Effect of Process Variables on Spaghetti Quality[1]

A. DEBBOUZ[2,3] and C. DOETKOTT[2]

Cereal Chem. 73(6):672–676

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 (Matveef 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 3^5 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

[1]Published with the approval of the Director of the Agricultural Experiment Station, North Dakota State University, Fargo, ND.

[2]Department of Cereal Science and Information Technology Services, respectively, North Dakota State University, Fargo, ND 58105.
[3]Corresponding author. Fax: 701/231-7723.

Publication no. C-1996-0925-03R.

extruded spaghetti samples were dried using a high-temperature drying cycle (Debbouz 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
***T*-Ratios for the Quality Parameters in the Response Surface Regression**

	Color		Cooking Characteristics		
Independent Variables[a]	Brightness L	Yellowness b	Firmness	Cooked Weight	Cooking Loss
Linear[b]					
X_1	−14.49**[c]	5.80**	2.28*	−6.53**	−7.45**
X_2	−28.19**	5.72**	7.20**	3.94**	−10.36**
X_3	−2.83**	3.54**	3.33**	6.21**	ns[d]
X_4	ns	ns	−2.71**	ns	ns
X_5	ns	7.97**	−2.36*	ns	ns
Quadratic[b]					
X_1^2	10.77**	−4.94**	−2.94**	8.13**	7.14**
X_2^2	10.07**	ns	−6.01**	−6.60*	7.72**
X_3^2	3.99**	ns	−5.93**	ns	2.08*
X_5^2	ns	ns	ns	−3.08**	ns
Cross product[b]					
X_1X_2	30.43**	−6.13**	−7.58**	3.72**	5.88**
X_1X_3	ns	−4.18**	ns	−8.66**	ns
X_1X_4	ns	ns	2.56*	ns	ns
X_1X_5	ns	−9.28**	ns	ns	ns
X_2X_3	ns	−2.00*	3.03**	0.97**	3.23**
X_2X_5	ns	−2.03*	ns	−2.17*	2.43*
X_3X_5	2.15*	ns	ns	ns	ns

[a] X_1 = water absorption, X_2 = barrel temperature, X_3 = screw speed, X_4 = water temperature, X_5 = mixing time.
[b] Included only if they had a significant effect on one or more quality parameters.
[c] ** = $P \leq 0.01$, * = $P \leq 0.05$.
[d] 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 ($P \leq 0.05$) 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 R^2 values and model significance were obtained for most of the quality factors tested, except for cooking loss (R^2 = 0.34). The R^2 represents the proportion of variability in the data explained or accounted for by the model

TABLE II
Regression Equations Describing the Response of Each Quality Parameter as a Function of the Significant Effects Retained in the Model

Quality Parameter	Equation	R^2
Brightness (L)	$216 - 7.47 X_1 - 1.37 X_2 - 0.274 X_3 - 0.121 X_5 + 0.0341 X_1X_2 + 0.00267 X_3X_5 + 0.0853 X_1^2 + 0.00319 X_2^2 + 0.00506 X_3^2$	0.90
Yellowness (b)	$-18.1 + 2.38 X_1 + 0.234 X_2 + 0.284 X_3 + 0.742 X_5 - 0.0056 X_1X_2 - 0.0076 X_1X_3 - 0.0235 X_1X_5 - 0.000731 X_2X_3 - 0.00103 X_2X_5 - 0.0319 X_1^2$	0.80
Firmness	$-7.65 + 0.854 X_1 + 0.235 X_2 + 0.233 X_3 - 0.063 X_4 - 0.000522 X_5 - 0.00597 X_1X_2 + 0.00201 X_1X_4 + 0.000954 X_2X_3 - 0.0164 X_1^2 - 0.00134 X_2^2 - 0.00528 X_3^2$	0.92
Cooked weight	$88.9 - 5.68 X_1 + 0.325 X_2 + 1.20 X_3 + 0.313 X_5 + 0.00685 X_1X_2 - 0.0319 X_1X_3 - 0.00587 X_2X_3 - 0.00222 X_2X_5 + 0.106 X_1^2 - 0.00344 X_2^2 - 0.0165 X_5^2$	0.85
Cooking loss	$63.7 - 2.97 X_1 - 0.367 X_2 - 0.144 X_3 - 0.0291 X_5 + 0.00498 X_1X_2 + 0.00109 X_2X_3 + 0.00114 X_2X_5 + 0.0427 X_1^2 + 0.00185 X_2^2 + 0.00199 X_3^2$	0.34

