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Optimization of the extrusion conditions and formulation of spaghetti enriched with full-fat soy flour based on the cooking and color quality

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Abstract
The influence of full-fat soy flour (FFSF) 0–27.0 g/100 g, water content 31.0–35.0 g/100 g and extrusion conditions on the cooking and color characteristics of spaghetti was investigated. The process was performed with a speed of 10–40 rpm and a water circulating temperature of 35–70°C. The results showed that adding FFSF causes decreases ($P \leq 0.05$) in cooking time, cooking weight, intensity and hue characteristics. However, the cooking loss and saturation of spaghetti increased ($P \leq 0.05$). The temperature and speed of the extruder had no significant effect on the cooking and color attributes. Interaction between them and the components, however, had a slight synergistic effect on characteristics. Also, interaction between the components and the water temperature has a negative effect on the color and cooking loss. Data analysis showed that the cooking and color characteristics were optimized when 56.9 g/100 g wheat flour, 12.1 g/100 g FFSF and 31.0 g/100 g water content at a screw speed of 40 rpm and a temperature of 35°C were applied.

Keywords: *Functional spaghetti, cooking characteristics, image analysis, processing variables*

Introduction

Durum wheat flour is the main ingredient in the formulation of pasta products; however, it is deficient in lysine, one of the essential amino acids. Therefore, many researchers have focused on improving the nutritional and cooking characteristic of pasta by the addition of other ingredients, such as lupine (Morad and Afifi 1980; Rayas et al. 1996), cowpea (Bergman et al. 1994), amaranth (Rayas et al. 1996), gluten (Cubadda et al. 2007), quinoa, broad bean, chickpea and buckwheat (Chillo et al. 2008), corn (Taha et al. 1992), resistant starch (Sozer et al. 2007), whey protein concentrates (Prabhasankar et al. 2007), wheat bran (Manthey and Schorno 2002), barley bran (Marconi et al. 2000) and dietary fiber of pea (Edwards et al. 1995). Even

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though the addition of these ingredients in pasta helps increase the nutritional value, it also affects the cooking characteristics of the final products. Good pasta should have good cooking resistance, minimum cooking loss, and high cooking weight, acceptable textural and sensory characteristics.

Soybean is a valuable source for soluble carbohydrate, proteins (rich in lysine) lipids, dietary fiber, minerals and vitamins. Consumption of soybean products is useful for having health bone, healthy brain, and good immune functionality and heart attack and cancer control (Anderson et al. 1999; Food and Drug Administration 1999; Badger et al. 2002). Many researchers have investigated the effect of defatted soy flour (Molina et al. 1982; Collins and Pangloli 1997; Ugarcic-Hardi et al. 2003; Shogren et al. 2006) and isolated soy protein (Breen et al. 1977; Limroongreungrat and Huang 2007) on the quality of pasta. However, the role of full-fat soy flour (FFSF) on the quality characteristics of spaghetti has not been investigated. Thus, the objective of this paper was to optimize the formulation and extrusion variables for the production of enriched and functional spaghetti.

Materials and methods

Materials

The hard wheat flour (HWF) was produced from an Iranian spring hard wheat variety, namely Golestan, and supplied by Razavi Company (Mashhad, Iran). The FFSF was produced from a Williyams soybean variety that was obtained from Toos Soya Company (Mashhad, Iran).

Flour analysis

The standard methods of the American Association of Cereal Chemists (AACC 1990) 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.

A mechanical laboratory sieve shaking method was used to determine the particle size distribution of the HWF and FFSF. The pre-weighed sample (10 g) was placed on the top sieve of the set of sieves comprising 475, 355, 212, 180 and 125 μm openings and shaken with the sieve shaker. After 20 min of shaking, the material on each sieve was weighed and recorded based on the percentage w/w.

