Effect of Process Variables on Spaghetti Quality

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ABSTRACT

Five process variables (water absorption, barrel temperature, screw speed, mixing time, and water temperature) were investigated to determine their effects on pasta quality. Response surface methodology (RSM) was used to identify the process variables levels yielding optimum pasta color and cooking characteristics. Water absorption and barrel temperature had the greatest effect on the response variables studied (pasta brightness, yellowness, firmness, cooked weight, and cooking loss). Screw speed was a significant factor in the response surface models for all the pasta quality parameters, except cooking loss. Mixing time had a significant effect on pasta color and firmness, while water temperature affected only firmness. Contour plots showed that spaghetti brightness and firmness improved at lower water absorption (30.5–31\%) and lower barrel temperature (35–45°C) and at intermediate screw speed (25 rpm). Spaghetti yellowness showed similar trend, except that it increased at higher barrel temperature. Cooking loss appeared to be minimized at water absorptions and barrel temperatures ranging from 31.5 to 32\% and 45 to 50°C, respectively.

The production of top-quality pasta requires not only high quality semolina but also optimal processing conditions. Semolina characteristics and their effect on pasta quality have been fully documented (Matveev 1966; Matsuo and Irvine 1970; Walsh et al 1971; Matsuo et al 1972; Seyam et al 1974; Dexter and Matsuo 1978, 1979, 1980; Grzybowski and Donnelly 1979; Dick and Matsuo 1988), while little information has been published regarding the influence of process variables on pasta quality. Among the processing stages, pasta drying was perhaps the most studied. A review of the processing conditions used for the production of pasta products showed a wide variation in parameters utilized by different manufacturers.

Hummel (1966) recommended mixing spaghetti dough 5–10 min at 30\% moisture, using water temperatures of 40–60°C for the coarser grade semolina and lower temperatures for the finer granulation. He also reported that the dough should be extruded at screw speeds between 20–40 rpm. Some of the advantages stated for mixing warm water include color improvement, dough softening and ease of extrusion, and smoother macaroni surface. Similar pasta manufacturing conditions have also been used by Matsuo and coworkers (1978).

Manser (1981) found that the best pasta was obtained when the pasta dough was extruded at 31\% absorption and at 40–50°C barrel temperature using drying temperature not higher than 80°C. According to Milatovic (1985), water temperatures between 36 and 45°C should be used for the cold dough making and water temperatures between 45 and 65°C should be used for the warm system, where pasta is usually dried at high temperature. He also suggested 15 min for mixing time and 29.5\% for dough moisture. Kobrehel and Abecassis (1985) used a temperature of 35°C to extrude a spaghetti dough that had been mixed for 25 min, while Kim and coworkers (1986) used only 2 min mixing time.

For experimental pasta extruders, Cubadda (1988) recommended screw speeds between 45 and 50 rpm, and barrel temperature and dough moisture not to exceed 50°C and 31\%, respectively. Whether all these processing conditions reported by the different macaroni manufacturers and pasta research laboratories make the best pasta possible is not known. The processing conditions used in pasta certainly need to be fully investigated for their optimization. Only two studies (Walsh et al 1971, Abecassis et al 1994) have reported the process parameter effects on pasta quality.

The objectives of this research were to study the process variables that had, according to the literature, the most effect on pasta quality and to optimize these variables for the production of high quality pasta.

MATERIALS AND METHODS

Raw Material

To conduct the experiment, 1,000 lbs. of commercial semolina (Durakota 1) was obtained from the North Dakota State Mill. The 10 bags (100 lbs. each) were uniformly blended together to produce a homogeneous semolina stock.

Semolina Analysis

The moisture, protein, ash, and wet gluten were determined on the semolina according to standard methods (AACC 1995). Mixograph evaluation of semolina was determined according to the standard method with some modifications. The semolina sample (10 g) was mixed 8 min at constant water absorption of 5.8 ml, using a spring setting of 8. The mixogram was scored by comparing it to reference mixograms (Dick and Youngs 1988).

