DEVELOPMENT OF CHICKEN ROLL RECIPE USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

The purpose of this study was to determine the optimum quantities of ingredients to yield a chicken roll product with desirable textural properties and coloring and a minimum cooking loss. Response surface methodology (RSM), a statistical technique, was applied for optimization. The optimum quantities for chicken roll production were found to be 8.66 g, 75.00 g and 53.83 g for wheat flour, distilled water, and minced chicken, respectively. The lowest cooking loss was achieved by a recipe with high wheat flour and distilled water content, whereas the highest cooking loss was observed in the recipe with the lowest wheat flour content and the highest minced chicken content.

Keywords: chicken, poultry, optimization, texture profile analysis, response surface methodology

1. INTRODUCTION

The consumption of poultry meat is gradually increasing around the world. Because of its high-quality protein and relatively low fat content, poultry meat, especially chicken meat, plays an important role in the human diet. In addition to this high nutritional value, the relatively low cost and great variety of chicken meat products make chicken meat a widely favored food (CHOULIARA *et al.*, 2008; MOK *et al.*, 2017).

In recent years, ready-to-eat (RTE) foods have become highly preferred food products. Some of the leading causes of the rising consumer demand for RTE foods include: changes in consumers' lifestyles, households in which both parents work long hours, the convenience of consumption, the minimal time required for RTE meal preparation, and the charm of flavorful products (BAE ET AL., 2010; JIANG AND XIONG, 2015). The consumption of RTE foods has risen almost 20% from 2007 to 2012; during these years, European consumers' demand for RTE meat and poultry products (e.g. meat balls, burger patties, sausages) has increased in accordance with this trend (FERREIRA *et al.*, 2016). In Australia, the consumption of RTE meat products has recently increased from 20% to 50% (JIANG and XIONG, 2015). According to a global report on the RTE food market, RTE food consumption is expected to rise 21.8% between 2018 and 2023 (Global Ready to Eat Food Market Report, 2017).

Hydrocolloids (e.g. pectin, xanthan, starch, guar gum, alginate) are frequently used in various food products as thickeners, gelling agents, emulsifiers, stabilizers, fat replacers, clarifying agents, flocculating agents, clouding agents, and whipping agents (LI and NIE, 2014; VIEBKE *et al.*, 2014). Guar gum, commonly used as a hydrocolloid, is a good stabilizer and water-binder, and it provides desirable structure and a slick fat-like mouthfeel for food products (ANDRÉS *et al.*, 2006). Starches occupy an important role in meat recipes (FENG *et al.*, 2013). Due to its unique white color, excellent mouthfeel properties, bland taste, and relatively small granules (2-7 μm), rice starch has become an alternative fat replacer that provides good textural properties for food products (PARK *et al.*, 2007; RESCONI *et al.*, 2015; TOMASCHUNAS *et al.*, 2013; WANI *et al.*, 2012). Because gum increases the viscosity of starch and affects gelatinization, the utilization of gum and starch in food systems has been researched in many studies (KIM and YOO, 2006; YOO *et al.*, 2005). The interactions between starches and gums enhance the rheological properties of starch, improve overall product quality, and reduce the cost of the products (KIM and YOO, 2006; SHI and BEMILLER, 2002). It was reported that guar gum and xanthan gum increased the viscosity of cationic tapioca starch suspensions (CHAISAWANG and SUPHANTHARIKA, 2005). FENG *et al.* (2013) studied the physicochemical properties, texture, and sensory evaluation of Chinese Cantonese-style sausage prepared from the Mesona Blumes gum-rice starch mixture; they reported that this gel could be used as a fat substitute in sausage (FENG *et al.*, 2013).

Alginate, a polysaccharide obtained from brown seaweed, is used as a thickening, film-forming, gel-producing, and emulsion-stabilizing agent in the food industry; this is due to its high water-solubility, high biodegradability, and low price, relative to natural casings (COMAPOSADA *et al.*, 2015; MARCOS *et al.*, 2016; NAKAUMA *et al.*, 2016). Mostly used in meat products, sodium alginate can be combined with calcium ions at room temperature to create a uniform, transparent, water-insoluble, and thermo-irreversible gel (BOLES and SHAND, 1998; COMAPOSADA *et al.*, 2015; LEON *et al.*, 2016). Calcium chloride solutions are most commonly used to provide the calcium ions necessary to achieve gelatinization (COMAPOSADA *et al.*, 2015; Hassan and RAMASWAMY, 2011). The US Food and Drug Administration applies the label ''Generally Recognized as Safe (GRAS)'' to citric acid, which is commonly used in meat and poultry processing for its antimicrobial and tenderizing effects (KHARE *et al.*, 2016). In some studies, combining citric acid and lactic acid reduced the microbial load of chicken drum sticks, while negatively affecting the sensory parameters (ZHU *et al.,* 2016). Coating chicken fillets with carrageenan, cinnamon oil, and citric acid extends the shelf life of chicken meat, under chilled conditions (KHARE *et al.,* 2016).