Spaghetti formulations

The amount of the basic ingredients used for making spaghetti was calculated based on the standard methods of the AACC (method 66-41; AACC 1990). The range of ingredients used in the formulation is as follows: HWF (42.0–69.0 g/100 g), FFSF (0–27.0 g/100 g) and distilled water (31.0–35.0 g/100 g). Table I presents the actual weight of each ingredient for preparing 8 kg dough mixtures for each formulation.

Table I. Actual composition of ingredients in the different mixtures (kg).

Mixture	HWF	FFSF	Water content
1	6.0	0.0	2.0
2	6.4	0.0	1.6
3	5.5	0.5	2.0
4	5.7	0.5	1.8
5	5.0	1.1	1.9
6	4.4	1.7	1.9
7	4.5	1.5	2.0
8	3.8	1.9	2.3
9	3.9	2.3	1.8

Spaghetti production

All of the ingredients were mixed for 10 min at 70 rpm in a laboratory pasta maker. Then four different extrusion conditions that were based on the temperature of the circulating water and the screw speed of the extruder (40 rpm and 70°C; 40 rpm and 35°C; 10 rpm and 70°C; and 10 rpm and 35°C) were employed. The mixing and extrusion processes were operated under partial vacuum (0.7–0.8 atm). Extruder pressure was in the range of 200–1,000 psi for different samples. Spaghetti samples were dried in a dryer with a temperature that was fixed at 50°C, but the relative humidity was reduced gradually from 95.0% to 65.0% during the 20 h drying period. The average diameter of spaghetti was 1.90 ± 0.03 mm.

Spaghetti cooking quality

Cooking time. The standard AACC method (method 16-50; AACC 1990) was employed for assessment of the cooking time. Approximately, 25 g spaghetti was cut into 5-cm-length strands and dispersed in 300 ml boiling distilled water in a 500-ml beaker. A strand of spaghetti sample was taken every 30 sec and compressed between two glass plates. The optimum cooking time (min) of spaghetti was established when no white core was observed after the spaghetti was compressed. The time for overcooking was obtained by adding 10 min to the optimum time needed for cooking the spaghetti.

Cooking loss. Cooking loss was determined according to the AACC method (method 16-50; AACC 1990). Preparation of the sample for cooking loss is similar to that in the previous 'Cooking time' section. Spaghetti samples were boiled according to the cooking and overcooking times observed in the previous section. The samples were drained on a Buchner funnel and rinsed with 50 ml distilled water. Finally, the cooking water was dried in an oven at 100°C after 20 h. The amount of residue in the cooking water is used as an indicator of cooking quality. The lower the residue, the higher the spaghetti cooking quality.

Cooked weight. The spaghetti was cooked until the optimum and overcooking times (based on procedure described in the 'Cooking time' section). Then sample was drained and the weight of spaghetti (g/100 g) was calculated using the following equation:

$$\text{Cooking weight (g/100 g)} = (\text{weight of dish including the spaghetti} - \text{weight of empty dish}) \times 4$$

Color quality

The image analysis technique was used for determination of spaghetti color. A strand (5 mm in length) of uncooked spaghetti was placed under a digital microscope (Dino-Lite AM-313; Nazca Inc., California, USA) and photographed with a 60x objective. Then, the pictures were analyzed with a Clemex software (version 6.0; Meyer Instruments Inc., Houston, TX, USA), for determining intensity (*I*), hue (*H*), and saturation (*S*) values. The *H*, *I* and *S* values indicate the yellowness, lightness and redness of the spaghetti color.

Statistical analysis

The design of experiments with mixtures and the applied response surface analysis has been used in this study. 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 Stat/Doe menu of the Minitab software (V14.2, 2005; Minitab Inc. Pennsylvania, state collage, USA) was used to build the experimental 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).

