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# Mechanical Characteristics of Spaghetti Enriched with Whole Soy Flour

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***Abstract*—**The influence of full-fat soy flour (FFSF) and extrusion conditions on the mechanical characteristics of dry spaghetti were evaluated. Process was performed with screw speed of 10-40rpm and water circulating temperature of 35-70°C. Data analysis using mixture design showed that this enrichment resulted in significant differences in mechanical strength.

***Keywords*—**Pasta, Mixture design, Enrichment, Texture.

## I. 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 [1], [2], cowpea [3], gluten [4], quinoa, broad bean, chick pea and buck wheat [5], corn [6], wheat bran [7], barley bran [8] and dietary fiber of pea [9]. Soybean belongs to the family of *Leguminosae*, originating from China. It contains soluble carbohydrate (12.0-14.0%), proteins (36.0-42.0%), lipids (18.0-22.0%), dietary fiber (12.0-14.0%) and many valuable compounds such as mineral salts (Ca, Fe, Zn), vitamins $B_1$, $B_2$ and niacin, and anti-oxidative substances such as Daidzein and Genistein isoflavones which are useful for bone's health, healthy brain and immune function. The most abundant storage proteins of soybean are the salt-soluble proteins termed globulins. The soybean globulins consist of 11S, 7S, and 2S fractions. The 11S globulins are referred to as glycinin and the 7S globulins are termed β-conglycinin. These two groups of proteins account for about 70.0–80.0% of the total seed globulin fraction. Because of their abundance, these proteins are mainly responsible for the nutritional quality of soybean foods. Like other legumes, the storage proteins of soybean are deficient in sulfur-containing amino acids (cysteine and methionine). Even though the addition of these ingredients in pasta helps in increasing the nutritional value, it also affected the mechanical characteristics. In our previous research, sensory and nutritional characteristic [10] and cooking quality [11] of spaghetti enriched with full fat soy flour were evaluated. Thus, the objective of this paper was to study the mechanical properties of this kind of enriched spaghetti.

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## II. Materials and Methods

### A. Materials

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

### B. Flours Analysis

The standard methods of AACC (1990) were employed for 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.

### C. Spaghetti Production

The amount of the basic ingredient used for making spaghetti was calculated based on the standard methods of AACC (66-41) [12], and the dough was mixed for 10 minutes at 70rpm in a laboratory pasta maker before it was transferred to an extruder. Extrusion was performed using a laboratory scale extruder with screw length of 400mm; barrel diameter of 35mm; die diameter of 200mm; flow rate of 6-26kg/h at a screw speed of 10-40rpm and temperature of circulating water of 35-70°C. The device was designed by R&D Center of Modern Food Technology, Ferdowsi University of Mashhad, Iran. Mixing and extrusion parts were operated under partial vacuum (0.7-0.8atm). The operating pressure of extruder was measured at a position just before the die section using a mechanical gauge that is fixed to the extruder. It was in the range of 200-1000psi for all the different samples studied. The average diameter of spaghetti was 1.90±0.03mm. Spaghetti samples were dried in a dryer at Adish Company (Mashhad, Iran). Temperature of dryer was 50°C and relative humidity was reduced gradually from 95.0% to 65.0% during 20h of drying period [10], [11].

### D. Mechanical STRENGTH

Mechanical strength of dried spaghetti was measured using a texture analyzer (QTS, CNS Farnell, UK) for breaking of spaghetti strand. Mechanical strength was expressed as force (gf) required breaking one strand of dried spaghetti. The conditions used throughout the experiment included a cross head speed of 10mm/min 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 texture analyzer.

*E. Experimental Design*

The design of experiments with mixtures and the applied response surface analysis has been used in many investigations for obtaining product compositions or formulations with optimized properties. In this mixture experimental design, the total amount is held constant and a measured property of the mixture changes when the proportions of the components of the mixture are changed. Therefore, the main purpose of using this design is to verify how the nutritional value and sensory attributes of spaghetti are 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 (Cornell, 2002) was constructed to enable the study of the effect of varying ratios of hard wheat flour, full fat soy flour, and water content and process conditions. The Stat/DOE menu of the MINITAB software (V14.2, 2005, Minitab Inc.) was used to build the experimental design.

*F. Statistical Analysis*

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. This canonical model differs from full polynomial models in that it does not contain a constant term intercept (equal to zero). Variables in the regression models, which represent two-ingredient or three-ingredient interaction terms, were referred to as ''non-linear'' terms [10], [11], [13].

## II. Result and Discussion

*A. Flours 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 5.0g/100g based on total weight, respectively. The protein, fiber, fat, moisture and ash in HWF were 8.3, 0.3, 0.9, 13.0 and 0.5g/100g based on total weight, respectively. All the nutrient compositions in FFSF were higher than the HWF, except for moisture content.