In previous studies, chicken rolls were produced and analyzed with different formulations and methods (BRECLAW and DAMSON, 1970; DU *et al.,* 2003; FURUMOTO and STADELMAN, 1980; GILLETT and CARPENTER, 1992; WANG and CHEN, 1987; XIAO *et al.,* 2011; YIM *et al.,* 2015). However, to the best of our knowledge, there is no published study addressing the optimization of chicken roll formulation based on some preferred properties. The aim of this study was to determine the optimum quantities of ingredients for a chicken roll product of a desirable color, with textural properties such as low hardness and high resilience, and a minimum cooking loss.

2. MATERIALS AND METHODS

2.1. Experimental Design

RSM was employed to determine the optimum values of three independent variables and evaluate the combined effects of those parameters. As the purpose of this study was to evaluate the interaction effects between food hydrocolloids and other ingredients, the water used in the experiments needed to be free of salt or any other impurities. For example, common drinking water contains salts that can change the effects of calcium chloride and sodium alginate; thus, distilled water was used. The wheat flour (5-35 g), distilled water (35-75 g), and minced chicken (20-60 g) were the parameters and levels employed. The coded values and the original values of the independent parameters are shown in Table 1. For the purpose of evaluating the pure error and the curvature of the complete design, a three-level three-factor Box-Behnken Design (BBD) was implemented, which indicated the need to compose a total of 17 experiments with 5 replicates of the center point.

Table 1. Variables and their levels in response surface design.

Independent variables	Symbols	Coded levels		
		-1	0	1
Wheat flour (g)	A	5	20	35
Distilled water (g)	B	35	55	75
Minced chicken (g)	C	20	40	60

2.2. Sample preparation

Fresh skinless chicken breasts were obtained from Keskinoğlu Poultry and Hatchery Ind. Inc., Manisa, Turkey. Different amounts of wheat flour (5-35 g), distilled water (35-75 g), and minced chicken (20-60 g) were added to obtain chicken rolls according to the experimental design. The other ingredients, which are sodium alginate, rice starch, guar gum, citric acid, wheat flour, and calcium chloride, were obtained from Smart Chemistry Inc., İzmir, Turkey. Before preparing the chicken meat batter, breast meat was ground through the mincer. Sodium alginate (2.4 g), rice starch (1.7 g), guar gum (0.85 g), citric acid (0.2 g), and wheat flour were added to 60±5°C distilled water, and blended for 1 minute. The minced chicken was added to this mixture, which was then blended for 1 minute. The chicken meat batter was thinned to 2 mm and dipped in a 125 mL 7% (w/v) calcium chloride ($CaCl_2$) solution for 1 minute. Then the batter was molded into round shapes (each with an internal diameter of 10 cm), sealed into plastic bags, and cooked in a 90°C water bath for 5 minutes (until the contents of the bags reached an internal temperature of 72°C).

2.3. Color measurement

A Chroma Meter (Konika Minolta CR-5, Konika Minolta, INC., Japan) was used to measure the surface color of chicken rolls based on the Hunter Lab system. Hunter Lab values were expressed as L* (lightness), a* (redness), and b* (yellowness). Color measurements were taken from both sides of each chicken roll and the mean color values of three replicates were calculated.

