product with desirable sensory properties. According to Sadrolodabaee & Shahabad (2014), cheese sample with 1% of mono and diglycerides had a higher overall acceptance rate than other samples. Pishelmi *et al.* (2017) utilized pre-gelatinized starch in the formulation of low-fat stirred yogurt and found that an increase in pre-gelatinized starch content led to an increase in overall acceptance scores. Heydari & Razavi (2021) observed that creaminess was improved by applying high pressure on corn and waxy corn starches, which are novel fat replacements. Abbasi & Nateghi (2022) showed that the apparent desirability of this cheese decreased as an increase in starch content occurred. Low-fat pizza cheese with only 3% starch, 75% milk powder, and 34% fat received the highest score.

## Optimization

The numerical optimization technique performed to optimize the formulation, when weight and importance values for all of responses were equal (Yolmeh *et al.*, 2014). The fat content, L*, b*, cohesiveness, springiness and adhesiveness attributes were considered for the optimization formulation of imitation cheese. The formulation containing 0.19% inulin, 0.4% starch, 0.35% NaCl, and 0.50% KCl was found as the optimal formulation. The fat content, L*, b*, cohesiveness, springiness and adhesiveness were acquired 4.67, 74.07, 18.72, 4.32, 0.52, and 3879.52 respectively, as the predicted results whose composite desirability values were equal to 0.83. The experimental results of fat content, L*, b*, cohesiveness, springiness and adhesiveness at the optimum formulation were 4.94, 72.67, 17.04, 3.96, 0.42, and 3914.65, respectively.

**Scanning electron microscope (SEM) images**

As shown in Fig.7, there were many large and small particles in the imitation cheese, which indicated that inulin crystals are accumulated in the continuous phase (Fig.7 (b)). Therefore, the effective volume fraction was increased, which can lead to important changes in the sensory and textural properties. There are particles of gelatinized and immersed starch granules in the continuous phase in samples containing starch and without inulin. As well as fat globules remains small and uniform by increasing the starch content (Fig.7 (c)). Disruption of fat globules was remarkably increased by increasing inulin and starch contents (Fig.7 (d)). Karami *et al.*, (2009) studied microstructural properties of fat during the accelerated ripening of ultrafiltered-Feta cheese. They showed through scanning electron microscopy images that with an increase in lipase levels from 2 to 6 g 100 kg$^{-1}$ of retentate, disruption of fat globules increased significantly.



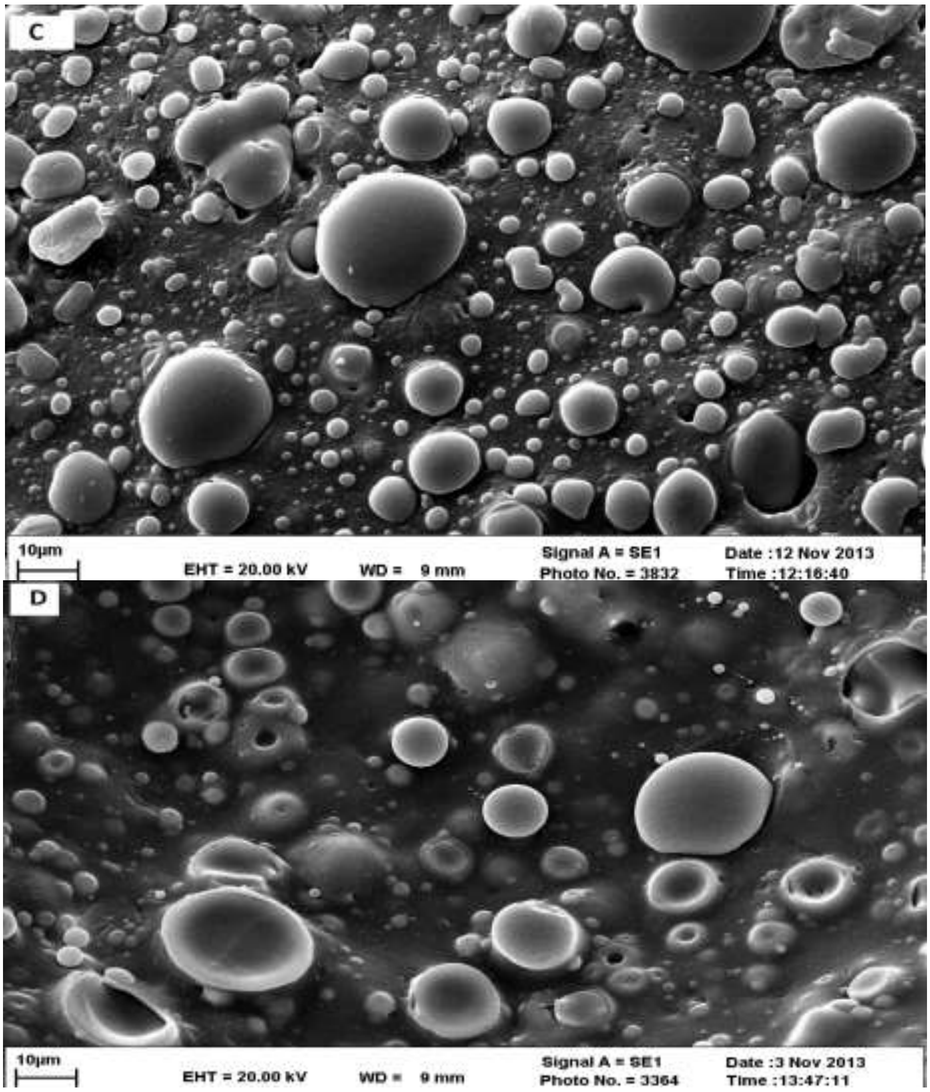



**Fig. 7. SEM images of control sample (A), imitation cheese containing inulin (B), imitation cheese containing starch (C), imitation cheese containing inulin-starch (D)**