The number of specks in semolina was determined on a flat surface by counting the visible specks (bran and black particles) in three different 1 in. sq. areas. The average of the three readings was converted to the number of specks per 10 sq. in.

The commercial semolina was of intermediate gluten strength (mixogram score = 6) and had 11.9\% protein, 0.72\% ash, 398 sec falling number, 32.3\% wet gluten, and 16 specks/10 sq. in.

Experimental Design

The process variables (independent variables) investigated were water absorption (30–32–34\%), water temperature during mixing (35–45–55°C), mixing time (3–5–10 min), barrel temperature (35–45–55°C), and screw speed (20–25–30 rpm). The dependent variables or pasta quality factors measured were spaghetti yellowness (b value), spaghetti brightness (L value), cooked weight, cooked firmness, and cooking loss. A 3\(^3\) factorial design was used with two replicates collected at each of the 243 combinations.

Pasta Processing and Drying

The spaghetti samples were produced using 900 g of semolina samples, as described by Walsh et al (1971). The process variables were changed to fit the conditions of the experimental design. The

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extruded spaghetti samples were dried using a high-temperature drying cycle (Debouz et al. 1994).

Spaghetti Analysis

Spaghetti L and b values were determined by light reflectance using a Minolta color difference meter (model CR310, Minolta Camera Co., Japan) according to the standard method (AACC 1995). The spaghetti samples were cooked according to the method of Dick et al. (1974). Cooked weight was determined by weighing the rinsed spaghetti and reporting the results in grams. Cooking loss of the cooking and rinse waters collected from each sample was determined by evaporating to dryness in an air oven at 115°C. The residue was weighed and reported as percentage of the original spaghetti sample.

Spaghetti firmness was measured by shearing two cooked spaghetti strands with a specially designed plexiglass tooth (Oh et al. 1983) attached to a texture analyzer (Texture Technologies Corp., Scarsdale, New York).

### TABLE I

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Color</th>
<th>Cooking Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brightness</td>
<td>Yellowness</td>
</tr>
<tr>
<td>Linearb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1</td>
<td>-14.49**</td>
<td>5.80**</td>
</tr>
<tr>
<td>X2</td>
<td>-28.19**</td>
<td>5.72**</td>
</tr>
<tr>
<td>X3</td>
<td>-2.83**</td>
<td>3.54**</td>
</tr>
<tr>
<td>X4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X5</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quadraticb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1^2</td>
<td>10.77**</td>
<td>-4.04**</td>
</tr>
<tr>
<td>X2^2</td>
<td>10.07**</td>
<td>ns</td>
</tr>
<tr>
<td>X3^2</td>
<td>3.99**</td>
<td>ns</td>
</tr>
<tr>
<td>X4^2</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cross productb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1X2</td>
<td>30.43**</td>
<td>-6.13**</td>
</tr>
<tr>
<td>X1X3</td>
<td>ns</td>
<td>-4.18**</td>
</tr>
<tr>
<td>X1X4</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>X2X3</td>
<td>ns</td>
<td>-9.28**</td>
</tr>
<tr>
<td>X2X4</td>
<td>ns</td>
<td>-2.03*</td>
</tr>
<tr>
<td>X3X4</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

- **X1** = water absorption, **X2** = barrel temperature, **X3** = screw speed, **X4** = water temperature, **X5** = mixing time.
- Included only if they had a significant effect on one or more quality parameters.
- **P** ≤ 0.05
- *Not significant.

**Statistical Analysis**

The data were analyzed using the response surface regression analysis procedure (RSREG) of the Statistical Analysis System (SAS Institute Inc., Cary, NC) and the fit model platform in the Analyze menu of JMP (SAS Institute). A second-order response surface model was initially fit to each of the five pasta quality factors using the five process variables as predictors. The full second-order response surface models included 20 terms (5 linear, 5 quadratic, and 10 cross products) plus an intercept. Fitted reduced models were also used in an attempt to obtain a more parsimonious description of the data. The reduced models included all the significant (P ≤ 0.05) linear, cross product, and quadratic terms. Linear terms that were not significant, but had significant cross product or quadratic terms, were also retained in the model. Because of the small differences observed between the full and reduced models, the simpler reduced models were used to generate the response surface contour plots. The responses evaluated were spaghetti brightness, yellowness, cooked firmness, cooked weight and cooking loss. Equations were calculated describing the response of each variable studied as a function of the experimental factors selected. Contour plots were generated for each pasta quality parameter using all pairs of process variables that were included in the models, with the remaining process variables held at their center points. These plots help identify trends in the product quality at different process variable levels.

