# Effect of Processing, Formula and Measurement Variables on Alkaline Noodle Color—Toward An Optimized Laboratory System

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## ABSTRACT

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A standardized laboratory method for assessing the color potential of flours for yellow alkaline (Cantonese) noodles is needed, especially for evaluating large numbers of small-scale samples such as found in wheat breeding populations. To develop such a method, a number of processing and formula parameters were varied and judged for optimum level based on 1) discrimination and mean separation of flours, 2) sensitivity to minor variation in the protocol parameter, 3) practicality and simplicity for the technician, and 4) time efficiency. Four flours milled from single-cultivar grain lots representing two with good and two with poor color potential were made into alkaline noodle sheets varying in thickness of 0.75–2.00 mm, water absorption of 33.0–39.0%, mixing time of 2–6 min, and NaCl levels of 0–4% (all flour weight basis). Commission Internationale de l'Eclairage (CIE) tristimulus color space ($L^*$, $a^*$, $b^*$) values were measured at 0–24 hr using white, yellow, and black background tiles. Noodle sheet side and a dough resting period were examined. The flours themselves were a consistently large, significant source of variation for color, especially lightness ($L^*$). Based on the optimization criteria, a noodle sheet thickness of 1.5–2.0 mm, an optimum to slightly over optimum water absorption (36% for the flours in this study) with some adjustment for protein content and dough handling properties, a mixing time of 4 min, no dough resting period, and 2% NaCl were selected. Color measurement at 24 hr on a white or otherwise light-colored background tile was judged best using a consistent side of the noodle sheet. Resting doughs for 1 hr slightly improved handling and sheeting characteristics but was not included for time efficiencies.

Noodles are an important part of the diet in many countries of eastern Asia. They are made from wheat (*Triticum aestivum* L.) flour, water, common salt (sodium chloride), and alkaline salts such as sodium carbonate, potassium carbonate, and sodium hydroxide. On the basis of color and formulation, Asian noodles can be divided into two general classes: white salted and yellow alkaline (Morris and Rose 1996, Nagao 1996). One defining difference between the two types is the inclusion of alkaline salts that give alkaline noodles their characteristic yellow color. There are three main subcategories of alkaline noodles. Cantonese noodles which are sold uncooked, Hokkien noodles which are sold partially cooked (parboiled), and instant noodles which are steamed and fried, or steamed and dried.

Cantonese noodles are prepared using Kan Sui, a mixture (solution) of alkaline salts that may include sodium or potassium carbonates, bicarbonates, phosphates, and even sodium hydroxide. Often a combination of one or more alkaline salts is used. Cantonese noodles may be stored for a day or even longer before being purchased, cooked, and consumed. The high pH conferred by the alkaline salts has many important roles in Cantonese noodle quality. Several of these roles include controlling microbial growth during storage, developing the characteristic yellow color, improving noodle texture (bite), developing aroma and flavor, and modifying dough, starch pasting, and cooking characteristics.

Although regional preferences for color vary, it is generally recognized that color is a primary quality parameter of Cantonese noodles (Moss 1971; Miskelly 1984, 1996). Color of Cantonese noodles results from two factors: 1) the pH-dependent development of variable amounts of yellow due to natural flour constituents, and 2) the development of undesirable colors of various levels of gray, brown, or other dark shades. A clear, bright yellow is desired. The yellow color of alkaline noodles is attributed to the presence of naturally occurring flavones in flour (Fortmann and Joiner 1978), recently identified as apigeninglycosides (Mares 1992, Wang and Mares 1995, Ward et al 1995). Colorless at acidic or neutral pH, these compounds become yellow under alkaline pH (Wang and Mares 1995, Ward et al 1995, Miskelly 1996, Mares et al 1997). Undesirable noodle colors are generally recognized as time-dependent darkening phenomena. Poor color develops or increases over time. In this context, the converse of discoloration, color stability is considered a desirable trait of a flour or wheat cultivar. Color stability is especially important for Cantonese noodles because they are stored uncooked. The presence of phenolic substrate oxidizing enzymes, those generically referred to as polyphenol oxidase (PPO), are generally invoked to explain the time-dependent darkening of alkaline noodles. Cultivars of wheat and their flours have variable levels of PPO that tend to be correlated with the rate of development or absolute level of undesirable dull brown and gray colors (Baik et al 1995; Crosbie et al 1996; Kruger et al 1992, 1994a,b; Miskelly 1996).

Tristimulus color meters facilitate the objective assessment of noodle color. Simultaneous measurements of lightness, yellowness, and red-green colorations may be accomplished using the Hunter color difference meter (Hunter Associates Laboratory, Reston, VA) (Miskelly 1984; Moss et al 1986; Kruger 1992, 1994a; Hatcher et al 1999) and the Minolta chromameter (Edwards et al 1989, Allen et al 1996a, Miskelly 1996). The CIE 1976 international color measurement system (Wyszecki and Stiles 1982) color values have been applied to the measurement of noodle color, with high $L^*$ values (lightness) universally preferred and $b^*$ values (yellowness) being variably desirable based on regional and individual consumer preferences. No clear consumer preferences for $a^*$ values have been established. Various formulations and methods of preparing Cantonese noodles in the laboratory have been reviewed and summarized by Miskelly (1996).

There has been growing interest among cereal chemists, particularly those involved in wheat cultivar development, for standardization of testing protocols for Asian products (Allen and Pleming 1997, Kruger 1997). An Asian Products Technical Committee was established by the Approved Methods Committee at the 1996 AACC Annual Meeting. Our laboratory developed and has been using a small-scale (100 g of flour) laboratory method for assessing alkaline noodle color potential of cultivars and breeding lines. The method is based on experience, published literature, and on-going discussions with end-users in eastern Asia. It

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serves as the base procedure from which we varied nearly all processing, formula, and measurement variables with the intent of establishing an optimized, standard testing protocol. Optimization of parameters was judged on the criteria listed above. The type of noodle that is dealt with in this research is the raw Cantonese noodle which, for simplicity, will be referred to as alkaline noodle.

## MATERIALS AND METHODS

### Grain Samples and Milling

Eltan, soft white winter, Penawawa, soft white spring, Idaho 377s (ID377S), hard white spring and Klasic, hard white spring wheat cultivars were selected a priori because they encompass much of the observed range in alkaline noodle color observed during the routine analysis of breeding lines conducted as part of the cultivar development activities of the Western Wheat Quality Laboratory. These cultivars include one soft and one hard wheat in each of the poor and good color lightness classes, all have white bran, and one of each hardness class (Penawawa and Klasic) is a lower amylose l-gene waxy genotype (Zeng et al 1997).