2.4. Cooking loss determination

The chicken rolls were individually weighed before and after cooking. The cooking loss was calculated using the following formula, and expressed as a percentage.

$$\text{Cooking Loss } (\%) = [(Raw\ weight - Cooked\ weight)/Raw\ weight] \times 100$$

2.5. Texture Profile Analysis (TPA)

The TPA of the chicken rolls was performed using TA.XT Plus Texture Analyzer (Stable Micro Systems, UK). Four uniform test samples, each with a 25 mm diameter, were cut from each chicken roll for the TPA, and the test samples were compressed twice, to 50% of their original height, using a 36 mm cylindrical probe (P/36R) at a test speed of 10.02 cm/min. Force-time deformation curves were obtained, using a 50 kg load cell. The curves were calculated using Texture Exponent 2.0.6.0 software (Stable Micro Systems). Texture profile parameters were defined as below:
Hardness (N) = maximum peak force for the first compression cycle.
Adhesiveness (N.min) = negative force area for the first bite to pull away the compressing probe.
Springiness (ratio) = ability of the sample to recover its original shape between the end of the first bite and the start of the second bite. Cohesiveness (ratio) = ratio of the positive areas during the second compression area to the first compression area.
Gumminess (N) = hardness × cohesiveness.
Chewiness (N) = springiness × gumminess.
Resilience (ratio) = ratio of the area during the withdrawal of the first compression to the area of the first compression.

2.6. Statistical analysis

For optimization, the Design-Expert version 7.0.0 (State-Ease Inc., Minneapolis, MN, USA) was used to evaluate the experimental design, statistical analysis, and regression models. Linear, Quadratic, Cubic or 2FI models were obtained according to experimental data. Constant terms A, B, and C (linear coefficients for wheat flour, distilled water, and minced chicken, respectively), AB, AC and BC (interactive term coefficients), A^2, B^2, and C^2 (quadratic term coefficients) were the coefficients of the model. To evaluate the fitness of the model, correlation coefficient (R^2), adjusted determination coefficient (Adj-R^2) and adequate precisions were used. The model was determined to fit when its P value < 0.05, lack of fit P value > 0.05, and Adeq. Precision > 4. For statistical significance, when a level was set at $P < 0.05$, an analysis of variance (ANOVA) was used to examine differences between means.

3. RESULTS AND DISCUSSION

3.1. Color measurement

L*, a*, and b* values of samples are shown in Table 2. L* values were between 68.140 and 76.540. The coefficients of the variables in the regression models and their significance are shown in Table 3.

Table 2. Design and results of Box-Behnken experiments (color values and cooking loss).

Runs	A	B	C	L*	a*	b*	Cooking loss (%)
1	0	0	0	72.839	-0.113	11.793	-0.50
2	0	1	-1	71.186	-0.824	9.724	-0.98
3	-1	1	0	75.268	-1.059	10.623	0.68
4	0	0	0	73.402	-0.334	11.738	-0.34
5	0	1	1	75.321	-0.018	11.871	2.12
6	1	0	1	70.067	0.474	12.479	2.27
7	0	0	0	73.433	0.013	12.385	3.76
8	1	-1	0	68.140	1.648	14.702	1.88
9	-1	0	1	76.540	0.373	11.067	8.82
10	0	-1	1	74.013	0.587	11.819	1.83
11	1	1	0	72.434	0.216	12.236	-1.41
12	0	-1	-1	69.260	0.593	13.353	2.63
13	-1	-1	0	75.288	-0.120	11.450	5.26
14	1	0	-1	68.195	0.558	13.003	2.50
15	-1	0	-1	72.358	-0.988	10.490	5.11
16	0	0	0	73.357	-0.194	12.120	2.05
17	0	0	0	72.897	-0.249	11.282	0.69

A: Wheat flour; B: Distilled water; C: Minced chicken.

Effects on the L* value of the chicken rolls that were statistically significant for the model ($p< 0.05$) included: the linear effects of wheat flour (A), distilled water (B), and minced chicken (C); the interaction effects of wheat flour and distilled water (AB), wheat flour and minced chicken (AC); and the quadratic effect of minced chicken (C^2) (Table 3). The L* value decreased when the amount of distilled water and wheat flour increased. However, it increased when the amount of minced chicken increased. Previous studies reported a high correlation between moisture and L* value for meat products (COSTA-CORREDOR *et al.*, 2009; GARCÍA-ESTEBAN *et al.*, 2003; SANABRIA *et al.*, 2004). DEVATKAL *et al.* (2011) determined that the addition of 10% sorghum flour into the chicken nugget formulation tended to lower the L* value of the products. Because meat muscles contain a high amount of water, increasing the meat content in the product increases the L* value (DEVATKAL *et al.*, 2011). In our study, increasing minced chicken content yielded greater lightness of the chicken rolls, but increasing the water content decreased the L* value of the samples. It is suggested that the cooking loss of the products increased in accordance with increased levels of water content. Thus, an increasing concentration of pigments (e.g., myoglobin) during the cooking process produces a darker coloration in the chicken rolls.