**RESULTS AND DISCUSSION**

Table I shows the process variables that had a significant effect on spaghetti color and cooking quality. Water absorption and extruder barrel temperature affected all of the spaghetti quality parameters tested. The extruder screw speed had an effect on spaghetti color and cooking properties (firmness, cooked weight). Mixing time affected mostly spaghetti yellowness and firmness. Pasta yellowness (b value) was higher when shorter mixing time and higher barrel temperatures were used (contour plots not shown).

Since most carotenoid pigment destruction by lipoxygenase occurs during the mixing stage (Tsen and Hlynka 1962, Linstroth 1981), a shorter mixing time would be expected to reduce pigment oxidation by lipoxygenase. Higher barrel temperatures may also have decreased lipoxygenase activity and destruction of the pigments during extrusion. This enzyme is heat-labile with optimum and inactivation temperatures of 30 and 68°C, respectively (Fox and Mulvihill 1982).

The regression equations that were used to generate the contour plots are presented in Table II. High R² values and model significance were obtained for most of the quality factors tested, except for cooking loss (R² = 0.34). The R² represents the proportion of variability in the data explained or accounted for by the model.

### TABLE II

<table>
<thead>
<tr>
<th>Quality Parameter</th>
<th>Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness (L)</td>
<td>216 - 7.47 X1 - 1.37 X2 - 0.274 X3 - 0.121 X4 + 0.0341 X1 X2 + 0.00267 X1 X3 + 0.0853 X1 X4 + 0.00319 X2 X4 + 0.00060 X4²</td>
<td>0.90</td>
</tr>
<tr>
<td>Yellowness (b)</td>
<td>-18.1 + 2.38 X1 + 0.234 X2 + 0.284 X3 + 0.742 X4 - 0.0056 X1 X2 - 0.0076 X1 X3 - 0.0235 X1 X4 - 0.000731 X2 X4</td>
<td>0.80</td>
</tr>
<tr>
<td>Firmness</td>
<td>-7.65 + 0.854 X1 + 0.235 X2 + 0.233 X3 - 0.063 X4 - 0.000522 X1 X2 - 0.000597 X1 X3 + 0.00201 X1 X4 + 0.000954 X2 X4 - 0.0164 X2 X4 - 0.00134 X2 X4² - 0.00258 X4²</td>
<td>0.92</td>
</tr>
<tr>
<td>Cooked weight</td>
<td>88.9 - 5.68 X1 + 0.325 X2 + 1.20 X3 + 0.313 X4 + 0.00685 X1 X2 - 0.0319 X1 X3 - 0.00587 X1 X4 - 0.00222 X2 X4 + 0.105 X1² - 0.000344 X4² - 0.0165 X4²</td>
<td>0.85</td>
</tr>
<tr>
<td>Cooking loss</td>
<td>63.7 - 2.97 X1 - 0.367 X2 - 0.144 X3 - 0.0291 X4 + 0.00498 X1 X2 + 0.00109 X1 X3 + 0.00114 X1 X4 + 0.0427 X2² + 0.00185 X3² + 0.00199 X4²</td>
<td>0.34</td>
</tr>
</tbody>
</table>

- **X1** = water absorption, **X2** = barrel temperature, **X3** = screw speed, **X4** = water temperature, **X5** = mixing time.
(Montgomery 1984). To generate the contour plots, a combination of two independent variables were plotted at a time for the five response variables. Selected contour plots, including the process variables that had the most effect on spaghetti color and cooking quality, are presented in Figures 1–8. Contour plots for spaghetti brightness and yellowness, as functions of water absorption and screw speed, are shown in Figures 1 and 2 respectively. Both quality parameters increased as water absorption decreased.