Eltan was grown at Almira, WA, in 1994-95; Penawawa at Connell, WA, in 1994; ID377S at Aberdeen, ID, in 1995; and Klasic at Fresno, CA, in 1995. A 30-kg sample of each wheat was cleaned and tempered overnight. The soft wheats Eltan and Penawawa were tempered to 14% moisture content. The hard wheats ID377S and Klasic were tempered to 16% moisture content. An additional 0.5% moisture was added 15 min prior to milling. All samples were milled on a Bühler MLU-202 pneumatic flour mill (Approved Method 26-21A, AACC 1995). A straight-grade flour was produced by combining the six flour streams. These four flour samples were used in all phases of the research and are referred to by cultivar name.

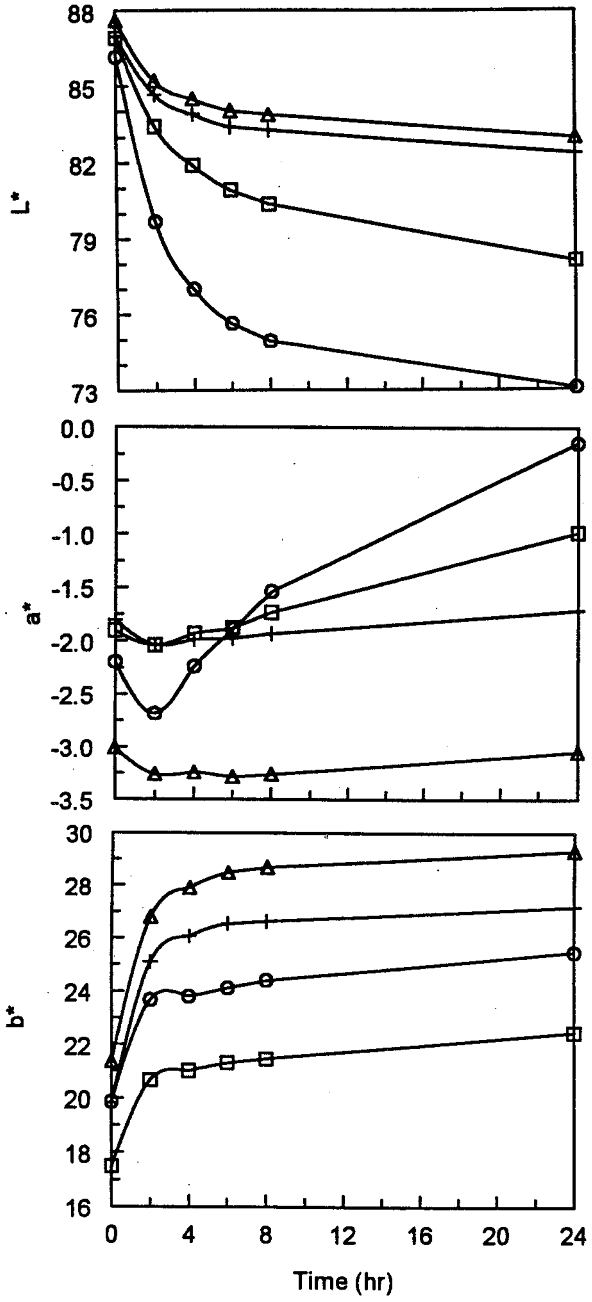

**Fig. 1.** Alkaline (Cantonese) noodle color values $L^*$, $a^*$, $b^*$ of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours measured at 0, 2, 4, 6, 8, and 24 hr.

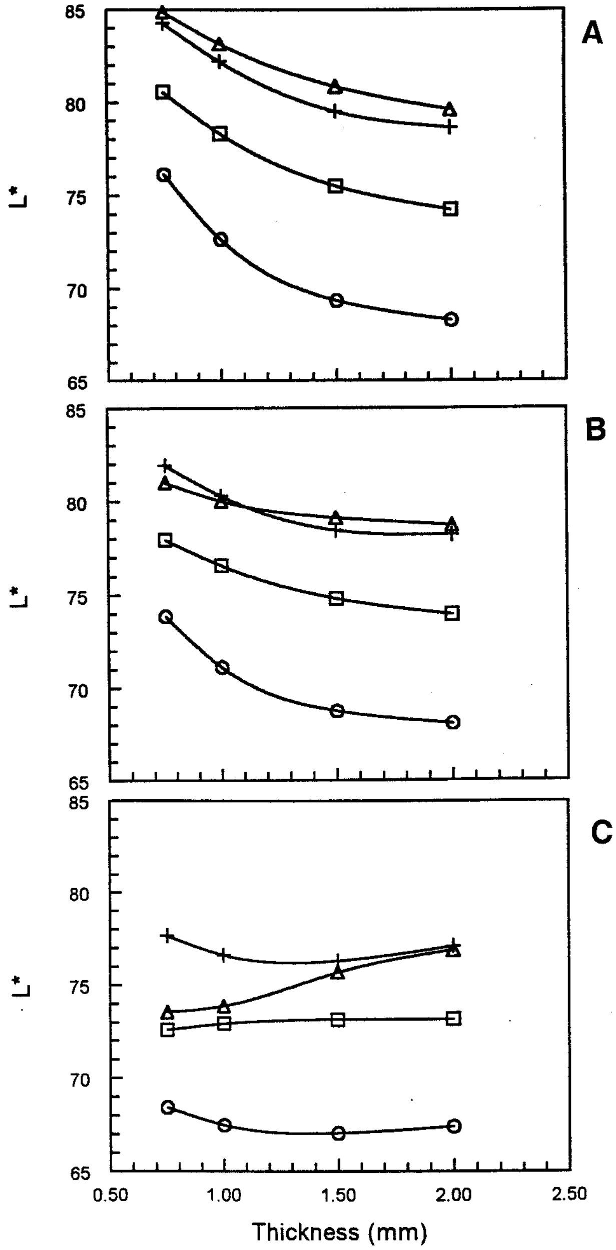

**Fig. 2.** Alkaline (Cantonese) noodle color value $L^*$ of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours measured at noodle sheet thicknesses of 0.75, 1.00, 1.50, and 2.00 mm using white (**A**), yellow (**B**), and black (**C**) background tiles.

### Analytical

Flour protein content (N × 5.7) was determined by the Dumas combustion method (Approved Method 46-30, AACC 1995) (model FP-428, Leco Corp., St. Joseph, MI) using ≈0.25 g of sample. Reagent-grade sodium carbonate, potassium carbonate, sodium hydroxide, and sodium chloride (J. T. Baker, Phillipsburg, NJ), were used with distilled water.

### Color Measurement

Noodle sheet color was measured with a chromameter (310, Minolta Camera Co., Ltd., Osaka, Japan) with a 50-mm (diam) measuring tube. $L^*$, $a^*$, and $b^*$ values (CIE 1976, Wyszecki and Stiles 1982) denote lightness (white-black), red-green, and yellow-blue, respectively (first color parameter of each axis is positive direction, second is negative). Measurements were made five times, each at a different location on the consistent (same) side of the surface of the noodle sheet. All color measurements were taken at 0 and 24 hr with a white background tile unless otherwise noted. Other variables were changed as noted. The color of the white tile (No. 05-1402) was $L^* = 93.89$, $a^* = -0.68$, and $b^* = -1.30$ and was obtained from Pacific Scientific Co. (Gardner/Neotec Instrument Div., Silver Springs, MD).

