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Textural characteristics of pasta enriched with full fat soy flour; An optimization study using Response Surface Methodology

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Abstract

The influence of 0-27 g/100g of full-fat soy flour (FFSF), 31-35g/100g of water content and extrusion conditions on the textural characteristics of spaghetti were evaluated. Process was performed with screw speed of 10-40 rpm and water circulating temperature of 35-70$^{\circ C}$. This enrichment resulted in significant differences in mechanical strength and cutting parameter. Based on the mixture surface and contour plots, it was found that the optimum textural characteristic of spaghetti could be obtained by addition of 20.6 g/100g FFSF and 35.0 g/100g water and process in screw speed of 40 rpm and temperature of 35^{oC}.

Keywords: Spaghetti; Mixture design; Rheology.

Introduction

Durum wheat flour is the main ingredient in the formulation of pasta products; however, it is deficient in lysine. Therefore, many researchers have focused on improving of pasta quality by addition of ingredients such as lupine (Rayas et al., 1996; Morad et al., 1980), cowpea (Bergman *et al*., 1994), gluten (Cubadda, *et al*. 2007), quinoa, broad bean, chick pea and buck wheat (Chillo, *et al*., 2008), corn (Taha *et al*., 1992), wheat bran (Manthey *et al*., 2002), barley bran (Marconi *et al*., 2000) and dietary fiber of pea (Edwards *et al*., 1995).

Dough rheology effects by substitution of gluten by proteins such as legume seeds proteins. This substitution causes dilution of gluten, and consequently, it weakens dough. Therefore, the gluten network has a great influence on the rheological parameters of the dough. Furthermore, the quantity of added water is very important, and it affects dough material distribution, dough hydration and subsequently gluten system development. The conversion of dough rheology may be due to the physicochemical changes of flour. This supported by the work of Kordonowy *et al*. (1985), who showed that as bran content in mixture of flour was increased, dough development time and water absorption was also increased. In addition, Morad *et al*. (1980) indicated that adding lupin and defatted soybean to wheat flour increased water absorption and dough stability and decreased dough development time. Moreover, Sroan *et al.* (2004) confirmed that soy lecithin (natural antioxidant) even at the minimum concentrations improves rheological properties of the dough.

Soybean has many valuable components and consumption of soybean products is useful for bone's health, healthy brain, immune function, controls the heart attack and some cancers. In our previous research, sensory and nutritional characteristic (Nasehi *et al*. 2009a) and cooking quality (Nasehi *et al*. 2009b) of spaghetti enriched with full fat soy flour were evaluated. Thus, the objective of this paper was to study the textural properties of this kind of enriched spaghetti.

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Materials and methods

Flour's analysis

The hard wheat flour (HWF) that produced from spring hard wheat (Golestan variety) was purchased from the main company (Razavi Corporation, Mashhad, Iran), whereas the full fat soy flour (FFSF) was obtained from the industrial unit (Toos Soya Corporation, Mashhad, Iran).

The standard methods of AACC (1995) were employed for the assessment of chemical composition of HWF and FFSF. All samples and their mixtures were analyzed for crude protein, crude fat, crude fiber, moisture, and ash.

Farinograph characteristics of flours were determined according to the approved method of AACC (54-21) using farinograph equipment (Brabender OHG, Duisburg, Germany). Farinograph characteristics of mixed flours such as water absorption, dough development time, mixing time, dough stability, mixing tolerance index and valurimitry index were extracted from farinograph curve.

Spaghetti formulations and production

The amount of the basic ingredient used for making spaghetti was calculated based on the standard methods of AACC (66-41). The range of concentration used in the formulation was as follows: HWF (42.0-69.0 g/100g), FFSF (0-27.0 g/100g) and distilled water (31.0- 35.0 g/100g).