*B. Mechanical Strength*

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

In general, the rupture force of the spaghetti without FFSF (control) was higher than for the enriched samples (Fig.1 (a)). The rupture force decreased ($P \leq 0.05$) from 47g in spaghetti made from HWF to 24g in sample enriched with 27g/100g FFSF (Table I). The interactions between ingredient and temperature of circulating water had negative significant effect on the rupture force via linear ($P \leq 0.01$) term and increased it via quadratic ($P \leq 0.01$) term. The interactions between water content and screw speed of extruder had negative significant effect on the rupture force via linear ($P \leq 0.01$) term. Also the interactions between HWF, screw speed of extruder and temperature of circulating water decreased it via linear ($P \leq 0.01$) term (Table II).

TABLE I
MEAN VALUES OF THE MECHANICAL STRENGTH OF SAMPLES [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 ≤ 0.05)

The work of Sun and Muthukumarappan [14] on the soy-based extrudates showed that by increasing soybean flour content and process temperature, shear force significantly increased.

When hardness values of enriched spaghetti were taken into consideration, it was noted that the enriched spaghetti samples had lower hardness compared to the control (Fig. 1 (b)). The hardness decreased ($P \leq 0.05$) from 452 g. in spaghetti made from HWF to 80g in sample enriched with 27g/100g FFSF (Table II). 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 II). This is not supported by the work of Sozer and Kaya [15] which showed that spaghetti enriched with bran had higher hardness and lower adhesiveness than other spaghetti samples.

TABLE II
PREDICTED MODEL FOR EXPERIMENTAL DATA OF MECHANICAL STRENGTH OF SAMPLES A, B

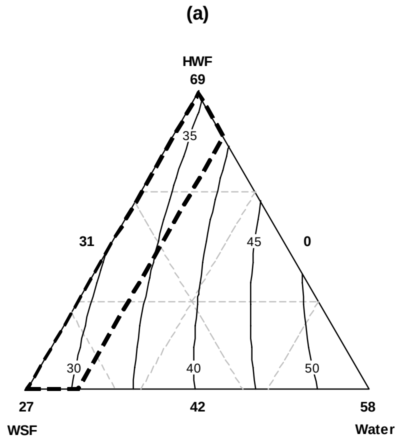
| Parameter | Predicted model | $R^2$ value | $R^2$ Adjust |
|---|---|---|---|
| Rupture force | $= 0.514\ F + 0.1009\ S + 0.309\ W - 0.0665\ WR^{***} - 0.7269FT^{**} + 0.0211\ FWT^{**} - 0.0540FRT^{***}$ | 0.80 | 0.759 |
| Hardness | $= 7.1878\ F - 2.8195S - 4.3138\ W - 0.0122\ FWT^{*}$ | 0.769 | 0.748 |
| 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.
***: *P≤0.001*, **: *P≤0.01*, *: *P≤0.05*, without *: Significance was not calculated because of it was a forced term.

The toughness of FFSF-based spaghetti was significantly (*P*≤0.05) lower than the spaghetti that was made from HWF (Fig. 1 (c)). The toughness decreased (*P≤0.05*) from 458g.mm in spaghetti made from HWF to 21g.mm in sample enriched with 27g/100g FFSF (Table I). The regression analyses indicated that the ingredients used in the formulation had significant effect on this parameter by linear (*P≤0.001*) terms. It was noted that interactions between ingredients, screw speed of extruder and temperature of circulating water showed negative significant effects on the toughness via quadratic (*P≤0.01*) term (Table II). This result is concurrence with the results obtained by Manthey and Schorno [7] who indicated that spaghetti strength is affected by wet gluten content; where gluten surrounds bran wheat and increases strength of spaghetti. In this research FFSF lowered gluten content in the mixture and caused decrease in mechanical strength of enriched spaghetti.

## III. 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. All predicted models for mechanical strength showed high regression ($R^2 \geq 75.0$). 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.



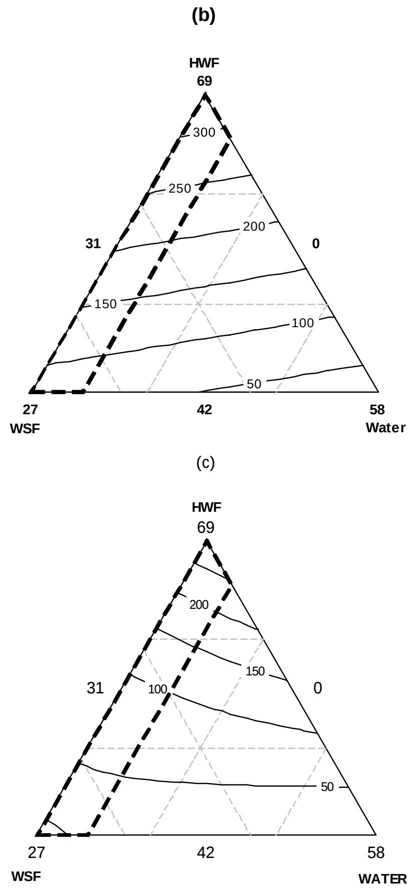




Fig. 1 Mixture contour plots of the predicted surface for mechanical strength of dried spaghetti enriched with whole soy flour dependent on components in the conditions optimized; (a), Rupture force (b) Hardness, (c) Toughness. (Dotted lines marker the range of spaghetti samples and Solid lines indicates characteristic amount).

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