### Base Noodle Formula and Sheet Preparation

The base formula consisted of 100 g of flour, 36% (v/w, flour weight basis [fwb]) water absorption, 0.5 g of sodium carbonate, and 2.0 g of sodium chloride. The salts were dissolved in distilled water and added to the flour during mixing. Dough water absorption was selected after evaluating the appearance and handling properties of the noodle sheet from all four flours. While insufficient water gave a sheet with irregular edges and a nonuniform surface, excess water rendered the dough sheet too extensible and difficult to handle. A dough sheet with a smooth uniform surface and edges was considered at optimum. A level of 36% absorption produced

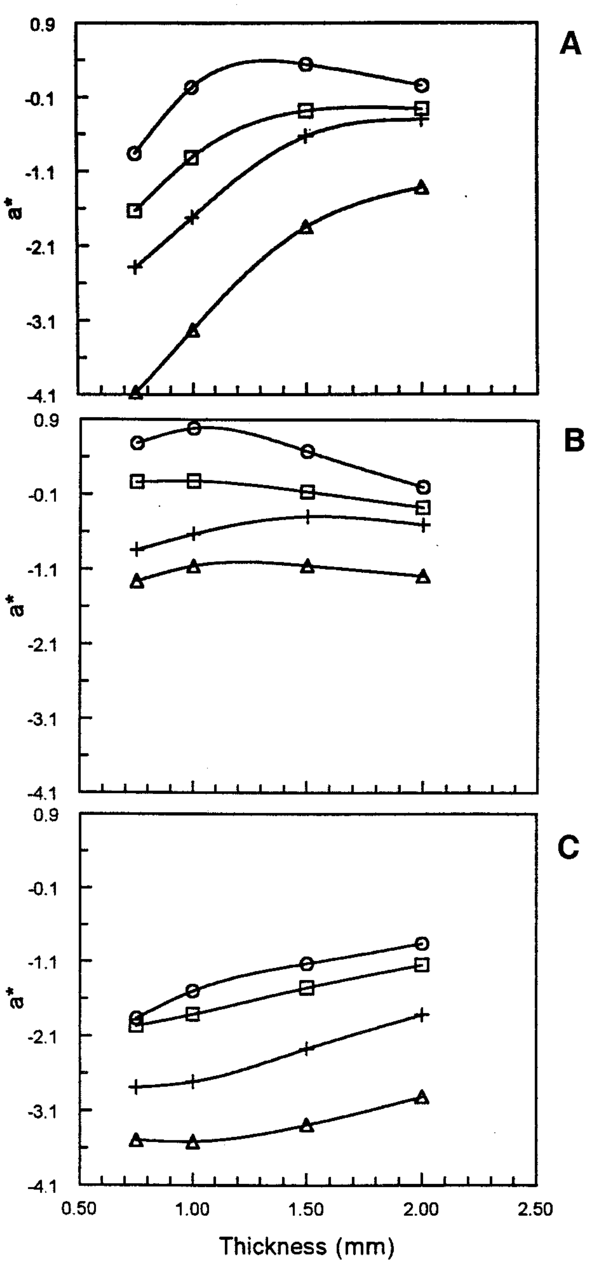

**Fig. 3.** Alkaline (Cantonese) noodle color value $a^*$ of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours measured at noodle sheet thicknesses of 0.75, 1.00, 1.50, and 2.00 mm using white (**A**), yellow (**B**), and black (**C**) background tiles.

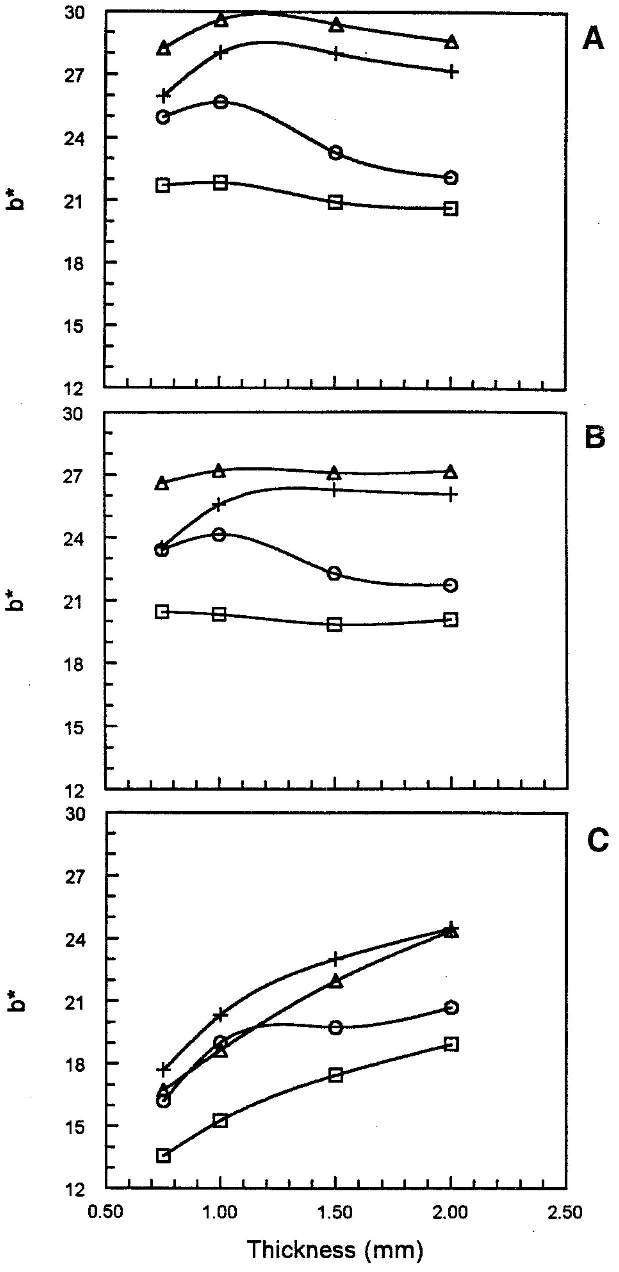

**Fig. 4.** Alkaline (Cantonese) noodle color value $b^*$ of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours measured at noodle sheet thicknesses of 0.75, 1.00, 1.50, and 2.00 mm using white (**A**), yellow (**B**), and black (**C**) background tiles.

satisfactory sheets for all flours, although the Eltan flour was slightly (1–2%) below optimum.