In order to spaghetti production, all the ingredients were mixed prior to extrusion for 10 minutes at 70 rpm in a laboratory pasta maker (designed by Research & Development Center of Modern Food Technology, Ferdowsi University of Mashhad, Iran). The extruder parameters were as follows: screw length of 400 mm; barrel diameter of 35 mm; die diameter of 200 mm, includes 40 Orifice with a diameter 1.8 mm; flow rate of 6-26 kg/h. Two extrusion variables studied were screw speed (10-40 rpm) and temperature of circulating water (35-70℃).

From the mixture design used in this study, four different extrusion conditions (based on the temperature of circulating water and screw speed of extruder) were employed. These conditions were 40 rpm and 70℃; 40 rpm and 35℃; 10rpm and 70℃; 10rpm and 35℃. The mixing and extrusion processes were operated under partial vacuum (0.7-0.8 atm). Pressure in extruder was in the range of 200-1000 lbf/in^2 for different samples. Spaghetti samples were dried in a dryer at a local factory (Adish Corporation, Mashhad, Iran). Temperature of a dryer was fixed at 50℃, but the relative humidity was reduced gradually from 95.0% to 65.0% during the 20 h of drying period. The average diameter of spaghetti was 1.90±0.03mm.

Textural measurements

Mechanical strength

Mechanical strength of dehydrated spaghetti was measured using a texture analyzer (QTS, CNS Farnell, UK) for breaking of spaghetti strand. Mechanical strength was expressed as the force (gf) required breaking one strand of dry spaghetti. The conditions used throughout the experiment included a cross head speed of 10 mm/minutes and a load cell of 5kg. The textural properties of samples, including rupture force (g), hardness (g) and toughness (g.mm) were determined using the computer software provided by a texture analyzer.

Cooking time

Duration needed for optimum cooking of spaghetti based on the standard AACC method (16-50), is the time that white core was not observed after compressed the cooked spaghetti, and overcooking was obtained by adding 10 minutes to the best time needed for perfect cooking the spaghetti.

Cutting test

Surface stickiness of the sample was determined according to Dexter et al. (1983) with some modifications according to Grant *et al.* (1993). To measure of spaghetti stickiness, a texture analyzer (QTS, CNS Farnell, UK) with a shiny aluminum plate (100mm× 100mm× 6mm) as base plate, an aluminum plate (100x100x6 mm) as a sample holder with a rectangular opening (44mm×44mm) for plunger-to-sample access, and a polished aluminum plunger (43mm× 43mm) for contact surface was used.

Stickiness test was started 13 minutes after the end of cooking. One minute before testing, sample holder plate was placed over the spaghetti strands, and excess water was blotted using tissue. The plunger was moved vertically with a computer software program. Throughout the testing, a cross-head speed of 40mm/minutes was applied and afterward; adhesiveness work (g.mm) and stickiness (N/mm2) values were measured.

Statistical analysis

The design of experiments with mixtures and the applied response surface analysis was used. The main purpose of using this design was to verify how the rheological properties of spaghetti were affected by the variation of the proportions of the mixture components, i.e. the ingredients used in the spaghetti formulation.

A mixture design via the 36-point-extreme-vertices was constructed to enable the study of the effect of varying ratios of HWF, FFSF, and water content, and process conditions. The software (V14.2, 2005; Minitab Inc. Pennsylvania, State Collage, USA) was used to build the empirical design, the Scheffe's canonical special cubic equation for three components and two process variables was fitted to data collected at each experimental point using forward selection stepwise multiple regression analysis as described by Cornell (2002).

Result and discussion

Farinograph experiment

Results of farinograph experiment of flours samples are shown in Table 1. The results indicated that mixtures with the maximum amount of FFSF had the highest value for absorption of water, dough development time, valurimitry index, mixing time and mixing tolerance index. These results are supported by the work of Paraskevopoulou *et al*. (2010), which showed that adding lupin protein isolate to wheat flour increase the dough development time and dough stability plus the resistance to deformation and the extensibility of the dough. These enhancing effects might be the result entrapment of lupin protein particles within the gluten network system. It found that the vegetable proteins in the dough are in the form of hydrated but not fully in dispersed particles form. Similar results were reported by Roccia *et al*. (2009) who found that the substitution of wheat protein by soy protein decreased mixture elasticity, indicating dough network weakening. Gluten network formation was interfered with soy proteins probably due to both non-covalent and covalent wheat–soy protein interactions.