[a] X_1 = water absorption, X_2 = barrel temperature, X_3 = screw speed, X_4 = water temperature, X_5 = 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).

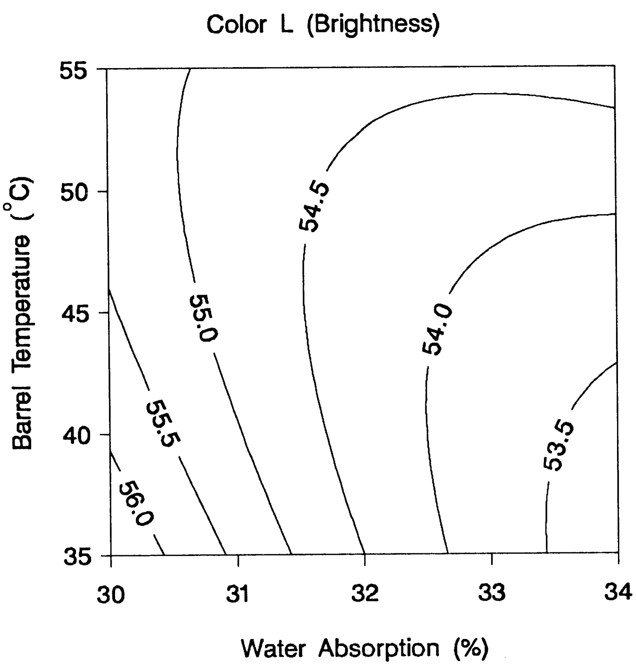

Fig. 1. Contour plot of spaghetti brightness (L value) as a function of water absorption and barrel temperature.

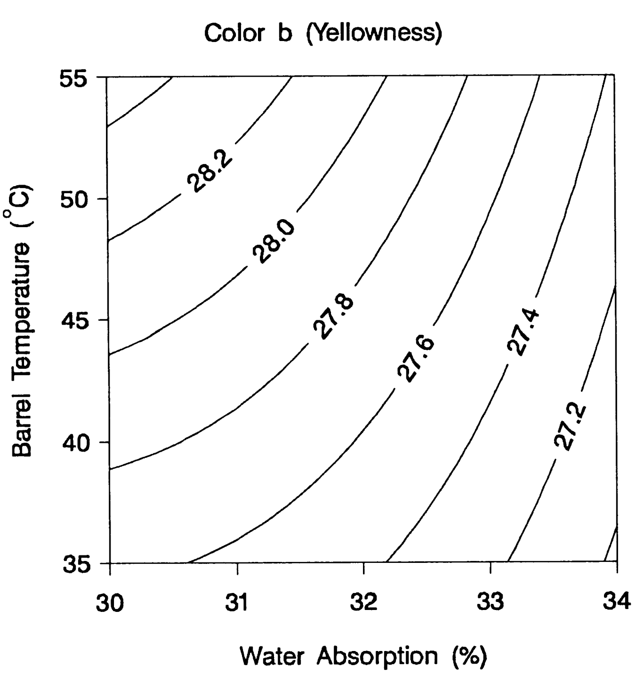

Fig. 2. Contour plot of spaghetti yellowness (b value) as a function of water absorption and barrel temperature.