The dough was mixed without resting using a pin-type mixer with a head speed of 130 rpm (Swanson-Working, National Manufacturing Co., A Division of TMCO, Inc., Lincoln, NE). This mixer is commonly used for preparing bread doughs in Approved Method 10-10B (AACC 1995). Water, or the appropriate solution, was added over 20 sec, dough was scraped off the head pins, and the sides and bottom of the bowl at 1 and 3 min; total mixing time was 4 min. The crumbly dough was removed from the mixing bowl and compressed into a rectangular block ≈18 × 9 × 2 cm (D × W × H). This dough piece was transferred to a noodle machine (Ohtake Noodle Machine Manufacturing Co., Ltd., Tokyo, Japan) modified to produce a sheet 10-cm wide by reducing the roll length with Teflon inserts, and compressed by smooth rolls operating at 8 rpm and a 4-mm gap. The resulting sheet was folded in half (ends joined, book fold) and passed crease end first between the rolls at a gap of 4 mm. This folding and sheeting cycle was repeated two more times. The irregular edges of the dough sheet were then trimmed off (≈6 mm off each edge of the sheet). The dough sheet was then gradually reduced in thickness, without folding, by passing it progressively between the rolls at each of the following gap settings: 3.2, 2.5, 2.0, 1.6, 1.3, and 1.0 mm. Final thickness of the noodle sheet was 1.0 mm ± 0.1 mm. The last roll gap adjustment was varied to accommodate the sheeting characteristics of the particular dough to achieve the desired final thickness. Final thickness was measured by a micrometer dial thickness gauge (Peacock Dial Thickness Gauge G, 0.01–10 mm, Ozaki Mfg. Co., Ltd., Ozaki, Japan). A 15-cm length of noodle sheet was cut transversely from the center of the sheet and used for color analysis. Noodle sheets were placed in plastic bags and stored at 25°C. All treatment combinations were replicated.

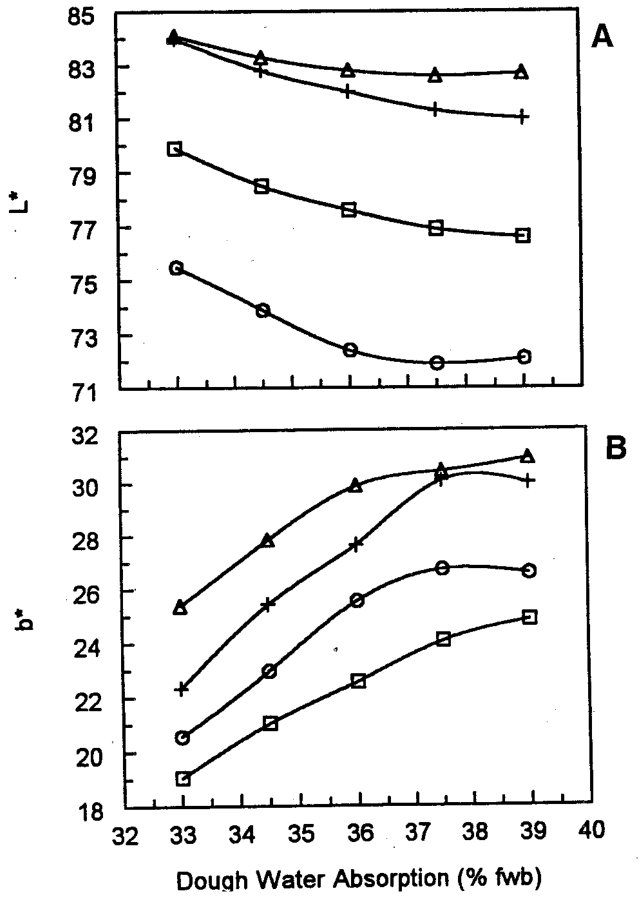

**Fig. 5.** Alkaline (Cantonese) noodle color values L* (**A**) and *b** (**B**) of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours prepared using water absorptions of 33.0, 34.5, 36.0, 37.5, and 39.0% (flour weight basis). Data averaged over three mixing times of 2, 4 and 6 min.

### Phase I Time Sequence

The base noodle formula and preparation method described above was used and color measurements were recorded at 0, 2, 4, 6, 8, and 24 hr.

### Phase II Noodle Sheet Thickness and Background Tile Color

The base noodle formula and preparation method described above was used with the following exceptions: four noodle sheet thicknesses of 0.75, 1.00, 1.50, and 2.00 mm were prepared for each flour, and color readings were taken using a white, black, and yellow background tile. The calibrated color of the yellow tile (No. 05-1402) was *L** = 82.50, *a** = 0.56, and *b** = 27.04. The calibrated color of the black tile (No. 05-1402) was *L** = 27.92, *a** = 0.08, and *b** = –0.58. Both were obtained from Pacific Scientific Co.

### Phase III Dough Water Absorption Level and Mixing Time

The base noodle formula and preparation method was used with the following exceptions: five water absorption levels of 33.0, 34.5, 36.0, 37.5, and 39.0% (fwb) were used, and the dough mixing time was 2, 4, and 6 min at each absorption level.

### Phase IV Differences in Noodle Sheet Side

The base noodle formula and preparation method was used; color measurements were made on both sides of the noodle sheet and compared.

### Phase V Dough Resting

The base noodle formula and preparation method was used with the exception that doughs were either rested 1 hr or sheeted immediately after mixing. Color measurements were conducted on both treatments 24 hr after the initial mixing and flour hydration.

### Phase VI Sodium Chloride Levels

The base noodle formula and preparation method was used with the exception that five sodium chloride levels of 0, 1, 2, 3, and 4% (w/w, fwb) were used.

**TABLE I**
**Phase I Model $R^2$ and *F*-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at 0, 2, 4, 6, 8, and 24 hr**

| Source | *L** | *a** | *b** |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | >0.99 | >0.99 |
| *F*-value[a] | | | |
| Model | 6,192 | 178 | 135 |
| Flour | 23,563 | 874 | 554 |
| Time | 11,741 | 158 | 272 |
| Flour x Time | 868 | 46 | 5 |

[a] All *F*-values are significant at $P < 0.001$.

**TABLE II**
**Phase I *F*-Values[a] of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at 0, 2, 4, 6, 8, and 24 hr**

| Time (hr) | *L** | *a** | *b** |
|---|---|---|---|
| 0 | 981 | 92 | 25 |
| 2 | 1,350 | 100 | 76 |
| 4 | 5,331 | 115 | 229 |
| 6 | 16,580 | 149 | 210 |
| 8 | 4,316 | 162 | 120 |
| 24 | 6,432 | 548 | 71 |

[a] All *F*-values are significant at $P < 0.001$.

## Data Acquisition and Statistical Analysis

Data were automatically transferred from the chromameter to a personal computer and imported into SAS software (SAS Institute, Cary, NC). The five repeated measures were averaged to represent the color of the particular sheet. Statistical analyses including analysis of variance (ANOVA) were conducted with the SAS general linear models procedure. Each phase was conducted and analyzed as a fully balanced factorial design with two replicates.

