Noodles. III. Effects of Processing Variables on Quality Characteristics of Dry Noodles[1]

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ABSTRACT

Cereal Chem. 62(6):437–440

Response-surface methodology was used to examine the effects of five variables on the quality of oriental dry noodles. The variables were water absorption, dough pH, mixing time, roll speed, and reduction percentage in roll gap. The seven responses were color and breaking stress of uncooked noodles, and surface firmness, cutting stress, resistance to compression, cooked weight, and cooking loss of cooked noodles. The measure-of-fit indicated that variability in color, breaking stress, cutting stress, resistance to compression, and surface firmness were accounted for by two to four of the variables ($R^2 = 0.94–0.69$) but variability in cooked weight and cooking loss were not. Water absorption and dough pH significantly affected the majority of quality characteristics of noodles, whereas roll speed and reduction percentage in roll gap affected the surface properties of cooked noodles. Mixing time was the least significant variable. The conditions most suitable for laboratory preparation of oriental dry noodles were: optimum absorption determined by the handling properties of sheeted dough, neutral dough pH, minimum mixing to form small spheres of dough (~5 mm diameter) distributed uniformly in a continuous flour phase, 30% reduction in roll-gap setting, and a slow roll speed during sheeting.

The quality of dry noodles depends largely on flour characteristics and on conditions used during noodle preparation. Dexter et al (1979) examined the changes in dough structure during noodlemaking by scanning electron microscopy. They found that a soft wheat flour gave better cooking quality for Japanese-style noodles than a durum flour. Full gluten development was not observed during sheeting of the noodle doughs at 32% absorption. Salt at 2% appeared to improve the uniformity of the gluten network in the fresh noodles made from both soft and durum flours.

Besides changes in the proportion of salt, water, and flour, a number of other variables might be expected to affect the quality of dry noodles. These include dough pH, mixing time, rest time of the dough, the number of sheeting steps, and the roll-gap reduction during sheeting. In this study, we used a multiple regression model of the central composite rotational design to study noodle quality as affected by absorption, dough pH, mixing time, sheeting speed, and reduction percentage in roll gap.

MATERIALS AND METHODS

Noodles

Noodle flour was obtained from a commercial mixture of U.S. Western white wheat, which is a subclass of white wheat containing common white plus a minimum of 10% club wheat. The flour contained 9.8% protein and 0.59% ash on a dry basis. It was milled by Fisher Mills Inc., Seattle, WA. Oriental dry noodles were prepared as described by Oh et al (1983). Distilled water was used and pH was adjusted with aqueous 0.1 *M* HCl or 0.1 *N* NaOH. After 1 min of slow-speed mixing, the dough was mixed at medium speed for 2–10 min and rested for 30 min. The pH of noodle dough was determined by suspending 10 g of dough in 100 ml of distilled water and reading the pH. Noodle dough was sheeted from an initial roll gap of 5.4 mm to 1.3 mm. Reduction percentages of 10, 20, 30, 40, and 50%, required 13, 6, 4, 3, and 2 sheeting steps, respectively.

Measuring Noodle Quality

Noodle color was measured by the Agtron reflectance spectrophotometer (Magnuson Engineers Inc., San Jose, CA) as described by Walsh (1970). Percent reflectance in the green mode, instead of the brightness value (L %), was used to measure noodle color. Breaking stress was measured by the Instron universal testing instrument as described by Voisey and Wasik (1978). Breaking stress values (g/mm^2) were calculated using the formula $B = 3FL/2WT^2$ (see Appendix), where F is the applied force (g), L is the span (mm), W is the width (mm), and T is the thickness of the noodle stick (mm).

Noodles (10 g, 14% mb) were cooked in tap water (1,000 ml, pH ~9) to determine the optimum cooking time, cooked weight, and cooking loss. Optimum cooking time and cooking loss were determined as previously reported (Oh et al 1985). Cooked weight was the wet mass after the cooked noodles were drained for 5 min at room temperature. Optimally cooked noodles (10 min) were tested for cutting stress and resistance to compression, with both measurements being corrected to a constant thickness of 2.4 mm (Oh et al 1983). Surface firmness was measured as described by Oh et al (1985). Noodle quality data are based on a minimum of three measurements.