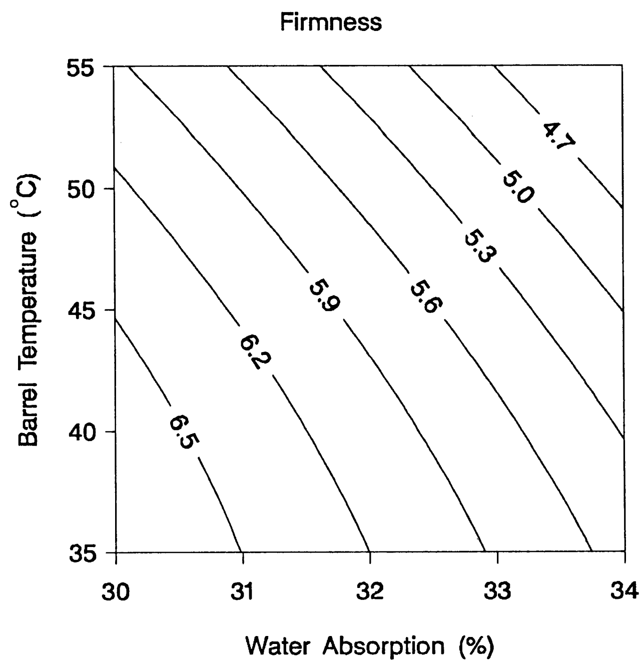

Fig. 3. Contour plot of spaghetti firmness as a function of water absorption and barrel temperature.

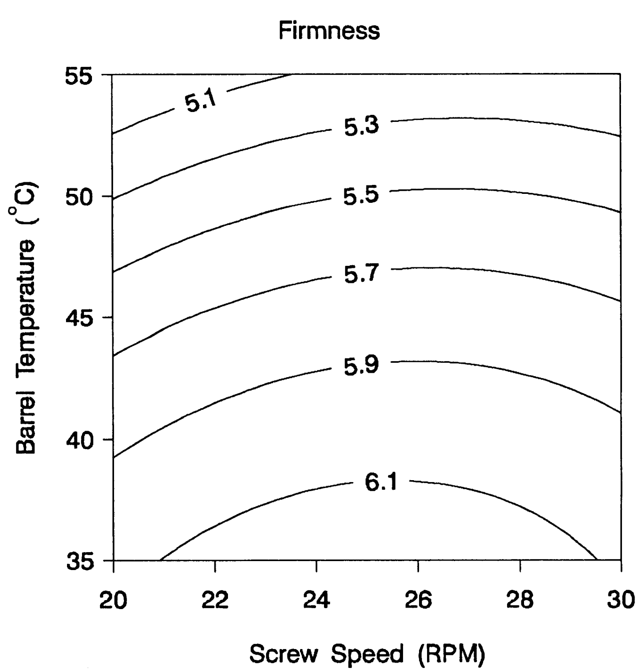

Fig. 4. Contour plot of spaghetti firmness as a function of screw speed and barrel temperature.

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.

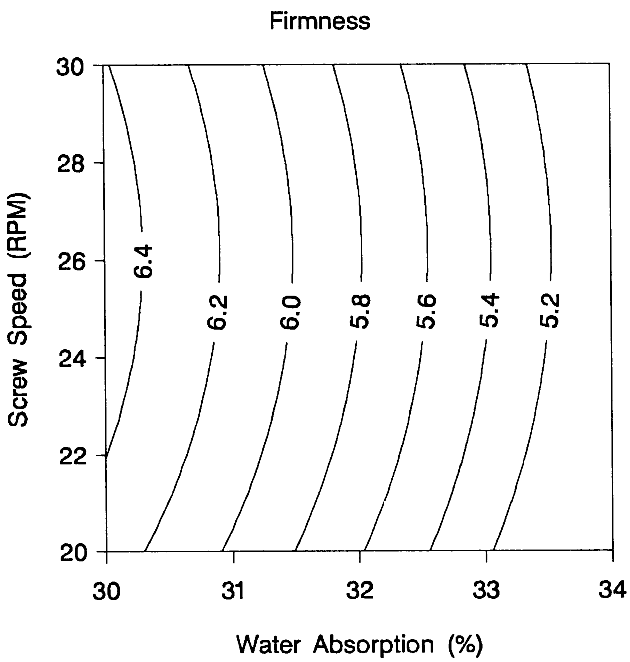

Fig. 5. Contour plot of spaghetti firmness as a function of water absorption and screw speed.