Optimization of parameters was judged on 1) discrimination and mean separation of flours, 2) sensitivity to minor variation in the protocol parameter, 3) practicality and simplicity for the technician, and 4) time efficiency. Discrimination and mean separation of flours was evaluated by comparing the overall ANOVA $F$-values for individual model components and interaction terms (flour vs. processing or formula variable) and the relative magnitude of ANOVA $F$-values of individual levels of each processing or formula parameter. Sensitivity to minor variations in the processing or formula parameter was judged by inspection of plots and trends (if any) in $F$-values. Practicality and simplicity for the technician involved time of noodle sheet preparation vs. color measurement, handling properties due to sheet thickness and water absorption, and dough mixing time. Time efficiency also involved preparation to measurement time (turnaround time), dough mixing time, and dough resting.

# RESULTS

## Phase I Time Sequence

All four flours had similar alkaline noodle lightness ($L^*$) values at 0 hr ranging from 86.2 to 87.6 (Fig. 1, top). Immediately after preparation, all samples began to darken. The time from when water or solution was added to the flour in the mixer to when the dough was sheeted and the color first measured (0 hr) was ≈10 min. Lightness decreased dramatically between 0 and 2 hr and then continued to decline at a progressively slower rate. Those flours that produced noodle sheets with poor lightness (low $L^*$ values) darkened proportionally more than those that produced lighter sheets. Consequently, at 24 hr the differences between flours were quite large (e.g. 73.1 for Penawawa and 83.0 for ID377S).

The overall ANOVA (Table I) indicated that nearly all (>99%) experimental variation could be explained by a model comprising flour, time, and flour-by-time interaction. Flour was, by far, the largest source of variation in noodle lightness, although the changes over 24 hr were also quite substantial. The flour-by-time interaction, though significant, was considered relatively unimportant because 1) the time responses were nonparallel (which produces interaction sums of squares), 2) the $F$-value was relatively small compared with those for flour and time, and 3) there was no change in rank order among any of the four flours during the 24-hr time period.

ANOVA conducted for flours at each individual time point indicated that from 4 to 24 hr, the mean separation (the ability to differentiate flours for noodle sheet lightness) was very high, with $F$-values ranging from 4,316 to 16,580 (Table II).

All alkaline noodle sheets were slightly green (i.e., slightly negative $a^*$ values) (Fig. 1, center). Changes in the red-green axis color space were variable among flours. Although all four flours exhibted some decrease in $a^*$ values at 2 hr compared with 0 hr, Penawawa in particular exhibited the greatest decrease, but then increased the most from 2 to 24 hr. ID377S was consistently the lowest, whereas Klasic and Eltan were intermediate at 24 hr. Eltan and Klasic exhibited little change in $a^*$ values from 2 to 24 hr.

The overall ANOVA (Table I) indicated a very good fit for the model ($R^2 > 0.99$) and that flour was the major source of variation in $a^*$ values. Although Penawawa exhibited a unique pattern of change over time, the ANOVA interaction was relatively small and only Penawawa changed in rank order. Like $L^*$, flours differed most in $a^*$ values at 24 hr. ANOVA for the individual times produced the greatest $F$-value at 24 hr ($F = 548$) (Table II), confirming that this time period gave the greatest mean separation.

The $b^*$ axis provides for variation in the yellow-blue color space. All flours produced yellow alkaline noodle sheets which rapidly increased in yellow value from 0 to 2 hr (Fig. 1, bottom).

**TABLE III**

**Phase II Model $R^2$ and $F$-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at Thicknesses of 0.75, 1.00, 1.50, and 2.00 mm Using White, Yellow, and Black Background Tiles**

| Source | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | >0.99 | 0.99 |
| $F$-value[a] | | | |
| Model | 339 | 379 | 94 |
| Flour (F) | 3,468 | 2,427 | 569 |
| Thickness (Th) | 388 | 457 | 52 |
| Tile (Ti) | 1,515 | 3,555 | 965 |
| F × Th | 21 | 26 | 12 |
| F × Ti | 35 | 53 | 19 |
| Th × Ti | 148 | 209 | 64 |
| F × Th × Ti | 2 | 14 | 1 |

[a] $F$-values ≥12 are significant at $P < 0.001$; $F$-values = 2 are significant at $P \leq 0.02$; $F$-values = 1 are not significant.

**TABLE V**

**Phase III Model $R^2$ and $F$-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at Mixing Times of 2, 4, or 6 min and Dough Water Absorption of 33, 34.5, 36, 37.5, and 39% (fwb)**

| Source | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | 0.99 | 0.99 |
| $F$-value[a] | | | |
| Model | 601 | 70 | 98 |
| Flour (F) | 10,962 | 1,303 | 997 |
| Mixing Time (MT) | 9 | 28 | 6 |
| Absorption (A) | 570 | 9 | 657 |
| F × MT | 2 | 2 | 2 |
| F × A | 17 | 9 | 7 |
| MT × A | 2 | 2 | 4 |
| F × MT × A | 1 | <1 | 1 |

[a] $F$-values ≥ 7 are significant at $P < 0.001$; $F$-values at 4–7 are significant at $P \leq 0.01$; $F$-values ≤ 2 are not significant.

**TABLE IV**

**Phase II $F$-Values[a] of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at Thicknesses of 0.75, 1.00, 1.50, and 2.00 mm Using White, Yellow, and Black Background Tiles**

| | White | | | Yellow | | | Black | | |
|---|---|---|---|---|---|---|---|---|---|
| Thickness (mm) | $L^*$ | $a^*$ | $b^*$ | $L^*$ | $a^*$ | $b^*$ | $L^*$ | $a^*$ | $b^*$ |
| 0.75 | 524 | 459 | 19 | 296 | 125 | 17 | 75 | 202 | 9 |
| 1.00 | 808 | 310 | 37 | 377 | 369 | 27 | 90 | 170 | 22 |
| 1.50 | 1,356 | 339 | 1,856 | 773 | 124 | 1,073 | 391 | 1,370 | 1,407 |
| 2.00 | 659 | 72 | 558 | 417 | 40 | 984 | 227 | 385 | 436 |

[a] $F$-values ≥ 72 are significant at $P < 0.001$; $F$-values at 17–37 are significant at $P \leq 0.01$; $F$-values = 9 are significant at $P < 0.03$.

From 2 to 24 hr, $b^*$ values increased fairly linearly, at essentially the same rate for all flours. The overall ANOVA produced a relatively very low $F$-value for flour-by-time interaction ($F = 5$) and, as before, flour was the predominant factor with an $F$-value of 554 (Table I). ANOVA of individual measurement times produced results similar to those for $a^*$ values with $F$-values ranging from 71 to 229 for the measurement times of 2 to 24 hr.