## Conclusion

Fat consumption is directly related to various diseases such as obesity, diabetes, hardening of blood vessels and blood pressure. The development of flavor, texture and appearance of cheese is largely influenced by fat. Imitation pizza cheese is a relatively high-fat product, containing 20-27% fat. Also, high amounts of sodium increase the risk of heart attack and high blood pressure. In this study, low-fat and low sodium imitation pizza cheese was properly developed and RSM was successfully applied for optimizing its formulation. The formulation containing 0.19% inulin, 0.4% starch, 0.35% NaCl, and 0.50% KCl was found as the optimal formulation of imitation cheese. At the optimal formulation, the fat content, L*, b*, cohesiveness, springiness and adhesiveness were measured were 4.94, 72.67, 17.04, 3.96, 0.42, and 3914.65, respectively. The replacement of fat by increasing the concentration of inulin or pre-gelatinized starch had a significant effect on the properties of imitation pizza cheese. With increased levels of inulin or starch, the resultant imitation cheeses had less hardness and adhesiveness; however, their cohesiveness and springiness were higher.

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# ارزیابی ویژگی‌های فیزیکوشیمیایی و بافتی پنیر پیتزای تقلیدی کم چرب و کم‌سدیم

معصومه مهربان سنگ آتش[1*]- مریم دادرس مقدم[2]- سید علی مرتضوی[3]- هانیه یاربی[4]

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## چکیده

رشد روزافزون بیماری‌های قلبی عروقی، فشار خون بالا، سفت شدن دیواره رگ‌ها و همچنین چاقی در بسیاری از کشورها، پنیر پیتزای کم‌چرب و کم‌سدیم را به یکی از موضوعات مورد مطالعه در سراسر جهان تبدیل کرده است. اثرات چهار متغیر مستقل شامل اینولین (۰/۰۲۵-۰ درصد)، نشاسته پیش‌ژلاتینه (۰/۵-۰ درصد)، NaCl (۰/۳۵-۱ درصد) و KCl (۰/۳۵-۱ درصد) مورد بررسی قرار گرفت. محتوای چربی پنیر پیتزای تقلیدی با افزایش سطوح جایگزینی اینولین و نشاسته به‌طور قابل توجهی به ۱۱/۹۱ درصد کاهش یافت ($P < ۰/۰۵$). همچنین مقادیر رطوبت و pH آن به‌طور معنی‌داری متفاوت بود ($p<۰/۰۵$). افزایش سطوح نشاسته پیش‌ژلاتینه شده و اینولین باعث کاهش سختی (از ۵/۰۴ به ۳/۵۵) و چسبندگی (از ۴۳۶۸/۸۹ به ۱۶۴۰/۵۴ درصد) شد، اما چسبندگی (از ۰/۳۶۵ به ۰/۴۳) و فنریت (از ۰/۵ به ۰/۴) را افزایش داد. افزودن NaCl و KCl، سختی محصول را افزایش داد. افزودن اینولین و نشاسته، $a^*$ را کاهش داده‌اند. $b^*$ با افزایش اینولین کاهش می‌یابد و با افزایش نشاسته اصلاح شده افزایش می‌یابد. فرمول حاوی ۰/۱۹ درصد اینولین، ۰/۴ درصد نشاسته پیش‌ژلاتینه، ۰/۳۵ درصد NaCl و ۰/۵ درصد KCl به‌عنوان فرمولاسیون بهینه برای پنیر تقلیدی کم‌چرب یافت شد. نتایج تصاویر میکروسکوپ الکترونی روبشی (SEM) نشان داد که کریستال‌های اینولین در فاز پیوسته انباشته شده‌اند که می‌تواند منجر به تغییرات مهمی در ویژگی‌های حسی و بافتی شود. این مطالعه به این نتیجه رسید که اینولین یا نشاسته را می‌توان برای جایگزینی تا ۳/۶ درصد از چربی موجود در پنیر پیتزا تقلیدی و ۰/۳۵ درصد NaCl و ۰/۵ درصد KCl برای کاهش محتوای سدیم محصول استفاده کرد.

**واژه‌های کلیدی:** اینولین، بهینه‌سازی، پنیر پیتزای تقلیدی، نشاسته پری‌ژلاتینه

۱- استادیار، گروه پژوهشی کیفیت و ایمنی مواد غذایی، پژوهشکده علوم و فناوری مواد غذایی، جهاد دانشگاهی خراسان رضوی، مشهد، ایران
(*- نویسنده مسئول: Email: mehraban@acecr.ac.ir)
۲- دانش‌آموخته مقطع کارشناسی ارشد، گروه علوم و صنایع غذایی، دانشگاه آزاد اسلامی واحد سبزوار، سبزوار، ایران
۳ و ۴- به‌ترتیب استاد و دانش آموخته مقطع دکتری تخصصی، گروه علوم و صنایع غذایی، دانشکده کشاورزی، دانشگاه فردوسی مشهد، مشهد، ایران
https://doi.org/10.22067/ifstrj.2023.84481.1283