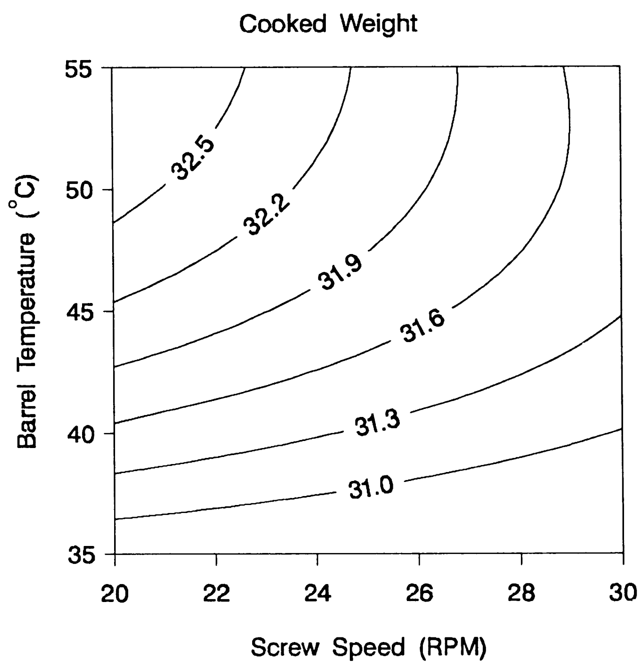

Fig. 7. Contour plot of cooked weight as a function of screw speed and barrel temperature.

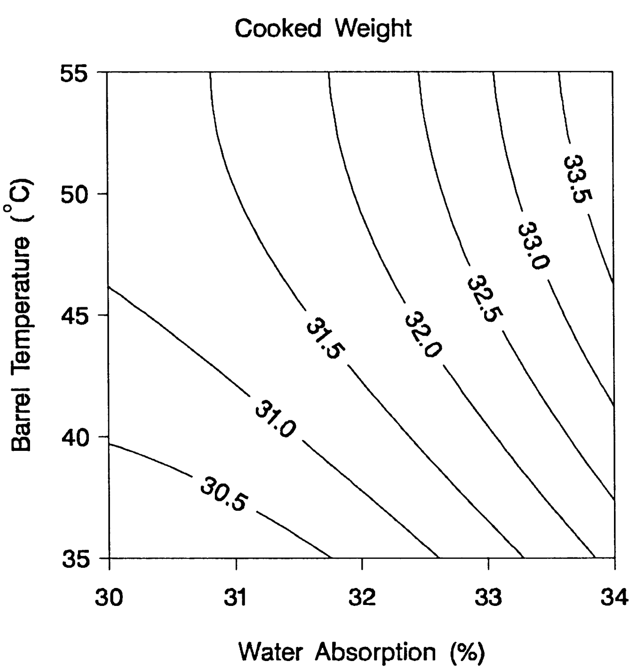

Fig. 6. Contour plot of cooked weight as a function of water absorption and barrel temperature.