Experimental Design

A response-surface design described by Cochran and Cox (1957) was used to study the relative contribution of a variable to noodle quality and to determine the optimum level for each variable in the noodlemaking process. Following preliminary trials, five independent variables were selected: water absorption (30–38%, 14% mb), dough pH (4.0–10.0), mixing time (2–10 min), roll speed (4–20 rpm), and reduction percentage in roll gap (10–50%). The reduction rolls were 18.0 cm in diameter, which gave a linear roll speed between 226 and 1,131 cm/min.

The experimental design, which consisted of five variables at five levels, required 32 runs. To increase precision, the design was randomized. Seven dependent variables were measured for each treatment: color and breaking stress for uncooked noodles, and surface firmness, cutting stress, resistance to compression, cooked weight, and cooking loss for cooked noodles.

The data obtained from the study were treated by multiple regression analysis for a second-order response-surface equation, which contained linear, quadratic, and interaction terms for the five independent variables. The best final equation was found using the stepwise regression procedure described by Draper and Smith (1981). To determine the effects of the variables on noodle quality, contour plots for each quality parameter were generated as a function of two variables, whereas the other variables were held constant at their center points. The optimum conditions to prepare

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dry noodles were obtained by superimposing contour plots. The acceptable limits for noodle quality were based on four commercial noodles from Japan, Korea, and Singapore.

RESULTS AND DISCUSSION

Table I summarizes the significant terms from the analyses of variance. Water absorption and dough pH affected almost all the properties of dry noodles, whereas the two sheeting variables affected mostly the surface characteristics of the cooked noodle. Mixing time (2–10 min) had little influence on noodle quality.

Table II gives the regression equations expressing noodle characteristics in terms of the experimental variables. The measure-of-fit for color, breaking stress, surface firmness, cutting stress, and resistance to compression was acceptable to good ($R^2 = 0.69–0.94$), but that for cooked weight and cooking loss was poor.

A contour plot of the color of uncooked dry noodles is shown as a function of water absorption and dough pH in Figure 1. The regression equation in Table II and the curves in Figure 1 show that noodle color was affected mainly by water absorption and, to some extent, by dough pH. The noodle became lighter in color as water absorption decreased. This may caused by a less compacted noodle structure at lower water absorption, or to enzymic browning at high absorption (Gerald and Thorn 1971).

At alkaline pH, flavonoid pigments present in the flour developed yellow color in the dough (Fortmann and Joiner 1971). Most of the yellow color faded during drying, probably due to pigment oxidation by air; however, some residual yellow color was retained in the dry noodle.

Figure 2 is a contour plot of the breaking stress of the dry noodle as a function of water absorption and dough pH. Between pH 4 and 8, breaking stress increased steadily with increasing water absorption, but between pH 8 and 10, the breaking stress leveled off as absorption increased. Strong noodle structure at high water absorption would account for the increased breaking stress. Gluten development and good adhesion between starch granules and gluten protein are established in a noodle dough when water is not limiting (Dexter et al 1979). Figure 2 shows that breaking stress went through a maximum as pH increased from 4 to 10.

The cutting stress of cooked noodles is shown as a function of water absorption and dough pH in Figure 3. Cutting stress was affected primarily by dough pH. The increased internal strength of the noodle at alkaline pH agrees with the strengthening of wheat doughs (53% absorption) at alkaline pH reported by Terada et al (1978). The regression equations for cutting stress and for resistance to compression have the same significant variables ($P = 0.05$), except for the second-order term for pH in the compression equation (Table I). As a single index of the internal firmness of cooked noodles, cutting stress was preferred over resistance to compression because it is measured by a single testing procedure and has good reproducibility (Oh et al 1983).