Oh et al (1985) also observed an increase in noodle brightness at lower water absorption. This is perhaps due to reduced enzymatic browning (polyphenol oxidase) and carotenoid pigment oxidation at lower water absorption (Nicolas 1978). Walsh et al (1971) using linear programming also found that high water absorption had an adverse effect on pasta color. Spaghetti yellowness showed an increasing trend at higher barrel temperature and screw speed (contour plot not shown). Abecassis et al (1994) also reported an increase in the spaghetti yellow index as the open surface of the die or extruding speed increased.

Although color and overall appearance of spaghetti are important quality characteristics to the consumer, the texture or the firmness of the cooked product and its solid loss to the cooking water are generally accepted as the ultimate quality parameters that greatly influence consumer acceptance.

The contour plot for spaghetti firmness as function of water absorption and barrel temperature is shown in Figure 3. It appears that pasta firmness increased as water absorption and barrel temperature decreased. This is in agreement with the results reported by Walsh and coworkers (1971).

Fig. 1. Contour plot of spaghetti brightness (L value) as a function of water absorption and barrel temperature.

Fig. 2. Contour plot of spaghetti yellowness (b value) as a function of water absorption and barrel temperature.

Fig. 3. Contour plot of spaghetti firmness as a function of water absorption and barrel temperature.

Fig. 4. Contour plot of spaghetti firmness as a function of screw speed and barrel temperature.
Screw speeds close to the midpoint (25 rpm) gave the best firmness (Figs. 4 and 5). This may be attributed to the gluten rheological properties. Gluten was perhaps not sufficiently developed at lower screw speed and overworked at higher extrusion speed. As previously reported (Matveef 1966, Matsuo and Irvine 1970, Feillet 1977), gluten has a very critical influence on pasta cooking quality.

Cooked weight had a tendency to increase as water absorption and barrel temperature increased (Figs. 6 and 7). This result concurs with the results obtained by Abecassis et al (1994). As shown in Figure 8, the lower cooking losses were obtained at barrel temperature and water absorption that ranged between 45 and 50°C and between 31.5 and 32%. Abecassis et al (1994) reported an increase in cooking loss of 250% when the barrel temperature was raised from 35 to 70°C. However, their study failed to show the critical limits or the optima for the process variables used.

Temperatures above 55°C have been reported to denature gluten and to adversely affect pasta quality (Milatovic and Mondelli 1991). Manser (1981) also found that the best pasta products were extruded in the temperature range of 40–50°C. The shaded area in Figure 9 shows the predicted optimal process variable values that will produce spaghetti with bright yellow color, high firmness, and low cooking loss. These values ranged between 30.5 and 31% for water absorption, and between 45 and 53°C for barrel temperature.

**Fig. 5.** Contour plot of spaghetti firmness as a function of water absorption and screw speed.

**Fig. 6.** Contour plot of cooked weight as a function of water absorption and barrel temperature.

**Fig. 7.** Contour plot of cooked weight as a function of screw speed and barrel temperature.

**Fig. 8.** Contour plot of cooking loss as a function of water absorption and barrel temperature.
CONCLUSIONS

Water absorption and barrel temperature had the most influence on spaghetti quality, since they had a significant effect on all of the response variables investigated. Screw speed had an effect on four (brightness, yellowness, cooked weight, and firmness) of the five quality parameters studied. Mixing time showed a significant effect on pasta yellowness and firmness; water temperature affected only pasta firmness. Spaghetti yellowness showed a increasing trend at lower water absorption and at higher barrel temperature. Lower water absorption and barrel temperature had a positive effect on pasta brightness and firmness. Cooking losses appeared to be minimized at water absorptions and barrel temperatures between 31.5 and 32% and between 45 and 50°C, respectively.

From the surface regression contour plots, it appears that spaghetti color and cooking quality were optimized at ~31% absorption, 25 rpm screw speed, and 45–53°C barrel temperature.

LITERATURE CITED


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