As we observed in our results, GARCÍA-ESTEBAN *et al.* (2003) also found that ham *Semimembranosus* (SM) muscle has a lower L* value, depending on dehydration (GARCÍA-ESTEBAN *et al.,* 2003).

The quadratic regression model for L* value is as follows:

$$L^* = +73.19 - 2.58A + 0.94B + 1.87C + 1.08AB - 0.58AC - 0.87C^2$$

a* values of the chicken rolls were between-1.059 and 1.648. The linear effects of wheat flour (A), distilled water (B), minced chicken (C), and the interaction effect of wheat flour - minced chicken (AC) were significant ($p < 0.05$). The 2Fl regression model for a* value results is shown below:

$$a^* = +0.033 + 0.59A - 0.55B + 0.26C - 0.36AC$$

a* values of the chicken rolls increased as distilled water content decreased, according to the regression model. As increased water content has a diluting effect on the myoglobin responsible for the color pigment of the meat, increasing the water content in the chicken roll resulted in a lower a* value. KHARE *et al.* (2015) also reported that decreasing the meat level in chicken noodles reduced the redness caused by the concentration of pigments (KHARE *et al.,* 2015).

The b* values of samples ranged from 9.724 to 14.702. Wheat flour (A) and distilled water (B) had a significant linear effect on b* value ($p < 0.05$). Thus, the decreased quantity of wheat flour yielded low b* values. The interaction effect of distilled water--minced chicken (BC) was statistically significant for the model ($p < 0.05$). It has been reported that the addition of 7.5% and 10.0% bean flour to beef sausages increases the yellowness of samples, depending on the dilution of the myoglobin in the meat and, to some extent, the color of the flour additives (DZUDIE *et al.,* 2002). The 2Fl regression model for b* value is as follows:

$$b^* = +11.89 + 1.10A - 0.86B + 0.92BC$$

Although the results of L* value are similar to some studies previously conducted on different poultry meat products, b* values were relatively higher than the values reported by previous studies (HEATON *et al.,* 2000; TANG and CRONIN, 2007; TANG *et al.,* 2005). Also, a* values were relatively lower than the values reported by TANG and CRONIN (2007) and TANG *et al.* (2005). Differences for a* and b* values could be related to the amounts of wheat flour and rice starch used in this study or to the different types of poultry meat used in previous studies.

Analysis of variance (ANOVA) of the regression models for all responses is shown in Table 4.

Table 3. The coefficients of the variables in the regression models and their significance.

	Constant	A	B	C	AB	AC	BC	A^2	B^2	C^2	Model
Hardness	89.05	17.02*	-16.33*	1.49	_	_	_	_	_	_	Linear
Adhesiveness	-9.97E-003	-2.39E-003*	-3.65E-003*	+1.35E-003	-1.65E-004	+3.42E-003*	-2.52E-003	_	_	_	2FI
Gumminess	69.68	12.40*	-13.65*	-0.21	_	_	_	_	_	_	Linear
Chewiness	59.79	9.57*	-13.04*	0.39	_	_	_	_	_	_	Linear
Resilience	0.38	-6.24E-003	-0.019*	-0.015*	_	_	_	_	_	_	Linear
L*	73.19	-2.58*	0.94*	1.87*	1.08*	-0.58*	-0.15	-0.53	0.13	-0.87*	Quadratic
a*	0.033	0.59*	-0.55*	0.26*	-0.12	-0.36*	0.20	_	_	_	2FI
b*	11.89	1.10*	-0.86*	0.083	-0.41	-0.27	0.92*	_	_	_	2FI
Cooking Loss	1.13	-1.83*	-1.40*	0.72	0.32	-0.98	0.97	1.87*	-1.40	1.67	Quadratic

*Significant at 5% level, A: Wheat flour; B: Distilled water; C: Minced chicken.

Table 4. ANOVA for examination of every regression model Adequac.