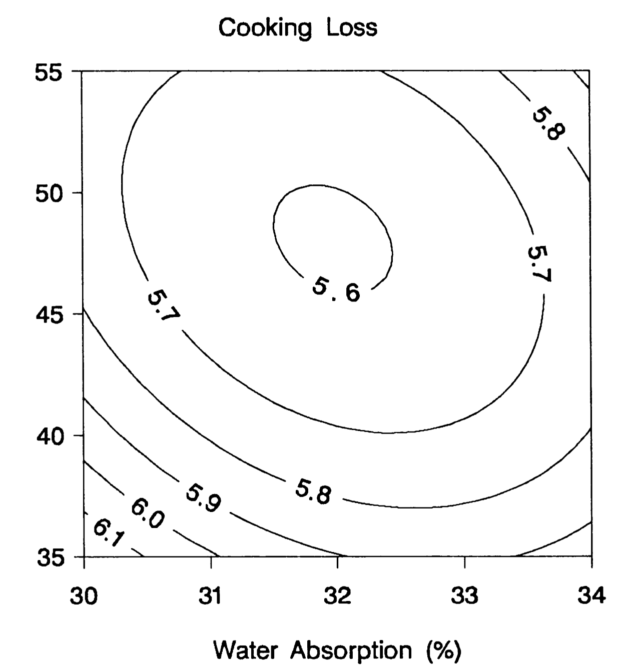

Fig. 8. Contour plot of cooking loss as a function of water absorption and barrel temperature.

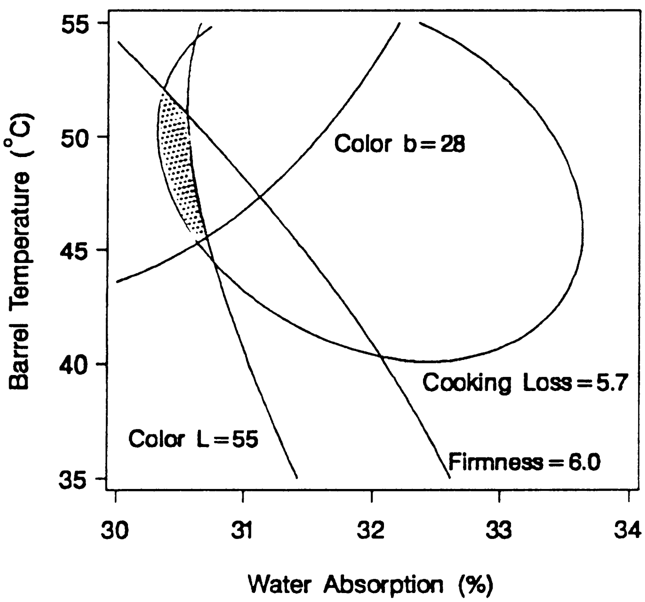

Fig. 9. Optimum region (shaded area) obtained by superimposing contour plots of spaghetti quality parameters as a function of water absorption and barrel temperature.

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

ABECASSIS, J., ABBOU, R., MOREL, M.-H., and VERNOUX, P. 1994. Influence of extrusion conditions on extrusion speed, temperature, and pressure in the extruder and on pasta quality. Cereal Chem. 71:247.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1995. Approved Methods of the AACC, 9th ed. Method 08-01, approved April 1961, revised October 1981 and October 1986; Method 14-22, approved October 1976, reviewed October 1982 and October 1994; Method 38-12, approved November 1995; Method 44-15A, approved October 1975, revised October 1981 and October 1994; Method 46-11A, approved October 1976, revised October 1982 and September 1985, reviewed October 1994; Method 54-40A, approved April 1961, revised October 1988 and October 1994, final approval November 1995. The Association, St. Paul, MN.

CUBADDA, R. 1988. Evaluation of durum wheat, semolina, and pasta in Europe. Pages 217-228 in: Durum Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem., St. Paul, MN.

DEBBOUZ, A., PITZ, W. J., MOORE, W. R., and D'APPOLONIA, B. L. 1994. Effect of bleaching on durum wheat and spaghetti quality. Cereal Chem. 72:128.

DEXTER, J. E., and MATSUO, R. R. 1978. The effect of gluten protein fractions on pasta dough rheology and spaghetti making quality. Cereal Chem. 55:44.

DEXTER, J. E., and MATSUO, R. R. 1979. Effect of starch on pasta dough rheology and spaghetti cooking quality. Cereal Chem. 56:190.

DEXTER, J. E., and MATSUO, R. R. 1980. Relationship between durum wheat protein properties and pasta dough rheology and spaghetti cooking quality. J. Agric. Food Chem. 26:899.

DICK, J. W., WALSH, D. E., and GILLES, K. A. 1974. The effect of field sprouting on the quality of durum wheat. Cereal Chem. 51:180.