Surface firmness of cooked noodles was affected primarily by the two sheeting variables and by pH (Table I). Figure 4 presents surface firmness as a function of roll speed and reduction percentage in roll gap. This plot shows that surface firmness increased as roll speed decreased and as reduction percentage increased. In other words, the noodle surface was firmer when the dough was between the rolls for a longer time, which is to be expected. Somewhat surprisingly, however, was the fact that a rapid reduction in dough thickness with few sheeting steps gave a firmer surface than a more gradual reduction with more sheeting steps. Moreover, the internal structure of the soft wheat noodle was

TABLE I

Significant Terms (*F* Values) from Analyses of Variance[a]

Independent[b] Variable	Color[c]	Breaking Stress	Cutting Stress	Resistance to Compression	Surface Firmness	Cooked Weight	Cooking Loss
Linear							
X_1	29.23***	8.85***	7.67***	15.36***	NS	2.21*	NS
X_2	20.94***	13.90***	375.81***	37.63***	13.69***	NS	5.67**
X_3	NS	NS	4.64**	4.37**	NS	NS	NS
X_4	NS	9.11***	NS	NS	6.52**	NS	2.35*
X_5	NS	4.16*	3.31*	NS	21.73***	2.88*	NS
Quadratic							
X_1^2	NS	6.29**	NS	NS	NS	2.54*	NS
X_2^2	20.17***	29.54***	NS	19.97***	11.43***	NS	NS
X_4^2	NS	NS	NS	NS	3.74*	NS	NS
X_5^2	NS	NS	NS	NS	NS	3.80*	NS
Interaction							
X_1X_2	9.31***	7.12**	NS	NS	NS	NS	NS
X_1X_5	NS	4.49**	NS	NS	NS	NS	NS
X_2X_4	NS	10.64***	NS	NS	NS	NS	3.89**

[a] Only significant terms are listed in the table.

[b] X_1 = Water absorption, X_2 = dough pH, X_3 = mixing time, X_4 = roll speed, X_5 = reduction percentage.

[c] *** = Significant at $P = 0.01$, ** = significant at $P = 0.05$, * = significant at $P = 0.15$, NS = not significant.

TABLE II

Best Prediction Equations Selected for Noodle Quality Parameters Obtained by Stepwise Regression and Measure-of-Fit of Data (R^2)

Noodle Quality	Equation[a]	R^2
Color****[b]	$301.7 - 5.59\ X_1 - 24.40\ X_2 + 0.64\ X_2^2 + 0.44\ X_1X_2$	0.89
Breaking stress (g/mm^2)****	$-10{,}905.2 + 630.83\ X_1 + 767.97\ X_2 - 59.46\ X_4 - 57.73\ X_5 - 7.63\ X_1^2 - 29.40\ X_2^2 - 14.79\ X_1X_2 + 1.76\ X_1X_5 + 9.04\ X_2X_4$	0.88
Cutting stress (g/mm^2)****	$16.7 - 0.21\ X_1 + 1.93\ X_2 + 0.16\ X_3 - 0.027\ X_5$	0.94
Resistance to compression (%)****	$10.4 - 0.50\ X_1 + 8.77\ X_2 + 0.27\ X_3 - 0.45\ X_2^2$	0.90
Surface firmness (g/mm)****	$7.1 + 7.64\ X_2 - 1.28\ X_4 + 0.17\ X_5 - 0.50\ X_2^2 + 0.04\ X_4^2$	0.69
Cooked weight (g)	$85.3 - 3.55\ X_1 - 0.15\ X_5 + 0.056\ X_1^2 + 0.003\ X_5^2$	0.40
Cooking loss (%)	$10.8 - 0.72\ X_2 - 0.27\ X_4 + 0.048\ X_2X_4$	0.32

[a] **** = Significant at $P = 0.001$.

[b] X_1 = Water absorption, X_2 = dough pH, X_3 = mixing time, X_4 = roll speed, X_5 = reduction percentage.

not adversely affected by the rapid reduction of dough thickness. These results imply that either less development of gluten achieved by fewer sheeting steps or a high pressure on the noodle dough gives a smooth cooked surface.

In commercial operations, there would be limitations on the use of rapid reduction of dough thickness. Commercial dough sheets often have a thickness >10 mm compared to a maximum thickness of 5.4 mm used in these experiments. The rapid reduction of thick dough sheets might stress roll bearings enough to cause mechanical damage. Also, too much stress on a thick dough sheet might damage noodle dough because of slippage at the rolls.

The striped area in Figure 5 shows a water absorption and dough pH that produce noodles of a quality expected to equal or exceed those in the marketplace. The commercial dry noodles had color values above 76, breaking stress values above 2,050 g/mm^2, cutting stress values above 21 g/mm^2, resistance to compression values above 30%, and a surface firmess value above 40 g/mm. The choice of the low limiting values of noodle attributes used in Figure 5 was arbitrary. Higher values could be used to improve noodle quality.