	Model					Lack of fit	
Responses	**F Value**	**P Value**	**R^2**	**Adj-R^2**	**Adeq. Precision**	**SS**	**P Value**
Hardness	23.51	<0.0001*	0.8443	0.8084	17.274	753.45	0.0735**
Adhesiveness	6.89	0.0041*	0.8051	0.6882	9.504	3.409E-005	0.5450**
Springiness	2.87	0.0771**	0.3985	0.2596	5.511	4.281E-003	0.9260**
Cohesiveness	3.36	0.0520**	0.4367	0.3067	5.834	4.169E-003	0.1790**
Gumminess	24.04	<0.0001*	0.8473	0.8120	17.486	432.80	0.1292**
Chewiness	17.34	<0.0001*	0.8001	0.7539	14.692	471.02	0.0980**
Resilience	4.92	0.0169*	0.5316	0.4235	7.626	2.698E-003	0.7154**
L*	50.07	<0.0001*	0.9847	0.9650	24.761	1.19	0.0854**
a*	15.77	0.0001*	0.9044	0.8471	14.717	0.61	0.0558**
b*	20.65	<0.0001*	0.9253	0.8805	16.417	0.91	0.5800**
Cooking Loss	4.00	0.0405*	0.8374	0.6282	8.227	4.46	0.7217**

Adj-R^2.adjusted determination coefficient; SS. Sum of square; *significant; ** not significant.

High F values (50.07, 15.77 and 20.65, for L*, a*, b*, respectively) and low P values (<0.0001, 0.0001, and <0.0001, for L*, a*, b*, respectively), indicate that the models were significant for L*, a* and b* values. The R^2 of predicted models for L*, a*, and b* values were 0.9847, 0.9044, and 0.9253, respectively. The Adj.R^2 value indicated a degree of linear fit between the predicted and experimental values, which were 0.9650 for L* value, 0.8471 for a* value, and 0.8805 for b* value. The P value of the lack-of-fit test was 0.0854 for L* value, 0.0558 for a* value and 0.5800 for b* value; these values indicate that the model fit the experimental data. Based on these results, the model of color parameters was adequate for predicting within the range of the variables employed.

3.2. Cooking loss determination

The cooking loss values of samples ranged from-1.41% to 8.82%, as shown in Table 2. The linear effects of wheat flour (A) and distilled water (B) and the quadratic effect of wheat flour (A^2) on the cooking loss of the chicken rolls were statistically significant for the model ($p< 0.05$) (Table 3). The negativity in cooking loss value can be explained by the interaction between the water in the water bath and in the chicken roll recipe during the cooking process.

Guar gum is widely used in the food industry for its thickening properties, which operate by its interaction with water and stabilizing effect on food matrices, and by its ability to favorably interact with gluten proteins and increase dough stability (LINLAUD *et al.*, 2009; SANDHU *et al.*, 2015). In our study, the thickening effect of guar gum on higher levels of water resulted in lower amounts of cooking loss. Therefore, increased quantities of distilled water produced low cooking loss values. WANG and CHEN (1987) also found that the cooking yields of poultry meats were higher when more water was added (WANG and CHEN, 1987).

The quadratic regression model for cooking loss results is shown below:

$$\text{Cooking loss} = +1.13 - 1.83A - 1.40B + 1.87A^2$$

The model was significant for cooking loss, with regard to F value (4.00) and P value (0.0405). The R^2 of the predicted model for cooking loss was 0.8374, indicating that more than 83% of the variability in cooking loss could be explained by the model. The regression model shows that cooking loss could be predicted within the range of the variables employed.

3.3. Texture Profile Analysis (TPA)

The results of the TPA are shown in Table 5. The hardness values of the chicken rolls were between 57.410 N and 123.069 N. Wheat flour (A) and distilled water (B) had a significant effect on the hardness of the samples ($p< 0.05$) (Table 3). The hardness of the chicken rolls rose when large amounts of flour were added to the formulation, but it fell when large amounts of water were added. This can be explained by the high water-and fat-absorption properties of flour and the softening effects of water. As we observed in our results, DEVATKAL *et al.* (2011) reported that the addition of 10% sorghum flour into chicken nuggets' formulation significantly increased the nuggets' hardness ($p<0.05$). By contrast, DZUDIE *et al.* (2002) found that the shear force and hardness of beef sausages decreased with the addition of common bean flour.

Table 5. Design and results of Box-Behnken experiments (TPA).