Results and discussion

Flour analysis

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 5.0 g/100 g based on total weight, respectively. The protein, fiber, fat, moisture and ash in HWF were 8.3, 0.3, 0.9, 13.0 and 0.5 g/100 g based on total weight, respectively. All the nutrient compositions in FFSF were higher than in HWF, except for moisture content. Shogren et al. (2006) reported that adding defatted soy flour to the formulation resulted in an increase in the protein, fiber, ash, lysine and threonine, and decreases the fat content in pasta. In term of the flour particle size distribution, more than 70% and 20% of HWF and FFSF particles could pass through a sieve of 125 μm opening, respectively. On the other hand, about 63% and 1% of flour particles of FFSF and HWF remained on the sieve with 212 μm opening, respectively. Therefore, FFSF had a higher percentage of coarse particles than HWF. Particle size affects the rate of hydration of flours during processing by influencing the appearance and firmness of spaghetti (Manthey et al. 2002).

Spaghetti analysis

Cooking quality. Table II presents the cooking quality of spaghetti, which includes cooking time, cooked weight and cooking loss after the optimum and overcooking times. Predicted equations obtained from the design are presented in Table III. Mixture contour plots that are related to these equations are shown in Figure 1a–e.

Cooking time. The optimum cooking time of spaghetti was longer for the spaghetti without FFSF (control) than for the enriched samples (Figure 1a). The cooking time decreased from 19.84 min in the spaghetti made from HWF to 8.42 in the sample

Table II. Cooking attributes of cooked spaghetti samples[a].

		Cooking loss (%)		Cooked weight(g)	
Mixture	Cooking time (min)	Optimum cooking	Overcooking	Optimum cooking	Overcooking
1	16.42	4.92	4.95	297.24	376.00
2	17.25	4.34	5.56	274.88	351.61
3	17.17	5.54	6.29	278.68	325.40
4	16.67	5.77	6.38	280.20	322.42
5	15.34	6.14	7.54	259.40	319.36
6	12.25	7.24	8.52	249.17	296.56
7	11.50	7.76	9.09	290.65	286.44
8	10.67	8.01	10.70	230.68	277.16
9	8.75	9.00	11.32	219.60	266.02
10	16.92	5.26	5.82	299.52	345.28
11	15.85	4.98	5.88	284.02	338.64
12	16.50	5.72	6.66	271.40	325.74
13	15.50	6.04	6.92	288.56	331.90
14	14.84	6.44	8.08	256.74	304.78
15	12.50	6.80	8.76	240.98	306.70
16	11.58	7.00	9.22	240.26	285.36
17	10.58	7.28	9.22	228.96	279.66
18	9.67	7.56	10.32	223.94	280.70
19	19.00	4.84	4.34	295.88	382.12
20	19.84	4.58	4.56	284.70	344.14
21	17.25	5.22	6.16	272.62	316.06
22	15.08	5.36	6.20	255.44	315.04
23	13.42	6.44	7.08	252.26	299.34
24	13.17	7.16	8.38	250.46	302.26
25	11.92	8.06	9.00	239.64	297.48
26	9.92	8.50	9.32	225.68	276.18
27	8.50	8.60	9.26	218.44	269.78
28	17.50	5.34	5.68	293.70	346.08
29	18.75	5.54	6.00	285.56	338.54
30	18.50	6.10	7.12	284.74	347.96
31	17.67	6.72	7.22	276.98	317.18
32	14.17	7.34	7.82	255.56	307.54
33	10.50	7.26	9.54	240.02	294.16
34	9.97	7.52	10.82	232.40	293.09
35	8.42	8.66	11.22	214.42	277.12
36	8.25	8.30	10.56	217.52	279.46
LSD[b]	1.778	0.868	0.674	16.99	17.05

[a]Mean belong to three replications.
[b]Least Significant Difference, $P \leq 0.05$.

enriched with 27 g/100 g FFSF. The regression analyses indicated that the ingredients used in the formulation had a significant effect on the cooking time in linear terms ($P \leq 0.001$). This is predictable because the amount of gluten in the enriched formula has been reduced as the HWF was replaced by FFSF. This causes formation of a weaker gluten network in the dough and provides a path for water to be easily absorbed into the spaghetti, and thus shorten the cooking time. These results were in agreement with previous researchers (Edwards et al. 1995; Manthey et al. 2002). On the other hand, the temperature and the extruder speed had no significant effect

Table III. Predicted model for experimental data of cooking attributes of the spaghetti.