Furthermore, the proximate analysis of flours showed that the amount of protein, fiber, fat, moisture and ash in FFSF were 37.7, 14.0, 18.0, 5.0 and 5.0g/100g based on complete weight, relatively. The protein, fiber, fat, moisture and ash in HWF were 8.3, 0.3, 0.9, 13.0 and 0.5g/100g based on total weight, respectively. All the nutrient compositions in FFSF were higher than the HWF, except for moisture content

Table 1. Farinograph characteristics of flours [a]

Substitution (%)	Water absorption (%)	Mixing time (min)	Dough development time (min)	Dough stability (min)	Mixing tolerance index (BU)	Valurimitry Index
0[b]	61.5	1	2.5	9.5	47	50
9.2	64.9	1.4	3.5	9.15	50	52
9.5	65	1.5	4.6	9.5	65	57
18.7	68.7	2.4	4.9	10.4	70	55
26.9	71.5	3.5	5.4	10.25	70	58

[a] Mean belong to three replications.

[b] Hard wheat flour

Table 2. Mean values of the mechanical strength of spaghetti from different formulations [a]

Mixture	Toughness (g.mm)	Hardness (g)	Rupture force (g)
1	75.62	151.2	37.40
2	213.53	255.60	26.80
3	239.23	351.75	41.20
4	114.17	205.05	34.60
5	73.25	153.4	32.60
6	76.57	145.84	36.84
7	45.63	133.17	29.83
8	33.12	90.20	30.60
9	44.63	106.00	24.60
10	425.25	452.60	47.00
11	348.35	403.34	50.34
12	245.71	273.84	48.00
13	207.47	231.50	43.00
14	198.22	236.00	45.00
15	60.27	157.50	40.17
16	43.13	129.34	38.17
17	53.96	140.50	31.00
18	42.32	121.34	33.34
19	335.92	376.00	40.17
20	405.21	446.00	49.17
21	177.99	283.67	45.50
22	163.06	263.00	45.00
23	109.16	205.34	40.83
24	53.75	137.84	38.34
25	54.64	133.00	33.50
26	42.23	119.67	34.67
27	33.27	103.17	36.84
28	457.99	373.33	50.17
29	453.19	439.67	48.40
30	253.19	323.17	48.83
31	146.68	161.50	38.00
32	107.17	189.17	43.84
33	34.73	141.34	40.00
34	45.89	114.34	38.50
35	21.38	81.67	38.34
36	32.29	195.34	40.50
LSD[b]	95.72	93.36	5.512

[a] Mean belong to three replications.
[b] The smallest difference in column ($P \leq 0.05$)

Textural characteristics

Mechanical strength

Table 2 shows the mechanical strength of spaghetti, which includes rupture force, hardness and toughness. Predicted equations obtained from the regression analysis are listed in Table 3. Mixture of contour plots which are related to these equations are shown in Fig. 1(a-c).

When hardness values of enriched spaghetti were taken into consideration, it was noted that the fortified spaghetti samples had lower hardness compared to the control (Fig.1b). The hardness decreased ($P \leq 0.05$) from 452 grams in spaghetti made from HWF to 80 grams in the sample enriched with 27 g/100g FFSF (Table 2). The regression analyses indicated that the interactions between water, HWF and temperature of circulating water decreased hardness via linear ($P \leq 0.05$) term (Table 3).

This is not supported by the work of Sozer *et al.* (2008) which showed that spaghetti enriched with bran had higher hardness and lower adhesiveness than other spaghetti samples.