Runs	A	B	C	Hardness (N)	Adhesiveness (N.min)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)	Resilience
1	0	0	0	82.077	-0.007	0.874	0.776	63.918	56.298	0.362
2	0	1	-1	72.848	-0.015	0.803	0.767	55.889	45.065	0.351
3	-1	1	0	67.193	-0.009	0.883	0.774	51.914	46.218	0.370
4	0	0	0	85.947	-0.013	0.889	0.808	69.472	58.818	0.372
5	0	1	1	78.032	-0.018	0.845	0.739	57.384	49.187	0.328
6	1	0	1	110.629	-0.007	0.859	0.762	84.605	73.447	0.361
7	0	0	0	81.591	-0.008	0.796	0.786	63.968	51.408	0.383
8	1	-1	0	123.069	-0.010	0.840	0.753	92.152	77.474	0.368
9	-1	0	1	78.479	-0.009	0.878	0.773	60.679	53.317	0.374
10	0	-1	1	103.109	-0.003	0.900	0.786	80.905	72.685	0.392
11	1	1	0	83.436	-0.015	0.814	0.768	63.492	51.823	0.375
12	0	-1	-1	119.455	-0.010	0.877	0.786	94.217	83.165	0.408
13	-1	-1	0	86.515	-0.005	0.895	0.818	70.623	63.327	0.410
14	1	0	-1	108.615	-0.018	0.860	0.818	88.664	76.981	0.409
15	-1	0	-1	57.410	-0.006	0.848	0.812	46.509	40.315	0.409
16	0	0	0	91.872	-0.008	0.832	0.798	72.836	61.076	0.394
17	0	0	0	83.586	-0.008	0.821	0.805	67.320	55.864	0.417

A: Wheat flour; B: Distilled water; C: Minced chicken.

This can be explained by the fact that the beef sausage formulation contained meat in large quantities and lacked any hydrocolloid that would have increased the hardness (DEVATKAL *et al.,* 2011).

The linear regression model for hardness is as follows:

$$\text{Hardness} = +\,89.05 + 17.02A - 16.33B$$

Adhesiveness results of the samples ranged from-0.018 N.min to-0.003 N.min. The linear effects of wheat flour (A) and distilled water (B) and the interaction effect of of flour--minced chicken (AC) were statistically significant ($p < 0.05$) for the adhesiveness of chicken rolls (Table 3). VERMA *et al.* (2015) also reported that incorporating 8% pea hull flour into low-fat low-salt chicken nuggets resulted in a decrease in the adhesiveness value of the samples (VERMA *et al.,* 2015). The 2Fl regression model for adhesiveness is shown below:

$$\text{Adhesiveness} = -9.967\text{E-}003 - 2.393\text{E-}003A - 3.654\text{E-}003B + 3.420\text{E-}003AC$$

Springiness values of the chicken rolls were between 0.796 and 0.900. Cohesiveness results of the samples ranged from 0.739 to 0.818. The high P values for springiness and cohesiveness indicated that none of the regression models were a fit for these textural parameters.

Gumminess values of the chicken rolls ranged from 46.509 N to 94.217 N. The linear effects of wheat flour (A) and distilled water (B) were significant for the gumminess of the chicken rolls. These effects showed that decreasing the quantity of wheat flour or increasing the quantity of distilled water yielded less gummy chicken rolls. DEVATKAL *et al.,* (2011) found similar results with an addition of 10% sorghum flour, which enhanced the gumminess of the chicken nuggets (DEVATKAL *et al.,* 2011). Furthermore, it was reported that 10% sorghum flour or 10% finger millet flour significantly increased the gumminess of chicken patties ($p<0.05$)(DAS *et al.,* 2015). The linear regression model for gumminess is as follows:

$$\text{Gumminess} = +69.68 + 12.40A - 13.685B$$

Chewiness values of the samples ranged from 40.315 N to 83.165 N. As they were for gumminess, the linear effects of wheat flour (A) and distilled water (B) were statistically significant for the chewiness of chicken rolls. The chewiness value decreased as the quantity of distilled water increased, while chewiness increased as the quantity of wheat flour increased. It has been determined that incorporating 8% pea hull flour into low-fat low-salt chicken nuggets increases the chewiness of the samples. Adding 10% sorghum flour to the recipes for chicken nuggets and for chicken patties recipes resulted in significantly higher chewiness values ($p<0.05$)(DAS *et al.,* 2015; DEVATKAL *et al.,* 2011; VERMA *et al.,* 2015). The linear regression model for chewiness is shown below:

$$\text{Chewiness} = +59.79 + 9.57A - 13.04B$$

Resilience values of the chicken rolls were between 0.328 and 0.417. The distilled water (B) and the minced chicken (C) each had an individual linear effect that was statistically significant for the model of resilience. Thus, the resilience value of the chicken rolls increased when the amount of either the distilled water or the minced chicken was decreased. The linear regression model for resilience is as follows:

$$\text{Resilience} = +0.38 - 0.019B - 0.015C$$

While the values of hardness are similar to those of the turkey rolls reported by Tang *et al.*, 2005, the values of cohesiveness and gumminess are relatively higher than those of the same turkey rolls (TANG *et al.*, 2005). These differences with regard to cohesiveness and gumminess (between our chicken rolls and the previously studied turkey rolls) could be related to the cooking methods and food additives used in this study.

The P value, F value, R^2, Adj-R^2 and Adeq. Precision estimates of the adequacy of each model are shown in Table 4. The models are significant for hardness, adhesiveness, gumminess, chewiness, and resilience; this is reflected by high F values (23.51, 6.89, 24.04, 17.34 and, 4.92, respectively) and low P values (<0.0001, 0.0041, <0.0001, <0.0001, and 0.0169, respectively). As springiness and cohesiveness had low F values (2.87 and 3.36, respectively) and high P values (0.0771 and 0.0520, respectively), the models are not significant for springiness and cohesiveness. The R^2 of the predicted models are 0.8443 for hardness, 0.8051 for adhesiveness, 0.8473 for gumminess, 0.8001 for chewiness, and 0.5316 for resilience; however the R^2 for springiness and cohesiveness are relatively low (0.3985 and 0.4367, respectively). The Adj.R^2 values are 0.8084 for hardness, 0.6882 for adhesiveness, 0.8120 for gumminess, 0.7539 for chewiness and 0.4235 for resilience. The low Adj.R^2 values for springiness and cohesiveness (0.2596 and 0.3067, respectively) indicate quite a low degree of linear fit between the predicted and experimental values for these models. Based on these results, the models for hardness, adhesiveness, gumminess, chewiness, and resilience are adequate for predicting within the range of the variables employed, but the models for springiness and cohesiveness are not adequate for this purpose.

3.4. Optimization of quantities of ingredients and the validation of the model

To optimize textural properties, color, and cooking loss values, numerical optimizations were applied. The aim of this study was to provide the formulation of the chicken roll resulting in the highest values of L*, a*, springiness, resilience and the lowest values of b*, cooking loss, hardness, adhesiveness, gumminess, and chewiness. As optimization criterion, all relevant product characteristics of chicken rolls were selected on the basis of maximum yield and quality variables, as determined by previous studies (ANDRÈS *et al.*, 2006; ANDRÉS *et al.*, 2006; DU *et al.*, 2003; SOMBOONPANYAKUL *et al.*, 2007).The effects of wheat flour, distilled water, and minced chicken contents on L* value (Figs. 1a-c) and cooking loss (Figs. 1d-f) are shown in 3-D surface plots. The wheat flour of 8.66 g, the distilled water of 75.00 g, and the minced chicken of 53.83 g are identified as the predicted optimum quantities of ingredients for the chicken roll. Based on these optimized quantities, the predicted values are 76.153 for L*, -0.3576 for a*, 11.3484 for b*, 3.02492 for cooking loss, 60.8873 for hardness, -0.01428 for adhesiveness, 46.508 for gumminess, 39.7841 for chewiness and 0.3564 for resilience. The desirability value of these predicted values was 0.703.

To verify the model's adequacy, all experiments were performed with optimum formulations. The experimental values of each response were compared with the predicted values, and the calculated error rates are shown in Table 6. The error rates of all responses are lower than 10%. Thus, a high level of agreement was observed between the experimental values and the predicted values.