Based on these results, the 24-hour time period was chosen as both convenient and providing powerful mean separation among the flours. Also, time-dependent changes were the least at this time. From a practical standpoint, minor differences in measurement times deviating from exactly 24 hr would be of little consequence. Although the greatest $F$-value for $L^*$ values was observed at 6 hr, the sums of squares for flours increased consistently from 2 to 24 hr, while the error sums of squares remained at similar levels; the exception was a lower error variance at 6 hr. At 24 hr, the least significant difference (LSD) ($P = 0.05$) for flours was 0.2, 0.2, and 1.3 for $L^*$, $a^*$, and $b^*$, respectively.

### Phase II Noodle Sheet Thickness and Background Tile Color

Having settled on 24 hr as the best measurement time, the effect of noodle sheet thickness and the color of the background tile were examined. The effect of sheet thickness on color was clearly dependent on the choice of background tile color (Figs. 2–4). The overall ANOVA demonstrated that flour was the predominant factor in variation for noodle lightness ($L^*$ values), with tile color second, and sheet thickness third (Table III). Again, models for all three color axes exhibited very high model $R^2$ values (>99%), indicating little residual unexplained error variance. Though relatively small in magnitude, the thickness-by-tile interaction was the largest of the interaction terms. Visual inspection of the $L^*$ values by sheet thickness plots revealed that the general trend for the white and yellow background tiles was decreasing lightness with increasing sheet thickness (Fig. 2A and B). On average, $L^*$ values were ≈1.6 units higher using the white tile compared with the yellow, although changes in $L^*$ values due to changes in thickness were less with the yellow compared with the white tile. The black background tile produced the lowest $L^*$ values, which tended to be less variable in response to sheet thickness (Fig. 2C). ANOVA for each individual thickness and tile combination showed that the best mean separation of flours was obtained with the white tile and 1.5 mm thickness (Table IV). Although the yellow tile produced results that were fairly similar to the white tile, the overall higher $L^*$ values and more consistent differentiation of the ID377S and Eltan flours (also reflected by higher $F$-values) indicated that the white tile was slightly preferable.

The background color tile had the largest effect on the $a^*$ and $b^*$ color space values (Table III), followed by flour. Sheet thickness and thickness-by-tile interaction were far secondary but significant additional sources of variation. Inspection of the plots (Figs. 3A and B) showed that against a white tile, $a^*$ (red-green) color space values differed most at noodle sheet thickness of 0.75 and 1.00 mm, and tended toward a common value with increasing sheet thickness where differences were smallest at 2 mm (smallest range in values). This trend was also present with the yellow tile, although the overall effect of sheet thickness was much less. Against the black tile, the general trend was fairly consistent among flours with an increase in $a^*$ values with increasing sheet thickness (Fig. 3C).

The yellow-blue ($b^*$) color space of the four flours was variably affected by the color of background tile (Fig. 4). Against the white and yellow tiles, Klasic $b^*$ values were little affected and were consistently the lowest, whereas Penawawa showed an initial small increase at 1.0 mm followed by a progressive decrease at 1.5 and 2.0 mm. ID377S exhibited the most yellow color. The white and yellow tiles produced similar color vs. thickness plots except that $b^*$ values were on average ≈1.6 units higher with the white background. Against the black tile, $b^*$ values generally increased with increasing sheet thickness, somewhat similar to the $a^*$ result.

ANOVA of individual dough sheet thicknesses demonstrated that the white and yellow background tiles generally produced similar mean separations for $a^*$ and $b^*$ values with the white tile having a modest, but fairly consistent advantage in higher $F$-values (Table IV). The black tile produced relatively similar mean separations compared with the other two tiles with highest $F$-values obtained at sheet thicknesses of 1.5 and 2.0 mm. With all tiles, the $F$-ratios obtained at a sheet thickness of 2.0 mm were

**TABLE VI**
**Phase III $F$-Values[a] of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at Mixing Times of 2, 4, or 6 min and Dough Water Absorption of 33, 34.5, 36, 37.5, and 39% (fwb)**

| Absorption (%) | $L^*$ | $b^*$ |
|---|---|---|
| 33.0 | 726 | 116 |
| 34.5 | 848 | 157 |
| 36.0 | 2,318 | 276 |
| 37.5 | 5,162 | 269 |
| 39.0 | 3,307 | 72 |

[a] All $F$-values are significant at $P < 0.001$. Analyses pooled over mixing times.

**TABLE VII**
**Phase IV Model $R^2$ and $F$-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours with Color Measurements Taken on Each Side of the Noodle Sheet**

| Source | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | 0.99 | 0.91 |
| $F$-value[a] | | | |
| Model | 405 | 82 | 12[b] |
| Flour (F) | 938 | 190 | 22 |
| Side (S) | 13 | <1 | 10 |
| F × S | 3 | <1 | 3 |

[a] $F$-values ≥ 22 are significant at $P < 0.001$; $F$-values at 10–13 are significant at $P \le 0.02$; $F$-values ≤ 3 are not significant.
[b] $F$-value significant at $P = 0.001$.

**TABLE VIII**
**Phase V Model $R^2$ and $F$-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours With and Without a 1-hr Dough Resting Period After Mixing**

| Source | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | 0.99 | 0.95 |
| $F$-value[a] | | | |
| Model | 362 | 97 | 20[b] |
| Flour (F) | 838 | 226 | 42 |
| Rest treatment (R) | 21 | <1 | 11 |
| F × R | <1 | <1 | <1 |

[a] $F$-values ≥ 42 are significant at $P < 0.001$; $F$-values at 11–21 are significant at $P \le 0.01$; $F$-values < 1 are not significant.
[b] $F$-value significant at $P = 0.001$.

**TABLE IX**
**Phase VI Model $R^2$ and $F$-Values of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at NaCl Levels of 0, 1, 2, 3, and 4% (fwb)**

| Source | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| $R^2$ | | | |
| Model | >0.99 | 0.99 | 0.99 |
| $F$-value[a] | | | |
| Model | 1,036 | 321 | 67 |
| Flour (F) | 6,455 | 1,911 | 305 |
| Salt (S) | 60 | 80 | 87 |
| F × S | 8 | 4 | 1 |

[a] $F$-values ≥ 8 are significant at $P < 0.001$; $F$-values = 4 are significant at $P \le 0.02$; $F$-values = 1 are not significant.

less than those obtained at 1.5 mm. No consistent pattern of either decreased flour sums of squares or increased error sums of squares could be identified as the cause. The LSD ($P = 0.05$) for flours using the white tile were 0.5 ($L^*$), 0.2 ($a^*$), and 0.4 ($b^*$) at a sheet thickness of 1.5 mm.