Cutting parameters

Table 4 shows the cutting test characteristics of spaghetti, which includes firmness, cutting force, work to cut (cutting energy) and maximum cutting stress. Predicted equations obtained from the regression analysis are listed in Table 5. Mixture of contour plots which are related to these equations are shown in Fig. 2 (a-f).

In general, the firmness of spaghetti after optimum cooking time was higher for the spaghetti contains FFSF (Fig.2a). The firmness increased (P≤0.05) from 3.97g.cm in spaghetti made from HWF to 8.43g.cm in the sample enriched with FFSF (Table 4). The interactions between ingredient and temperature of circulating water had positive significant effects on this character via linear (P≤0.01) term (Table 5). When spaghetti samples were overcooked (Fig.2b), the firmness was not changed significantly (P≤0.05).

Several factors are believed to be important in the firmness estimation, flour composition (particularly type of protein and its composition), cooked pasta diameter and water absorption are the main ones. Our study also revealed that protein composition had an impressive effect on pasta firmness. This finding was in agreement with that of Grant et al. (1993) who reported that firmness of spaghetti made from weak wheat was lower than control. They discovered that cutting parameter of spaghetti in relation to damaged starch was due to shortage gluten content. Furthermore, Edwards et al. (1995) showed spaghetti enriched with bran after optimum and over cooking, time was softer than control, due to disrupter gluten-starch network.

Stickiness parameters

Table 4 shows the stickiness parameters of spaghetti which includes adhesiveness work and stickiness. Predicted equations obtained from the regression analysis are listed in Table 5. Mixtures of contour plots which are related to these equations are shown in Fig. 3(a-d).

In general, the adhesiveness work after optimum cooking time of enriched samples was lower than control (Fig. 3a). This parameter decreased (P≤0.05) from 308 g.mm in spaghetti made from HWF to 213g.mm in a sample enriched with FFSF (Table 4). When spaghetti samples were overcooked, this parameter decreased significantly (P≤0.05) in enriched spaghetti (Fig. 3b). The regression analyses indicated that the ingredients used in the formulation had a significant effect on this parameter for optimum and over cooking time via linear (P≤0.001) term (Table 5). When a stickiness value of enriched spaghetti was taken into consideration, it was found that this parameter was not changed significantly (P≤0.05) after optimal and over cooking time (Fig. 3 c & d). This finding was supported by Rho et al. (1989), who concluded that fatty acids produced in a storage period restrict inflation of starch and therefore, affect the viscosity of starch and decrease stickiness of a noodle. On the other hand, Matsuo et al. (1986) confirmed that unipolar lipids prevent surface stickiness in spaghetti.

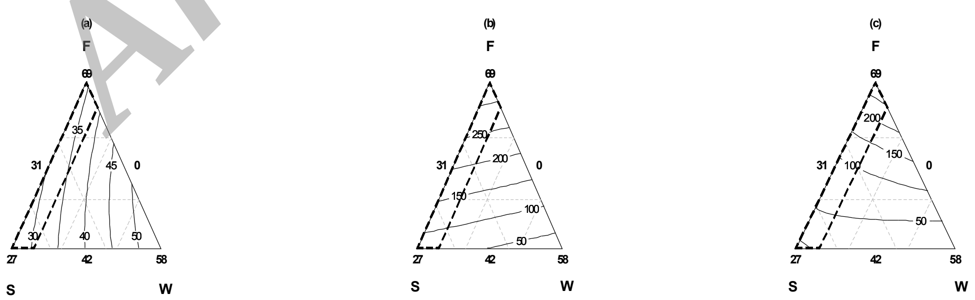

Fig. 1. Mixture contour plots of the predicted surface for cooking and color quality of pasta enriched with full fat soy flour (FFSF) dependent on components in the conditions optimized; (a), Rupture force (b) Hardness, (c) Toughness

Table 3. Predicted model for experimental data of Mechanical strength of the spaghetti [a, b]