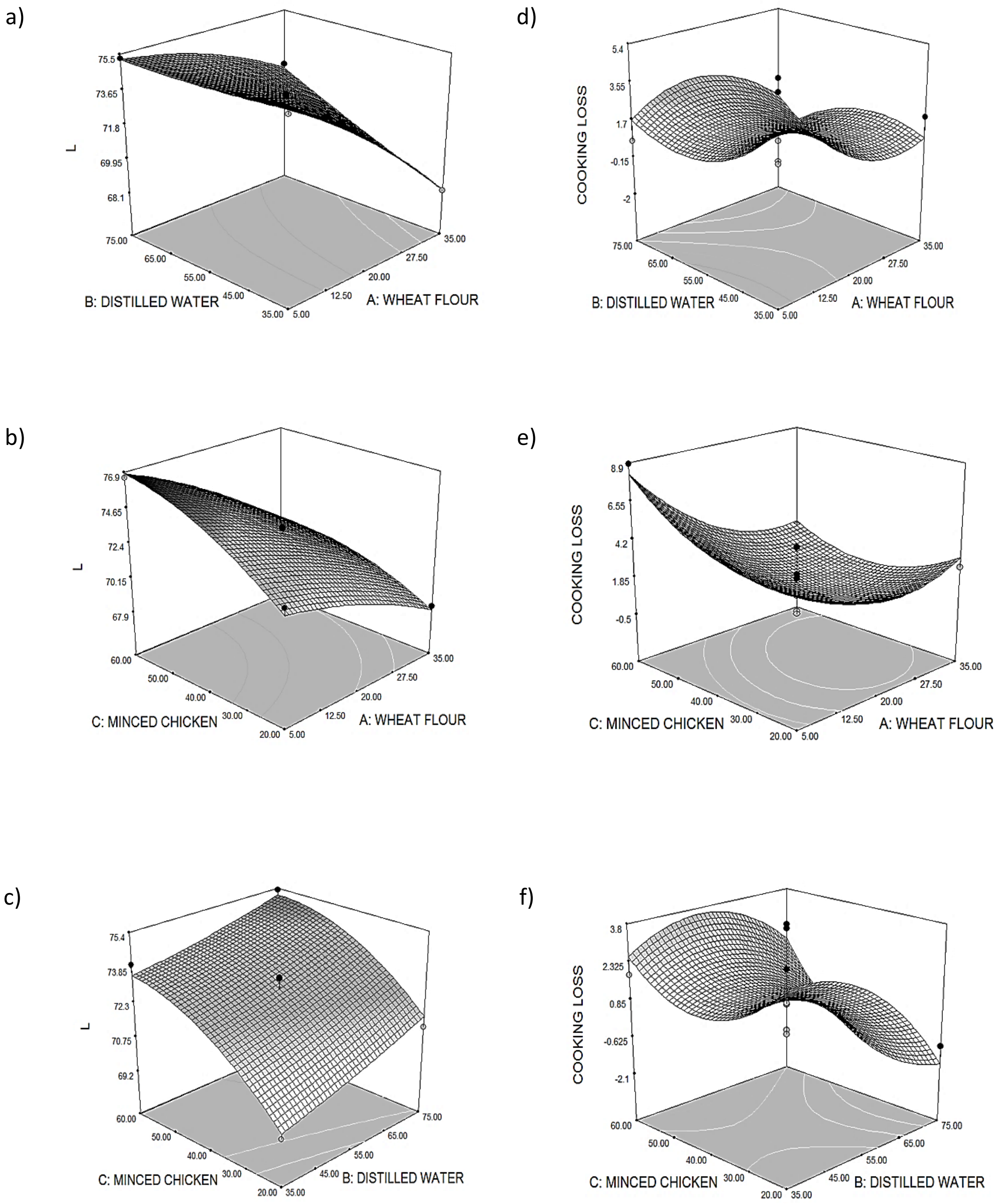

Figure 1. Response Surface Plots for L* Value (a,b,c) and Cooking Loss (d,e,f).

4. CONCLUSIONS

The interest in poultry and poultry products has grown over the last decade. To meet this increasing demand in today's living conditions, different fast food products need to be developed. A limited number of studies have been conducted on the optimization of new product development. In this study, the most suitable recipe for the chicken roll, a fast and healthy product with desirable textural and physical properties, has been determined. According to the results of this study, adding wheat flour to the chicken roll recipe increases the hardness and gumminess of the product. However, increasing the water content in the formulation decreases the hardness, gumminess and chewiness of the product. It was observed that the L* values of the chicken rolls made with a low wheat flour content and a high minced chicken content were relatively higher than those in the other experiments. As a result of this study, an alternative poultry product that is ready-to-eat and rich in desired textural and quality characteristics has been developed; future studies should aim to determine the product's sensorial and microbiological properties.

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