DICK, J. W., and MATSUO, R. R. 1988. Durum wheat and pasta products. Pages 507-547 in: Wheat Chemistry and Technology, Vol. II. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

DICK, J. W., and YOUNGS, V. L. 1988. Evaluation of durum wheat, semolina, and pasta in the United States. Pages 237-248 in: Durum Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem., St. Paul, MN.

FEILLET, P. 1977. La qualité des pâtes alimentaires. Ann. Nutr. Diet. 12:299.

FOX, P. F., and MULVIHILL, D. M. 1982. Enzymes in wheat, flour, and bread. Pages 107-152 in: Advances in Cereal Science and Technology, Vol. V. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

GRZYBOWSKI, R. A., and DONNELLY, B. J. 1979. Cooking properties of spaghetti. Factors affecting cooking quality. J. Agric. Food Chem. 27:380.

HUMMEL, C. 1966. Macaroni Products: Manufacture, Processing and Packing. C. Hummel, ed. Food Trade Press: London.

KIM, H. I., SEIB, P. A., POSNER, E., DEYOE, C. W., and YANG, H. C. 1986. Milling HRW to farina: Comparison of cooking quality and color of farina and semolina spaghetti. Cereal Foods World 31:810.

KOBREHEL, K., and ABECASSIS, J. 1985. Effect of high temperature drying of pasta products on the composition and activity of peroxidase in relation with the color of spaghetti. Lebensm. Wiss. Technol. 18:277.

LINSTROTH, J. 1981. What's new? Color in semolina and macaroni. Macaroni J. 63:16.

MANSER, J. 1981. Optimale Parameter fur die Teigwarenherstellung am Beispiel von Langwaren Getreide Mehl Brot 35:75.

MATSUO, R. R., and IRVINE, G. N. 1970. Effect of gluten on the quality on the cooking quality of spaghetti. Cereal Chem. 47:173.

MATSUO, R. R., BRADLEY, J. W., and IRVINE, G. N. 1972. Effect of protein content on the cooking quality of spaghetti. Cereal Chem. 49:707.

MATSUO, R. R., DEXTER, J. E., and DRONZEK, B. L. 1978. Scanning electron microscopy study of spaghetti processing. Cereal Chem. 55:744.

MATVEEF, M. 1966. Influence du gluten des blés durs sur la valeur des pâtes alimentaires. Bull. ENSMIC 213:116.

MILATOVIC, L. J. 1985. Produzione di lasagna ricce con farina di grano tenero ed essiccazione ad alta temperature. Tec. Molitoria 5:419.

MILATOVIC, L. J., and MONDELLI, G. 1991. Processes and unit operations in industrial pasta manufacturing. Pages 69-95 in: Pasta Technology Today. Chiriotti-Pinerolo: Italy.

MONTGOMERY, D. C. 1984. Design and Analysis of Experiments. John Wiley and Sons: Singapore.

NICOLAS, J. 1978. Effects de different paramètres sur la destruction des pigments carotenoïdes de la farine de blé tendre au cours du petrissage. Ann. Technol. Agric. 27:695.

OH, N. H., SEIB, P. A., DEYOE, C. W., and WARD, A. B. 1983. Noodles. I. Measuring the textural characteristics of cooked noodles. Cereal Chem. 60:433.

OH, N. H., SEIB, P. A., and CHUNG, D. S. 1985. Noodles. III. Effect of processing variables on quality characteristics of dry noodles. Cereal Chem. 62:437.

SEYAM, A., SHUEY, W. C., MANEVAL, R. D., and WALSH, D. E. 1974. Effect of particle size on processing and quality of pasta products. Assoc. Oper. Millers Bull. December: 3497.

TSEN, C. C. and HLYNKA, I. 1962. The role of lipids in oxidation of dough. Cereal Chem. 39:209.

WALSH, D. E., EBELING, K. A., and DICK, J. W. 1971. A linear programming approach to spaghetti processing. Cereal Sci. Today 16:385.

[Received February 6, 1996. Accepted July 17, 1996.]