Parameter	Predicted model	R^2 value	R^2 Adjust
Rupture force	$= 0.514\,F + 0.1009\,S + 0.309\,W - 0.0665\,WR^{***} - 0.7269FT^{**} + 0.0211\,FWT^{**} - 0.0540FRT^{***}$	0.80	0.759
Hardness	$= 7.1878\,F - 2.8195S - 4.3138\,W - 0.0122\,FWT^{*}$	0.769	0.748
Toughness	$= 6.704\,F + 16.2931\,S - 3.436\,W - 0.5109\,FS^{**} + 0.0519\,FSRT^{*} - 0.0309\,FWRT^{***}$	0.845	0.817

a F: Hard wheat flour, S: Full fat soy flour, W: Water content, R: Screw speed of extruder. T: Temperature of circulating water.
b ***: P≤0.001, **: P≤0.01, *: P≤0.05, without *: Significance was not calculated because of it was a forced term.

Table 4. Mean values of the cutting and stickiness parameters of spaghetti from different formulations [a]

Mixture	Stickiness (N/m2)		Adhesiveness work (g.mm)		Maximum cutting stress (g/mm^2)		Work to cut (g/mm)		Cutting force (g)		Firmness (g.cm)	
	Over	Opt	Over	Opt	Over	Opt	Over	Opt	Over	Opt	Over	Opt
1	265.28	305.1	344.4	281.0	9.76	11.59	43.37	52.22	95.34	107.0	4.36	4.82
2	334.25	342.4	294.4	258.1	10.00	11.23	44.03	43.75	99.00	102.0	4.22	3.97
3	509.3	448.3	282.9	266.3	10.48	11.49	44.21	46.86	100.0	110.3	4.92	4.50
4	353.6	382.0	300.9	265.9	11.22	13,20	50.21	57.41	110.3	122.0	4.78	5.30
5	329.0	326.3	294.2	269.8	11.74	14.22	50.27	58.86	111.7	130.7	4.52	5.41
6	350.2	344.9	266.1	264.4	11.50	14.66	49.28	61.38	105.7	127.0	5.88	5.32
7	376.7	331.6	271.2	251.4	13.00	17.51	61.67	76.55	124.0	148.7	5.10	6.50
8	448.3	313.0	282.1	245.6	12.32	14.09	54.65	60.42	114.0	124.0	5.42	5.32
9	419.1	435.1	235.6	228.0	13.35	18.40	59.27	71.31	122.0	152.7	4.60	5.92
10	300.6	307.7	329.7	284.0	9.65	13.08	44.47	56.99	100.0	124.7	3.52	5.43
11	373.1	280.0	314.3	274.5	7.39	16.36	33.62	68.69	73.34	151.0	4.70	6.34
12	385.5	360.8	314.0	239.0	11.08	13.44	48.07	58.38	108.3	124.3	5.06	5.40
13	295.3	260.0	314.6	260.9	10.20	14.07	49.64	63.51	104.0	103.3	4.41	5.88
14	389.1	321.0	282.6	251.6	10.00	14.19	43.71	59.3	101.0	131.7	4.44	5.50
15	369.6	362.5	275.0	234.7	9.93	20.36	44.60	93.84	99.00	183.0	4.81	8.43
16	482.8	565.0	265.6	228.8	10.84	16.90	48.34	74.15	108.0	154.0	4.72	6.76
17	314.8	442.1	276.0	213.7	11.79	18.40	49.90	86.5	111.7	164.0	4.67	7.70
18	422.6	341.4	260.8	237.4	11.36	19.27	49.08	91.46	108.0	170.0	4.10	8.10
19	318.3	323.6	338.2	290.6	8.62	12.65	39.44	51.74	66.89	112.4	4.50	4.59
20	369.6	364.3	328.8	285.8	10.53	12.01	45.47	51.56	104.3	113.0	5.08	4.85
21	431.5	397.9	311.8	183.2	10.18	15.69	50.03	70.42	105.7	148.3	5.2	6.66
22	341.4	341.4	312.7	278.2	10.63	13.41	49.92	55.76	108.3	127.0	4.56	5.28
23	410.3	329.0	301.8	280.0	10.35	15.52	46.10	67.06	102.3	139.7	4.25	6.04
24	463.4	387.3	285.5	232.7	10.34	17.63	45.00	75.64	97.67	155.7	4.00	6.68
25	509.3	413.8	287.4	241.5	9.60	17.13	42.67	79.93	90.00	148.0	4.67	6.90
26	521.7	311.3	242.6	245.0	11.90	18.87	51.43	78.82	108.3	161.3	4.67	6.74
27	481.1	334.3	259.6	241.6	11.53	14.98	50.28	69.74	107.0	139.3	4.17	6.49
28	373.1	273.2	354.6	271.1	8.77	11.40	41.09	49.71	89.00	110.0	3.71	4.79
29	328.9	443.9	371.6	308.4	8.24	11.51	36.60	46.20	83.66	107.5	3.77	4.45
30	491.7	562.4	315.0	270.8	8.67	13.60	37.85	61.18	86.33	128.3	4.32	5.70
31	535.9	408.5	311.6	278.0	9.86	13.35	42.76	49.92	99.67	125.5	3.88	4.81
32	527.9	295.2	284.0	257.2	8.90	12.70	39.35	54.41	87.66	114.3	4.01	4.93
33	410.3	326.3	267.24	218.0	10.10	15.03	43.20	62.83	93.75	128.7	3.87	5.37
34	631.4	554.4	233.8	234.3	9.50	14.21	40.96	61.36	89.75	124.3	3.87	5.37
35	382.0	228.1	280.5	231.6	9.76	15.67	41.87	69.37	95.25	131.7	3.86	5.83
36	527.9	299.8	237.1	238.3	10.70	16.30	42.00	71.11	98.3	134.7	4.00	5.87
Lsd[b]	110.5	-	27.96	32.01	1.201	2.222	6.126	11.68	11.84	17.49	0.6197	1.016