### Phase III Dough Water Absorption Level and Mixing Time

Dough mixing time had essentially no effect on $L^*$, $a^*$, or $b^*$ color space values compared with the differences among flours (Table V). Similarly, no interaction effects were considered important. Water absorption (the amount of water added to the flour during mixing) had a significant affect on $L^*$ values and $b^*$ values but not on $a^*$ values (Table V). As seen earlier, the four flours differed significantly and were the greatest source of ANOVA variation ($R^2 > 0.99$).

Figure 5A shows that the general trend was for reduced lightness with increasing water. ID377S, which produced the lightest noodle sheet, was the least sensitive to changes in absorption, whereas the poorest flour for sheet lightness, Penawawa, exhibited the greatest decrease in lightness with increasing absorption. Differences among flours were greatest at the higher absorption levels. As mixing time was not a significant source of variation and mixing time interaction terms were likewise not significant, this treatment effect was dropped and degrees of freedom and sums of squares pooled for the ANOVA for individual absorption levels. ANOVA for individual absorption levels showed that the greatest mean separation among flours for $L^*$ values was at the higher absorption levels (≥ 36.0%) (Table VI). The most apparent advantage of the higher absorption levels was the greater discrimination between ID377S and Eltan (Fig. 5A). LSD ($P = 0.05$) for $L^*$ values for flours ranged from 0.4 at 33% absorption to 0.2 at 37.5% absorption.

As observed earlier, the four flours were by far the greatest source of variation for the red-green ($a^*$) color space, whereas mixing time and water absorption had little effect (Table V). The individual flour means across mixing times and absorption levels were similar to those observed in the previous phases and were –0.07, –0.95, –1.53, and –3.01 for Penawawa, Klasic, Eltan, and ID377S, respectively.

For $b^*$, the yellow-blue color space, flour and water absorption were both similar and highly significant sources of variation (Table V). Again, mixing time and interaction terms were of little consequence. The general trend was increased yellowness with increased absorption (Fig. 5B). The $b^*$ values of ID377S and Eltan tended to converge at the highest absorption levels, however the rank order of flours did not change across the entire absorption range examined. ANOVA of individual absorption levels indicated that good mean separation among flours occurred at all but the highest (39.0%) absorption level (Table VI). LSD ($P = 0.05$) for $b^*$ values for flours ranged from 1.0 at 39% absorption to 0.6 at 36% absorption.

### Phases IV and V Differences in Noodle Sheet Side and Dough Resting

Differences in noodle sheet surfaces (i.e., top vs. bottom) were minor when compared with the contribution of the flours themselves (Table VII). However, means across flours for $L^*$ and $b^*$ values differed by 1.5 and 1.3 units, respectively, indicating that a consistent side should be measured.

Similar to sheet side, a 1-hr dough resting period had little effect on noodle sheet color compared with flours (Table VIII). The greatest effect was seen in $L^*$ values where a 1-hr dough resting period reduced lightness by 0.7 units (means across flours).

### Phase VI Sodium Chloride Levels

As before, the effect of flour was greater than the process or formula variable, in this case concentration of NaCl, on variation in alkaline noodle color (Table IX). Compared with the contribution of flour, NaCl had its greatest effect on $b^*$ values but was still considered a secondary effect. Plots of $L^*$, $a^*$, and $b^*$ values versus NaCl concentration showed that increasing NaCl concentration produced a small increase in lightness and a small decrease in the green dimension (less negative $a^*$ values) (data not shown), and a decrease in yellow (decreased $b^*$ values) (Fig. 6). ANOVA of individual NaCl concentrations showed no particular trend in mean separation of flours and differences in $F$-values were considered largely a reflection of random replicate-to-replicate variation (Table X).

### Sheet Handling Properties

With the base formula (2% NaCl and 36% absorption), some peeling (separation) and streaking of the noodle sheet occurred, particularly for the Eltan and Penawawa flours at sheet thicknesses of 1.00 and 0.75 mm. The thinner the noodle sheet, the more frequent or worse the problem, particularly with the two soft wheat flours. Peeling problems were rarely encountered with the ID377S and Klasic hard wheat flours. Based on our prior experience, the problem with soft wheats is often related to lower flour protein content (data not shown), although gluten strength may also be involved. The Eltan and Penawawa flours (8.8 and 9.1% flour protein, respectively) exhibit the rather weaker gluten strength, which is characteristic of their market class. Generally, alkaline noodles are prepared with higher protein, stronger gluten wheats such as those commonly used for pan bread. Generally, peeling and streaking increased with increasing salt concentration. At 0 and 1% NaCl, few problems in sheeting were encountered.

## DISCUSSION

Differences among flours milled from individual wheat cultivars was, by far, the largest source of variation for alkaline (Cantonese)

**TABLE X**
**Phase VI *F*-Values[a] of Analysis of Variance (ANOVA) of Alkaline Noodle Dough Sheet Color of Four Different Wheat Flours at NaCl Levels of 0, 1, 2, 3, and 4% (fwb)**

| NaCl (%) | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|
| 0 | 3,284 | 351 | 119 |
| 1 | 5,546 | 291 | 54 |
| 2 | 970 | 2,257 | 47 |
| 3 | 670 | 252 | 35 |
| 4 | 1,284 | 514 | 140 |

[a] $F$-values ≥ 119 are significant at $P < 0.001$; $F$-values ≤ 54 are significant at $P < 0.003$.

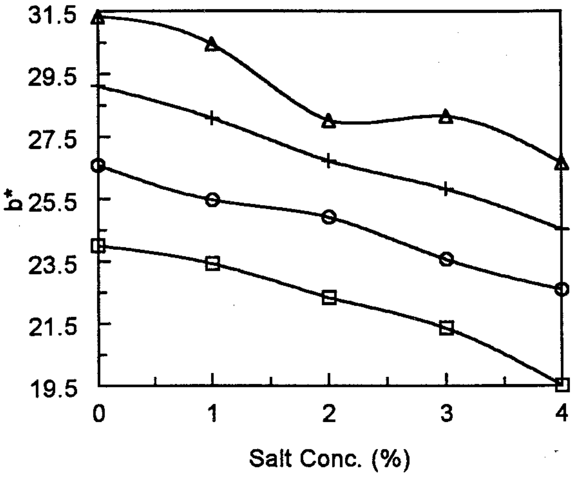

**Fig. 6.** Alkaline (Cantonese) noodle color value $b^*$ of Eltan (+), ID377S (Δ), Klasic (□ ), and Penawawa (○) cultivar flours prepared using 0, 1, 2, 3, and 4% NaCl (flour weight basis).

noodle color (Tables I, III, V, VII) (Baik et al 1995, Mares and Wang 1995, Martin et al 1995, Crosbie et al 1996). Lightness, or high $L*$ values in the CIE color space, has been identified as a universally desirable trait for alkaline noodle flours (Moss 1971; Miskelly 1984, 1996). Although different flours may vary initially for $L*$ values, it is the rate and ultimately the degree of discoloration that is important from a consumer standpoint. Clearly, the four flours included in this study differed markedly in the extent of discoloration after 24 hr (Fig. 1, top). Our experience has shown that both the relative ranking of these cultivars and the dramatic differences among them for $L*$ values is characteristic of these cultivars, suggesting that much of the variation encountered among different wheat cultivars is genetically controlled (Mares and Wang 1995, Lang et al 1998). Moss (1971) did not find significant differences among six cultivar flours for subjective alkaline noodle color grade and apparent lightness. Differences were noted for apparent yellowness however. Miskelly (1984) noted that cultivar was a significant source of variation for alkaline paste lightness and yellowness; growing seasons and sites affected alkaline paste yellowness but not lightness. The results reported here point toward greater differences in $L*$ values among flours, compared with values for $a*$ and $b*$. At this time, the results clearly indicate that the large differences among flours may facilitate large genetic gains in improving alkaline noodle color potential of commercial flours.