Parameter	Predicted model	R^2 value	R^2 adjusted
CT	$=0.2414F-0.1199S+0.0712W$	0.916	0.911
CL	$=0.0051F+0.1312S+0.1421W+0.0062WT^{*}$	0.856	0.843
OCL	$=0.079F-0.069S+0.0014W+0.0105SW^{*}+0.0064SWT^{***}-0.0064FRT^{***}$	0.956	0.958
CW	$=2.3955F-0.1739S+3.947W+0.0002FSWR^{*}$	0.868	0.856
OCW	$=2.2836F+6.9659S+5.9336W-0.2322SW^{*}$	0.892	0.882
I	$=1.2723F+0.7654S+1.2613W+0.0315SWR^{**}-7.6797\times10^{-4}FSWR^{**}-0.7984\times10^{-4}FSWT^{**}+0.0023SWRT^{*}$	0.816	0.773
H	$=0.4854F+0.3208S+0.3231W-0.0153WRT^{*}$	0.723	0.697
S	$=0.1533F+1.4032S+0.3695W-0.01758FS^{**}+0.0617SR^{**}+0.0027SWT^{***}$	0.890	0.872

CT = optimum cooking time, CL = cooking loss for optimum cooking, OCL = cooking loss for overcooking, CW = cooked weight for optimum cooking, OCW = cooked weight for overcooking, I = intensity, H = hue, S = saturation, F = HWF, S = FFSF, W = water content, R = screw speed of extruder. T = temperature of circulating water. $^{***}P \leq 0.001$, $^{**}P \leq 0.01$, $^{*}P \leq 0.05$; unlabeled, significance was not calculated because it was a forced term.

on the cooking time. This finding is based on the equation obtained from the mixture design presented in Table III.

Cooking loss. When cooking loss values of enriched spaghetti were taken into consideration, it was noted that the enriched spaghetti samples had higher cooking loss compared with the control after the optimum cooking time (Figure 1b). The cooking loss increased from 4.0% in spaghetti made from HWF to 9.0% in samples enriched with 27 g/100 g FFSF (Table II). The regression analyses indicated that the ingredients used in the formulation had a significant effect on this parameter in linear terms ($P \leq 0.001$). When spaghetti samples were overcooked, the percentage of cooking loss increased significantly ($P \leq 0.05$) from 4.5% to 11% (Table II). The regression analyses indicated that the ingredients used in the formulation had a significant effect on this parameter after overcooking via quadratic terms ($P \leq 0.05$).

A similar explanation for the effect of a shorter cooking time can be made regarding this matter. This is probably due to the formation of a weaker gluten network in the enriched dough spaghetti. This finding was supported by Rayas et al. (1996) in spaghetti enriched with lupin. The cooking loss was higher than the control because addition of non-gluten flour made from lupin decreased the gluten strength and interrupted and weakened the overall structure of spaghetti. Therefore, solid materials will migrate to the cooking water more easily. Similarly, Kordonowy and Youngs (1985) reported that addition of wheat bran to spaghetti formulation increased the cooking loss because it destroys the gluten matrix.