a Optimum cooking (opt), over cooking (over).
bThe smallest difference in column (P ≤ 0.05)

Table 5. Predicted model for experimental data of the cutting and stickiness parameters of the spaghetti [a, b]

Parameter		*Predicted model*	*R^2 value*	*R^2 Adjust*
Firmness	Optimum cooking	=0.0416 F + 0.1096 S + 0.0654 W – 0.0157 WT***	0.670	0.639
	Overcooking	= 0.0394F + 0.0530 S + 0.0496 W + 0.1185 $\times 10^{-4}$ FSWR*** + 0.0004 SWRT**	0.531	0.471
Cutting force	Optimum cooking	= 1.3358 F + 2.650S + 0.8363 W + 4.909 SR* - 0.1423 SWR* - 0.2933 WT***	0.750	0.709
	Overcooking	= 0.9217 F + 1.3565 S + 1.0139 W+ 0.0002 FSWR*** + 0.0759 FRT**	0.601	0.549
Work to cut	Optimum cooking	=0.3533 F + 1.3325 S + 0.8615 W – 0.1734 WT***	0.727	0.701
	Overcooking	= 0.3159 F + 0.5998 S + 0.6405 W + 0.0001 FSWR*** + 0.0824 WRT***	0.651	0.606
Maximum cutting stress	Optimum cooking	= 0.129 F + 0.3297 S + 0.1123 W – 0.0280 WT**	0.735	0.710
	Overcooking	= 0.0937 F + 0.1791 S + 0.0917 W + 0.2357 $\times 10^{4}$ FSWR*** + 0.0170 WRT***	0.739	0.705
Adhesiveness work	Optimum cooking	= 3.4583 F + 1.6806 S + 1.3399 W	0.450	0.418
	Overcooking	= 2.7616 F – 0.2601 S + 4.4 W	0.760	0.745
Stickiness	Optimum cooking	=5.5619F+6.6271S 0.03366W	0.025	0.000
	Overcooking	= 5.7881F + 9.8154S – 0.8403W – 0.0528 FSR**	0.434	0.381

a F: Hard wheat flour, S: Full fat soy flour, W: Water content, R: Screw speed of extruder. T: Temperature of circulating water.
b ***: P≤0.001, **: P≤0.01, *: P≤0.05, without *: Significance was not calculated because of it was a forced term.