Processing and formula parameters, including dough mixing time, water absorption, noodle sheet side, dough resting period, and NaCl level, had much less relative effect on alkaline noodle color compared with flour (Tables V and VII) (Shelke et al 1990, Kruger 1994a, Hatcher et al 1999). Baik et al (1995) and Hatcher et al (1999) reported significant differences for $L*$ values due to water absorption. Clearly, water absorption is important. With a set of flours with less inherent difference compared with those used here, water absorption would necessarily gain in importance (Chan and Corke 1997). Conversely, color measurement parameters, including measurement time, noodle sheet thickness, and background tile color, had large and significant effects (Tables I and III) (Kruger et al 1992, 1994a; Ross and Pudney 1994; Allen et al 1996a; Miskelly 1996) and therefore should be carefully controlled. Considering the variables examined in the present research, alkaline noodle color can be accurately and reproducibly measured. The high model $R^2$ values for all phases indicates few extraneous, uncontrolled sources of error variance compared with the effects of the variables under study, most notably different cultivar flours.

Considering what might be identified as optimum formula and processing parameters, 24-hr measurement time is advantageous as it provides 1) excellent discrimination among flours, 2) the rate of change in color is very low (on the order of 0.06–0.14 $L*$ units/hr, ID377S and Penawawa, respectively), 3) it is convenient (make sheets one day, measure the next), and 4) it is reasonably time efficient. If necessary, relative rankings of flours could be made within 2–4 hr. Several authors (Baik et al 1995; Martin et al 1995, 1996; Mares and Wang 1996) have suggested shorter measurement times, longer times, or the use of change in color over time (i.e., $\Delta L*$, $\Delta a*$, and $\Delta b*$), or simply caution in selecting a specific time (Kruger et al 1992). Corke et al (1997) developed an automated system for noodle color measurement.

Determining the optimum background tile color may require additional research, although light colors (white to pale yellow) appear to be preferable (Allen et al 1996a,b; Crosbie et al 1996). The Royal Australian Chemistry Institute Cereal Chemistry Division has made available a set of pale yellow tiles for alkaline noodle color measurement (RACI Yellow Noodle Tiles Set No. 8) (Allen et al 1996b). One solution to the issue of background tile color is to simply use a noodle sheet that is sufficiently thick (Allen et al 1996a) or use multiple sheet layers to achieve infinite optical thickness (Solah et al 1997). On the other hand, if texture and cooking measurements are anticipated, then sheeting to the desired final thickness for cut noodles may be preferable. Certainly, noodle sheet thickness is important for accurate, reproducible color measurements. For $L*$ values, sheets 1.5 mm or thicker appear to provide the best color measurements (Fig. 2). A final sheet thickness of 1.5 mm also accommodates cutting noodle strands from the same sheet (Miskelly 1996). For Hokkien noodle a thicker sheet appears preferable (Miskelly 1996). Allen et al (1998) have suggested two methods, one using single-thickness color measurement against a uniform background tile, the second using multiple layers to achieve infinite optical thickness.

Higher levels of water absorption (≥36%) provided the best discrimination among flours for $L*$ values (Fig. 5A, Table VI). Sheeting problems were also minimized at the higher absorption levels. Only at the highest level (39%) did some doughs become too slack (extensible) to handle. Again, with sheets <1.5 mm, the problem was exacerbated. From the standpoint of developing a standardized method, determination or selection of the appropriate water absorption may present a dilemma. For routine color evaluation of breeding material, preparing more than one noodle sheet to evaluate different absorption levels, or to try and obtain an optimum absorption is neither practical nor desirable due to limited flour supply and technician time. Again, an advantage of erring on the side of overhydrating appears to be a decreased rate of change for $L*$ values (Fig. 5A). Based on the results presented here, absorption may be of more critical importance when assessing the intensity of yellow ($b*$) (Fig. 5B and Table V). Hatcher et al (1999) found a general increase in $b*$ values with increasing water absorption. Counter to the common experience with mixing bread doughs, flours with lower protein content often require more water for optimum consistency compared with flours of higher protein. Although mixing had little relative effect on noodle color, 4 min was considered to give reasonably uniform water incorporation while shortening the time between samples.

Apparently, due perhaps to sheeting, the two sides of a noodle sheet are not exactly alike. However, any difference in color is very minor (Table VII). It is important to consistently measure the same side of noodles sheets so as to eliminate this source of variation.

Dough resting is common in commercial noodle manufacture, although because it represents a reduction in time efficiency and throughput, its time is minimized. The results presented here indicated that dough resting period had no particularly significant effect on noodle sheet color (Table VIII). However, when considering noodle texture, dough resting may be more important.

We found that sodium chloride concentration has little effect on noodle sheet lightness or $a*$ values (Table VII). Yellowness ($b*$) tended to decrease with increasing NaCl (Fig. 6). Miskelly (1981) reported that increased NaCl concentration increased yellowness but decreased lightness, whereas Shelke et al (1990) indicated that NaCl had no significant effect. From the standpoint of differentiating flours, a given level of NaCl in the 0–2% range had no effect on the relative ranking of flours for any of the three color axes (Table VII and data not shown). Selection of an optimum NaCl concentration may be important in the processing and handling properties of the noodles and might affect cooked noodle texture.

In conclusion, our results indicate that the optimum levels of the processing and formula parameters investigated include color measurement at 24 hr, a white or light-colored background tile, a sheet thickness of 1.5–2.0 mm, an optimum to slightly over optimum water absorption (36% for the flours in this study) with some adjustment for protein content and dough handling properties, 4 min of mixing time, no dough resting period, and 2% NaCl.

We hope that the results presented here will stimulate further research and discussion regarding the standardization of testing procedures for Asian noodles and lead to an AACC Approved Method for noodle color. The major limitation to conducting research to gain further understanding of Asian noodle quality is the lack of standardized methods.

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