Figure 5 shows that optimum dry noodles could be made in the laboratory from a soft wheat flour using a water absorption of 32–35% and a dough pH of 6.0–9.0. Mixing time was set at 3 min, as long mixing did not improve the noodles. After considering their effects on the surface firmness of noodles and on the mechanical wear of rolls, the reduction percentage and roll speed were set at 30% and 8 rpm, respectively. The optimized conditions to produce laboratory noodles fell within the central region of the experimental design, which was replicated six times.

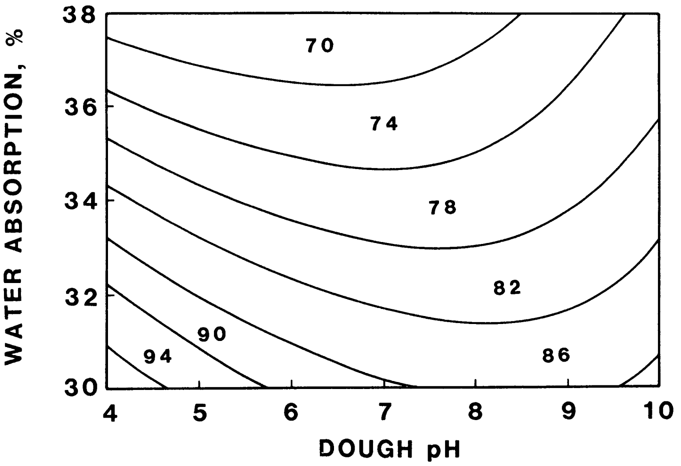

Fig. 1. Color (% reflected light) of uncooked noodles as a function of water absorption and dough pH at the center points for the other independent variables (mixing time 6 min, roll speed 12 rpm, 30% reduction in roll gap).

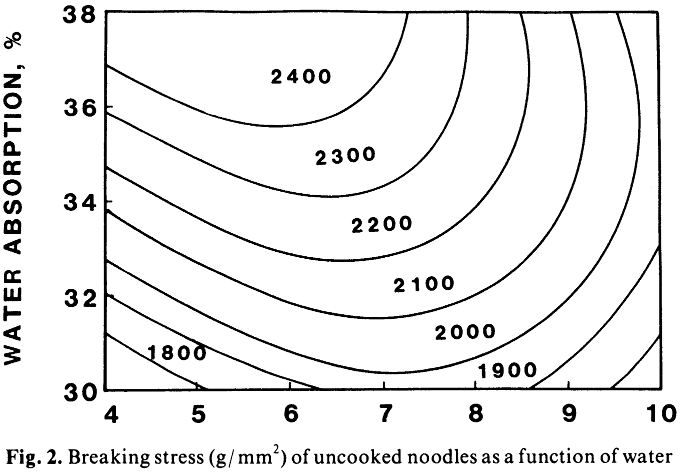

Fig. 2. Breaking stress (g/mm^2) of uncooked noodles as a function of water absorption and dough pH at the center points for the other independent variables (6 min mixing time, roll speed 12 rpm, 30% reduction in roll gap).

In summary, an optimized noodlemaking test to determine flour quality for dry noodles consisted of setting the optimum water absorption, using a neutral dough pH, using a brief mixing time, and sheeting the dough with a 30% reduction in roll gap setting and a slow roll speed.

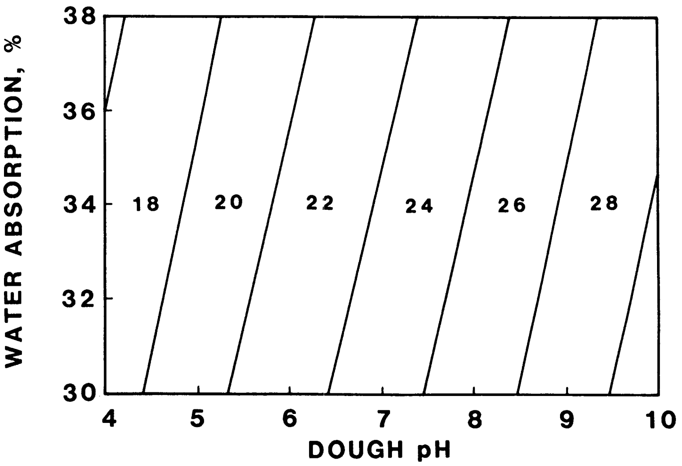

Fig. 3. Cutting stress (g/mm^2) of cooked noodles as a function of water absorption and dough pH at the center points of the other independent variables (6 min mixing time, roll speed 12 rpm, 30% reduction in roll gap).