It was noted that interactions between ingredients and the temperature of circulating water increases the cooking loss significantly for the optimum cooking time and for overcooking (Table III). But interactions between ingredients and extrusion variables illustrated positive significant effects on the cooking loss for the overcooked spaghetti. This shows that for temperature and the extrusion time are critical factors for degradation of texture. This result is concurrent with the results obtained by other researchers (Milatovic and Mondelli 1991; Abecassis et al. 1994;

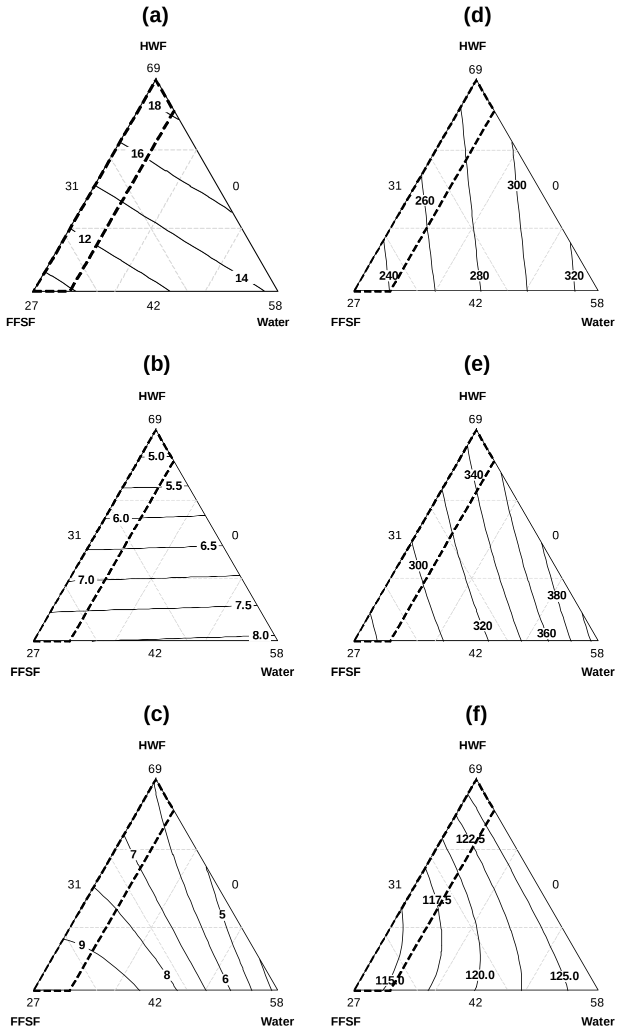

Figure 1. Mixture contour plots of the predicted surface for cooking and color quality of spaghetti enriched with FFSF dependent on components in the conditions optimized: (a) optimum cooking time, (b) cooking loss for optimum cooking, (c) cooking loss for overcooking, (d) cooked weight for optimum cooking, (e) cooked weight for overcooking, (f) intensity, (g) hue, and (h) saturation.

Debbouz and Doetkott 1996) who discovered that cooking loss will increase when the temperature of the extruder was higher than 55°C.

Cooked weight. The cooked weight of FFSF-based spaghetti for the optimum cooking time and overcooking was significantly lower ($P \leq 0.05$) than the spaghetti that was made from HWF (Table II and Figure 1d,e). The regression analyses indicated that the ingredients used in the formulation had a significant effect on this parameter for the optimum cooking time in linear terms ($P \leq 0.001$), and for overcooking, via quadratic terms ($P \leq 0.05$). This was in disagreement with Morad and Afifi (1980), who found that the cooked weight of macaroni was increased when lupin flour was added to the formulation. In addition, Kordonowy and Youngs (1985) reported that the cooked weight of spaghetti made up from whole wheat was higher than the control. The decrease in cooked weight observed in this study may be due to heat treatments given during production FFSF for removal of components that contribute to the beany flavor. This stage could probably result in denaturation of proteins, which reduces the water absorption and contributes to the decreased cooked weight. Beside that, the presence of phospholipids in FFSF could also limit the water absorption in spaghetti during cooking. Results from Table III show that interactions between ingredients and the screw speed of extruder showed positive significant effects on the cooked weight for the optimum cooking time. It was found that temperature of circulating water had no significant effect on the cooked weight. However, Abecassis et al. (1994) and Debbouz and Doetkott (1996) reported that increased temperature

Table IV. Color quality of uncooked spaghetti samples[a].