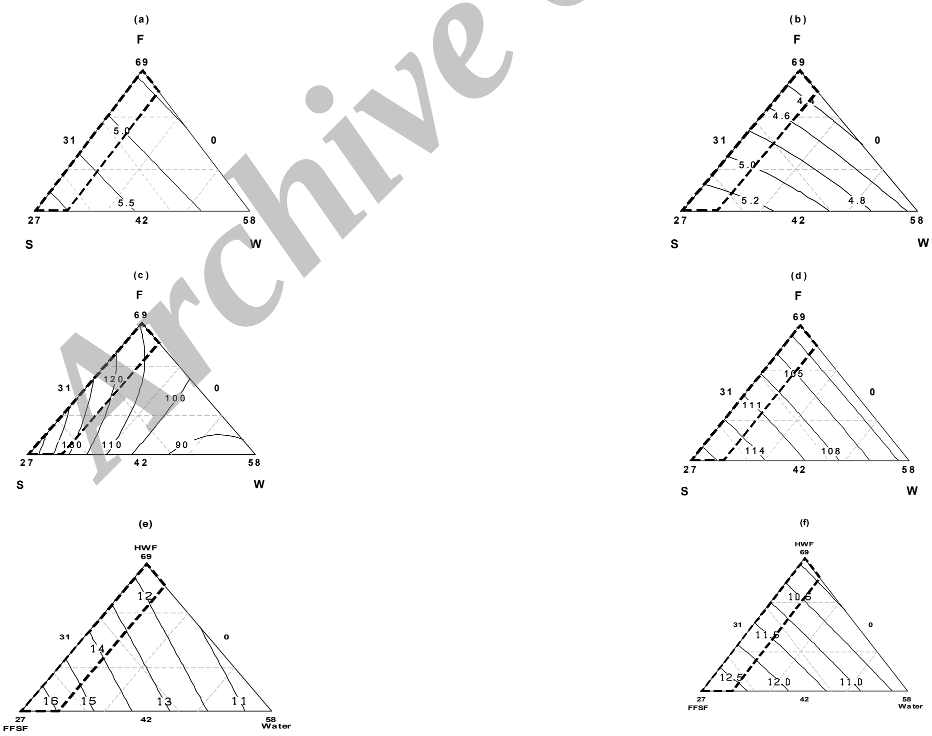

Fig. 2. Mixture contour plots of the predicted surface for cooking and color quality of pasta enriched with full fat soy flour (FFSF) dependent on components in the conditions optimized; (a) Firmness for optimum cooking, (b) Firmness for overcooking, (c) Cutting force for optimum cooking, (d) Cutting force for overcooking, (e) Maximum cutting stress for optimum cooking, (f) Maximum cutting stress for overcookin