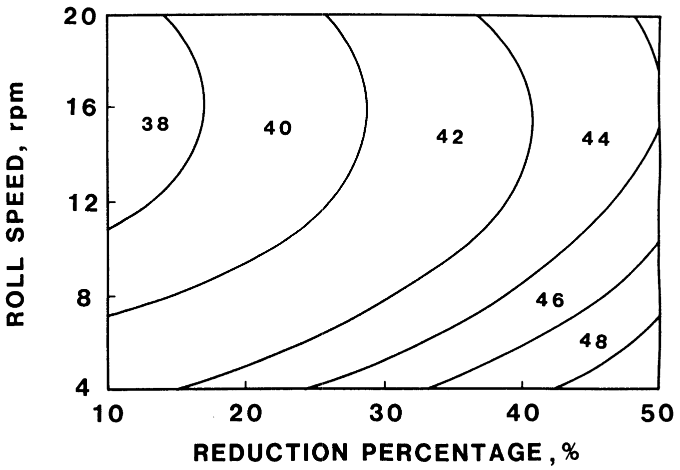

Fig. 4. Surface firmness (g/mm) of cooked noodles as a function of roll speed and reduction percentage at the center of the other independent variables (34% water absorption, dough pH 7.0, 6 min mixing time).

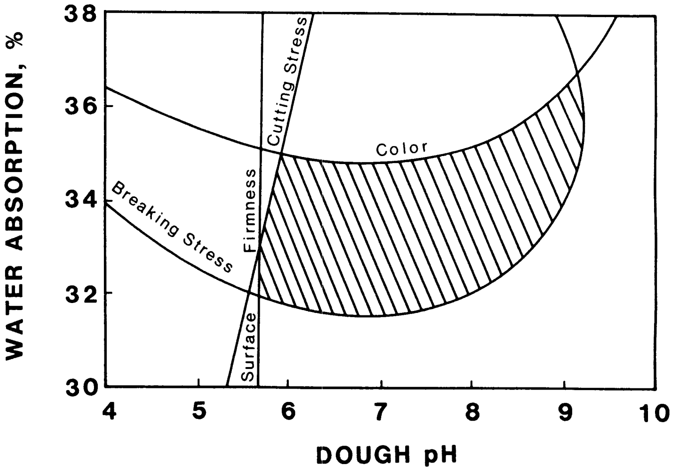

Fig. 5. The acceptable (striped) area obtained by overlapping the contour plots of noodle quality parameters as a function of water absorption and dough pH. Resistance to compression is not shown, as it did not decrease the optimum area.

ACKNOWLEDGMENT

We thank the Kansas Wheat Commission for financial support.

APPENDIX

Breaking Stress Formula

The following assumptions have been made to derive the stress equation based on the theory of simple bending (Timoshenko and Young 1962): 1) the maximum stress during bending occurs at the midpoint of a noodle stick, 2) the stress is compressive at the top half of the cross-sectional surface and is tensile at the bottom surface, and 3) the cause of breakage is the tensile stress at the bottom surface rather than the compression stress at the top surface.

$$\text{Tensile stress at midpoint} = \frac{\text{Moment } (M)}{\text{Modulus of cross section } (Z)},$$

where $M = F/2 \times L/2$, $Z = I/(2/T)$, I = Moment of inertia = $WT/12$.

Thus, tensile stress at midpoint = $3FL/2WT^2$, where F is the applied force (g), L is the length (mm), W is the width (mm), and T is the thickness of the noodle stick (mm). The units of breaking stress are g/mm^2.

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[Received November 13, 1984. Revision received March 19, 1985. Accepted March 26, 1985.]