Mixture	Hue	Intensity	Saturation
1	42.0	128.0	22.0
2	42.0	130.0	20.4
3	43.0	124.6	22.3
4	43.0	116.7	23.0
5	41.8	113.6	25.0
6	38.6	113.5	35.6
7	39.2	113.0	35.8
8	39.5	113.2	38.6
9	38.0	112.6	39.0
10	45.0	125.0	23.0
11	44.0	126.0	22.2
12	43.0	124.0	23.0
13	42.0	125.0	25.0
14	42.0	117.0	26.0
15	41.5	116.0	30.0
16	39.0	115.0	31.0
17	41.0	114.0	33.0
18	40.0	112.0	35.0
19	41.5	128.0	21.6
20	43.0	125.0	23.0
21	41.8	124.3	23.0
22	43.2	124.3	24.3
23	40.3	135.3	26.2
24	39.2	126.0	27.0
25	39.0	123.2	28.2
26	38.0	120.0	31.5
27	38.0	116.7	31.2
28	40.8	127.0	22.2
29	43.2	125.2	23.2
30	42.8	123.3	25.2
31	44.8	120.3	26.2
32	41.0	124.6	24.4
33	40.7	122.2	26.8
34	39.0	119.8	27.6
35	40.0	107.0	37.8
36	39.7	107.6	37.6
LSD[b]	2.249	5.255	3.095

[a]Mean belong to three replications.
[b]Least Significant Difference, $P \leq 0.05$.

of extruder resulted in a positive effect on the cooked weight of durum wheat spaghetti.

Color quality. Table IV presents the color characteristics of all uncooked spaghetti based on *H*, *I* and *S* values obtained from the image analysis technique. The predicted equations obtained from the mixture design are presented in Table III, while the mixture contour plots related to these equations are shown in Figure 1f–h. The *I* value decreased significantly ($P \leq 0.05$) from 130 in the HWF spaghetti to 110 in samples enriched with 27 g/100 g FFSF. The *H* value decreased significantly ($P \leq 0.05$) when FFSF was added to the formulation (Figure 1g), whereas the *S* value increased significantly ($P \leq 0.05$) from 20 in the control to 39 in sample with highest amount of FFSF. The regression analyses indicated that the ingredients used in the formulation had a significant effect on the *H*, *I* and *S* values in linear terms ($P \leq 0.001$), and also for *S* via quadratic terms ($P \leq 0.05$). Bergman et al. (1994) also discovered that spaghetti enriched with cowpea had higher values in darkness, yellowness and redness. However, Morad and Afifi (1980) and Rayas et al. (1996) showed that the color of spaghetti enriched with lupin was the same as the control. On contrary, addition of wheat or barley bran to spaghetti resulted in a darker color compared with the control (Edwards et al. 1995; Marconi et al. 2000). Therefore the changes in values of color could be due to the presence of more carotenoids and bran in FFSF than HWF.

Conclusions

Addition of FFSF decreased ($P \leq 0.05$) the cooking weight, cooking time, hue and saturation of color, whereas the cooking loss and intensity were increased. All predicted models for cooking quality and saturation of color were high ($R^2 \geq 85.0$), that for intensity was good ($R^2 \geq 77.0$) and that for hue observed low correlation ($R^2 \leq 75.0$) in this study. These results suggest that the temperature of circulating water and the screw speed of the extruder had no significant effect on the quality of enriched spaghetti. Interaction between them and the components, however, had a good effect on the characteristics of spaghetti. Based on this study, the optimum cooking and color characteristics of spaghetti was created when 56.9 g/100 g HWF, 12.1 g/100 g FFSF and 31.0 g/100 g water content were added and processed at a screw speed of 40 rpm and a temperature of 35°C was applied.

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