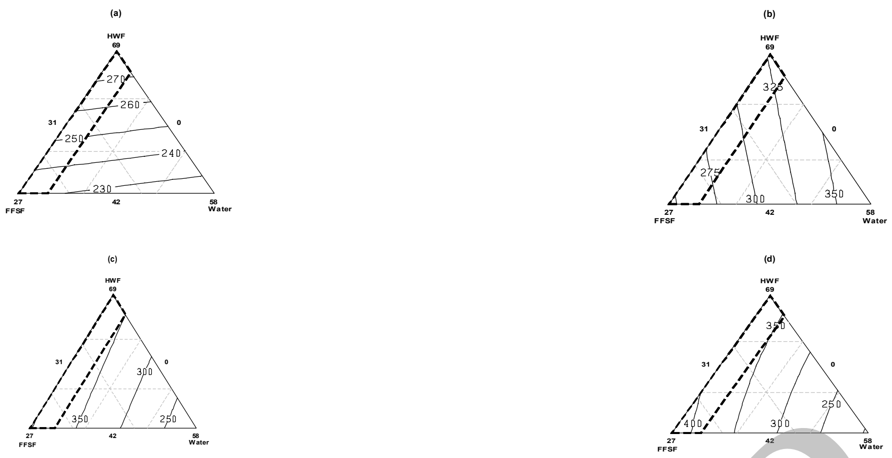

Fig. 3. Mixture contour plots of the predicted surface for cooking and color quality of pasta enriched with full fat soy flour (FFSF) dependent on components in the conditions optimized; (a) Adhesiveness work for optimum cooking, (b) Adhesiveness work for overcooking, (c) Stickiness for optimum cooking, (d) Stickiness for overcooking

Conclusions

Addition of FFSF and extrusion processing conditions influenced the texture of spaghetti. This enrichment resulted in significant differences (P≤0.05) in mechanical strength and cutting parameters, but when FFSF was increased, no significant difference was observed in the stickiness characteristics after optimum and over cooking time. All predicted models for mechanical strength showed high regression ($R^2 \geq 75.0$), while for cutting and stickiness parameters, the value was low ($R^2 \leq 75.0$). Our results revealed that temperature of circulating water and screw speed of extruder had no significant effect independently on the textural characteristic of FFSF-fortified spaghetti. Of course, the interaction between them and components after optimum cooking time had a positive on the cutting parameters. On the other hand, interaction between components and process variable after over cooking time had a negative mechanical strength and cutting parameter. Based on the mixture surface and contour plots, the ideal textural characteristic of spaghetti was produced when 44.4 g/100g HWF, 20.6 g/100g FFSF and 35.0 g/100g water content were added and processed at screw speed of 40 rpm and temperature of 35oC. The textural characteristics of spaghetti measured at these perfect conditions were as: toughness, 69.9 (g.mm); firmness after optimum cooking, 6.95 (g.cm); firmness after over cooking, 4.67 (g.cm); stickiness after optimum cooking, 371.7 (N/m^2); and stickiness after over cooking, 381.6 (N/m^2).

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بهینه‌سازی ویژگی‌های بافتی فرآورده‌های خمیری حاوی آرد کامل سویا با استفاده از روش سطح پاسخ

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چکیده

تاثیر افزودن آرد کامل سویا در دامنه ۰ تا ۲۷ درصد و آب از ۳۱ تا ۳۵ درصد در فرمول و همچنین شرایط مختلف اکستروژن بر روی ویژگی های بافتی اسپاگتی به منظور تولید فرآورده سلامتی بخش، مورد بررسی قرار گرفت. فرآیند در اکسترودری با سرعت چرخش مارپیچ در دامنه ۱۰ تا ۴۰ دور بر دقیقه و آب سیرکولاسیون با دمای ۳۵ تا ۷۰ درجه سانتی‌گراد، انجام شد. نتایج نشان داد که افزودن آرد کامل سویا سبب اختلاف معنی‌داری در استحکام مکانیکی و شاخص های برشی شد. بررسی آماری نتایج با استفاده از طرح مخلوط نشان داد که بهترین اسپاگتی زمانی تولید می شود که فرمول حاوی ۲۰/۶ درصد آرد کامل سویا، ۴۴/۷ گرم بر صد گرم آرد نول و ۳۵ گرم بر صد گرم آب در اکسترودر با سرعت چرخش مارپیچ ۴۰ دور بر دقیقه و دمای آب سیرکولاسیون ۳۵ درجه سانتی گراد، فرآوری شود.

واژه‌های کلیدی: اسپاگتی، رئولوژی، طرح مخلوط.

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